Chapter 1
Educational Augmented Reality Games

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Abstract Augmented Reality (AR) games, in the education sector, have the potential to enable new forms of learning and transform the learning experience. However, it remains unclear how these AR games whose designs are based on diverse game genres can be used to leverage the conventional education process in the context of different theoretical paradigms and models used in learning. This chapter addresses these challenges by providing an analysis of game genres, learning paradigms, theories and models used in different AR games in the field of education. Hence, we present a selected number of previous studies of AR games in the field of education, which are classified by year of publication, school subject, research method, game genres, AR systems, learning environment, learning paradigms and theories, target group(s) and study sample size. The classified data is analysed to identify how AR games designed based on diverse game genres can be used to benefit the educational process in the context of different theoretical paradigms and models used in learning.

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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-centered learning and enhance learning experiences.

Digital games are gaining increased visibility in education providing an enhanced experience in learning. Research has demonstrated games are effective with respect to learning and retention (Jan 2009; 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. Amongst others, this creates an opportunity for exploring experiential student-centered learning rather than the typical educator-centered 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 from 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 introducing 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 the 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 categorize 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, the 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 20th 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 behavior, 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 increase the number of consolidation processes through repetition and improve reflexes, promote critical thinking, and help 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 mean 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 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 human brain perceives things, how does it make 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 experiences. Unlike behaviorism, 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 memorize 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, learner constructs their own subjective interpretation and meaning of what is being learnt of objective reality. AR games offer several 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 allowing students to construct 3D mathematical and geometrical models in a shared AR workspace, supporitng new dynamic opportunities for playful interactions to promote higher-level learning, and to help develop personal meanings 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 a 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 these experiences into knowledge. Such AR games can also be used to gather evidence from an experience and afterward to communicate, analyse and visualise the knowledge gained based on personal requirements. For example, AR game Table Mystery (Boletsis and McCallum 2013) helps to learn the elements of the periodic table, which is created through the transformation of experiences, is an example of the use of Humanism.

Connectivism claims that learning occurs not only in individual 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 to provide the scaffolding for connectivist learning and provide the channels for interacting with dynamic sources of data. For example, AR game Electric Agents (Revelle et al. 2014) 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 the learning paradigms. Here we shortly describe each learning theory or model 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) [i.e. Astrid's steps (Nilsson et al. 2012)] while **Situated learning** theory argues that learning is not transmission of abstract and contextualized knowledge between individuals, but a social process within certain conditions which include activity, context and culture (Anderson et al. 1996) [i.e. Outbreak (Rosenbaum et al. 2007); Mad city Mystery (Squire and Jan 2007); Eco-

MOBILE (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) [i.e. AmonPlanet (Hodhod 2014), Electric Agents (Revelle et al. 2014)]. **Case-based learning** model introduces 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 maximize training safety and minimize 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 a desired goal (Hubbard 2012) [i.e. Mystery at the Library (Fitz-Walter et al. 2012); (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) [i.e. Parallel (de Sainte-Foy 2015); Leometry (Laine et al. 2016)]. **Challenge-based learning** is similar to problem-based learning, but with this model, learners formulate their challenges (Wikipedia 2012) [i.e. PasswARG (Eishita et al. 2014); UniRallye (Rogers et al. 2015)]. In **Enquiry-based learning** model learners are encouraged to use real-world examples; inquiry represents questioning that forwards curiosity in learners (Wikipedia 2016a) [i.e. 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 traveling or surfing the web (Edutech wiki 2016).

1.2.3 Models and Theories for Humanism

Experiential learning model defines 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) [i.e. Furio et al. (2013a); 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).

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

	Behaviorism	Cognitivism	Constructivism	Humanism	Connectivism
Timeline	Since 1900s	Since 1960s	Since 1960s	Since 1970s	Since 2000s
What is learning	Development of desired behavior	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 behavior	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 organization) and is focused on establishing connections
Critics	Ignores learner and his mental processes, depends exclusively on obvious behavior	Views knowledge as objective and external to the learner	More psycho-logically 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 coun-terexamples	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

(continued)

Table 1.1 (continued)

	Behaviorism	Cognitivism	Constructivism	Humanism	Connectivism
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	

1.3 Games, Gamification and Game-Based Learning

In this section, we explore the digital games and their genres. In the context of education, physical games have been used for years in the educator-centered 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, the digital games came to the forefront (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 (loose) (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, and objective as shown in Table 1.2. It needs to be stressed that other game genres might be found in the literature.

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 characterized 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

However, we have based our analysis on (Wikipedia 2014) since it covers all games in the analysed papers.

Different game genres can have different impact 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) emphasizes activities and learning techniques used in educational games and discusses how to combine gameplay and 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).

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

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

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, leaderboards 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.

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 utilizes 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 phrases and their different combinations: “augmented reality”, “education”, “learning”, “game-based learning”, “gamification”, “edutainment”, “augmented reality games” and “AR games”.

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 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 AR games

Table 1.4 Inclusion and exclusion criteria

Inclusion	Exclusion
Papers that reported using AR games for educational purposes (formal or informal)	Commercial applications available on Google Play or Apple App Store
Literature reviews focused on AR games development	Papers reporting on AR use in education without gaming components
Literature reviews discussing educational dimensions of AR games	Papers reporting on ideas or pilot studies without a description of the evaluation methodology

focused on education available on Google Play[1] and Apple App Store,[2] as well as 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 methodology. 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.

1.4.1 Game Examples

We have identified 30 papers describing AR games in educational settings based on the described method. In order to better understand the results and analysis section we have selected and described six games as illustrative examples of different genres based on different learning paradigms and using different learning theories in more details. The description also includes the rationale of our classification.

1.4.1.1 Outbreak @ The Institute

The game Outbreak @ The Institute (Rosenbaum et al. 2007) presents a simulation based game simulating the spread of an infectious disease across university campus. The players can take one of the several roles such as doctors, medical technicians, or public health experts and try to identify the source and to contain a disease outbreak that can spread among real and/or virtual characters based on a preselected disease model. As such, the game could be categorised also as a role-playing game but since the participants were in the class on medical technology and game was a part of the curriculum, we (as well as the authors of the game) categorised it as simulation. Moreover, players are given loosely defined tasks, limited amount of time, and it is on them to decide on goal states, which creates a realistic situation in which they must evaluate trade-offs and decide on a satisfactory balance.

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

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

This study used authenticity of the system as a whole to frame the research, which is related to constructivism and situated learning. The findings suggest participants perceived the game as authentic. They demonstrated their personal embodiment in the game through verbal and physical reactions to the virtual disease, the shift from meta-level to person-level goals, seriousness and responsibility with which they treated their roles, showing an understanding of the interdependence of the roles and the importance of communication, and seeing that their actions had an effect on the outcome of the game in a realistic way. Participants thus constructed their own knowledge of the world in terms of their personal embodiment in the game, their experience playing different roles and the understanding of the dynamic model underlying the game.

1.4.1.2 Astrid's Steps

The Astrid Lindgren Landscape (Nilsson et al. 2012) is an outdoor mobile AR educational game aiming to enhance and augment the experience of a visit of a culturally significant place, the childhood home of the children's book author Astrid Lindgren. It allows players to learn about and explore the physical space through a treasure hunt game. Players activate content by moving between places and pointing their mobile devices at different markers and in different directions through various design concepts. The aim of the game was to visit a number of places of interest, and collect ingredients for a classic dish, which allows players to actively construct knowledge and create their ideas in such a way that it makes sense to them in their own frames of reference as opposed to simply absorbing information.

A set of eight design concepts (not all of them used in the final prototype) identified during the design stage are visible in Fig. 1.1. Leaving Traces allowed visitors to write notes and leave geographically tagged photos at specific places for others. The Time Machine allowed users to point the phone camera towards a scenery and see how it looked like in the past by moving the slider. The Show and Tell Guide was intended for a guide holding a visual marker while the rest of the group pointed their phone cameras to it in order to visualise content related to guide's explanation. The Interactive Map took advantage of a physical map with hidden information about interesting sites displayed when viewed through the mobile phone. Mythical Creatures from Astrid Lindgren's books could be visualised and taken photos of by looking at the landscape through a mobile phone. The Sidekick allowed the guide to carry a visual marker in order to dramatise a guided tour while visitors could see the sidekick when viewed through the phone. The Walking Quiz featured a treasure map showing user's position and where the questions or challenges are spatially placed. The Spatial Audiobook played stories of the author by pointing users' phones at specific artefacts.

In this study, the inquiry-based learning contexts were incorporated into contextual gaming scenarios for promoting students' learning performance. The main gaming interface enables players to learn in various gaming contexts based on the natural and cultural environment that supplies the content of learning.

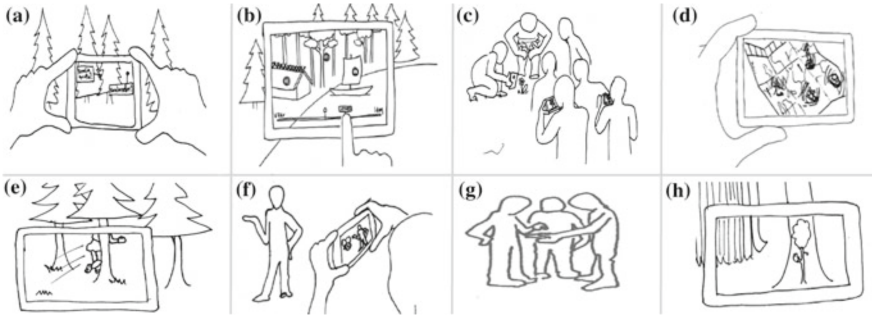

Fig. 1.1 The game design concepts: **a** leaving traces, **b** time machine, **c** show and tell guide, **d** interactive map, **e** mythical creatures, **f** sidekick, **g** walking quiz, and **h** spatial audiobook. Courtesy of (Nilsson et al. 2012)

1.4.1.3 Amon Planet

AmonPlanet (Hodhod 2014) is an AR game intended to teach computational thinking skills through a storytelling. For example, the story starts with an Bigaliens' invasion of a Zeomons' planet. Several of the Zeomons manage to escape and land on the player's back yard. Bigaliens followed them and try to capture them and challenge the player to attend a universal intellectual competition. The Zeomons agree to train the player to get them prepared. A series of activities are then provided. One such activity involves fractions. In order to understand that fractions can be represented as a subset, the learner is presented with a fraction and a number of food items. To fulfil this task the Zeomon will ask the learner to bring his favourite toy to the game to become a part of the virtual world. Next, the player needs to share a fraction of the sweets (e.g. 3/8 sweets) with his toy by clicking on 3 out of 8 pieces of sweets. If the answer is correct, the toy can give the player a balloon or jump up and down or fireworks will appear. If the answer is wrong, the sweets jump back to the original positions indicating the player has to try again. These pedagogical agents provide the support and scaffolding for the learner until learners adapt the knowledge into their own cognitive structure. Snapshots of the game are visible in Fig. 1.2.

The game is characterised as a role-playing game since it provides the player with flexibility in terms of character development, problem resolution, and by playing a

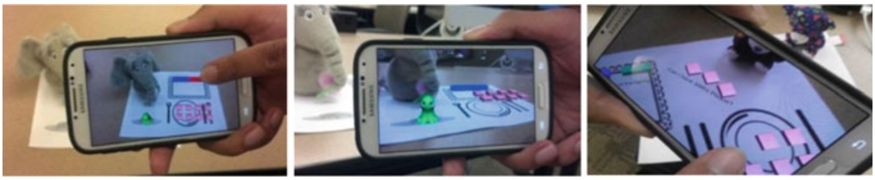

Fig. 1.2 Snapshots of AmonPlanet game. Courtesy of (Hodhod 2014)

role in the story. Through the intelligent tutoring components, the game also provides the necessary scaffolding essential for real knowledge acquisition.

1.4.1.4 Monster Adventure

The Luostarinmäki Adventure (Viinikkala et al. 2014) aims at presenting the daily life of a 19th century city. The player takes the role of Frans, a 23 year-old man from the countryside who comes to the city for the wedding of his cousin. As the player, Frans is unfamiliar with a 19th century city, and people he meets try to explain various aspects of city life (see Fig. 1.3). It is soon revealed that the wedding ring has been stolen from the groom. The game then takes a form of a detective story in which the player has to follow clues and find the thief and the ring to save the day.

The game is an adventure as the player is the hero of a story that needs to solve a mystery by solving various tasks. This game first immerses players in an experience and then encourages reflection about them in order to develop new skills, new attitudes, or new ways of thinking. It also describes the natural human desire, based on self-actualization and development of personal potentials which emphasises the humanistic behavior of learning.

Fig. 1.3 The player is presented with a snap of the past during the game. Courtesy of (Viinikkala et al. 2014)

1.5 Results and Analysis

Based on the described criteria, 30 papers from peer-reviewed journals and conferences were analysed. Each AR game and study reported was then categorized and classified along these criteria: year of publication, school subject, research question or study aim, research method, game genre, AR system (e.g. handheld, projector based, head-mount display), learning environment, learning paradigm and learning theories, target group(s) and learning activities. All AR games presented are also listed and summarised in Table 1.5. A more detailed table can be found in Appendix 1.

Table 1.5 Summary of AR games in education

Study	School subject	#	Game genre	Learning environment	Learning paradigm	Learning theories and models	Learning activities
Outbreak (Rosenbaum et al. 2007)	Biology (medicine)	21	Simulation	Outdoor (school garden)	Constructivism	Situated learning, Goal-based learning	Immersion, feedback, problem
Mad city Mystery (Squire and Jan 2007)	Biology (ecology)	28	Role play	Outdoor (sites around the university, near a lake)	Constructivism	Situated learning, Inquiry-based learning, Scaffold of learning	Imitation, practise, problem, creativity play
Environmental detectives (Squire and Klopfer 2007)	Biology (ecology)	76	Simulation	Outdoor/indoor (any)	Constructivism	Situated learning, Inquiry-based learning	Immersion, problem, creativity play
Astrid's steps (Nilsson et al. 2012)	Culture	20	Treasure hunt	Outdoor (in the woods)	Constructivism	Contextual learning, Inquiry-based learning	Problem, creativity play
Mystery at the library (Fitz-Walter et al. 2012)	Library education	7	Adventure	Indoor (library)	Constructivism	challenge based learning, Goal-based learning	Feedback, problem, creativity play
First colony (Echeverria et al. 2012)	Physics (Electronics)	45	Simulation	Indoor (classroom)	Constructivism	Collaborative learning	Immersion, work with others
Tangram AR (Santoso et al. 2012)	Math (spatial reasoning)	N/A	Puzzle	Indoor (school)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play

(continued)

Table 1.5 (continued)

Study	School subject	#	Game genre	Learning environment	Learning paradigm	Learning theories and models	Learning activities
Thus, et al. (Furio et al. 2013a)	Biology (ecology)	79	Treasure hunt	Indoor (summer school)	Humanism	Experiential learning	Interact, practice
Thus, et al. (Furio et al. 2013b)	Psychology	234	Treasure hunt	Indoor (summer school)	Humanism	Experiential learning	Interact, practice
EcoMOBILE (Kamarainen et al. 2013)	Biology (ecology)	71	Simulation	Outdoor (lake)	Constructivism	Situated learning, Goal-based learning	Immersion, feedback, problem, creativity play
Table Mystery (Boletsis and McCallum 2013)	Chemistry	N/A	Adventure	Indoor (science center)	Humanism	Experiential learning	Interact, practice
Martinez et al. (Zarzuela and others 2013)	Biology (ecology Animals)	5	Puzzle	Indoor (any)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
ARMuseum (Chatzidim-itris et al. 2013)	Chemistry	N/A	Treasure hunt	Indoor (museum)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
AmonPlanet (Hodhod 2014)	Mathematics (fractions)	N/A	Role play	Outdoor (any)	Constructivism	Scaffold of learning	Imitation, association, practise
Electric agents (Revelle et al. 2014)	Language literacy (vocabulary)	34	Action	Indoor (living room)	Constructivism Connectivism	Scaffold of learning, Collabora-tive Learning	Imitation, association, practise, work with others
PasswARG (Eishita et al. 2014)	Any	35	Treasure hunt	Indoor/outdoor	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
REENACT (Blanco-Feŕandez et al. (2014)	History	61	Simulation	Indoor	Humanism	Experiential learning	Interact, practice
Luostarinmäki Adventure (Viinikkala et al. 2014)	History	56	Adventure	Outdoor (museum)	Humanism	Experiential learning	Interact, practice

(continued)

Table 1.5 (continued)

Study	School subject	#	Game genre	Learning environment	Learning paradigm	Learning theories and models	Learning activities
UniRallye (Rogers et al. 2015)	Navigation	30	Treasure hunt	Indoor (university campus)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
Parallel (from Sainte-Foy 2015)	Physics (electromagnetism)	160	Simulation	Indoor (school)	Constructivism	Problem based learning, Goal-based learning	Feedback, problem
Hwang et al. (Hwang et al 2016)	Biology (ecology)	57	Board, puzzle	Outdoor (butterfly garden)	Constructivism	Situated learning, Goal-based learning	Feedback, problem, creativity play
Leometry (Laine et al. 2016)	Mathematics (geometry)	61	Adventure	Indoor (school)	Constructivism	Problem based learning, Goal-based learning	Feedback, problem
Lin et al. (Lin et al. 2016)	Mathematics (geometry)	N/A	Puzzle	Indoor (school)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
AREEF (Oppermann et al. 2016)	Environment awareness	36	Action	Indoor (swimming pool)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
ARmatika (Young et al. 2016)	Mathematics (arithmetic)	30	Puzzle	Indoor (school)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
Calory battle AR (Laine and Suk 2016)	Physical exercise	29	Treasure hunt	Outdoor	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
AR Ole Cierraojos (Tobar-Mu ~ noz et al. 2017)	Language literacy (reading comprehension)	51	Puzzle	Indoor (school)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play

(continued)

Table 1.5 (continued)

Study	School subject	#	Game genre	Learning environment	Learning paradigm	Learning theories and models	Learning activities
EduPARK (Pombo et al. 2017)	Any	74	Treasure hunt	Outdoor (park)	Constructivism, behaviorism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play
Hsu (Hsu 2017)	Language (English)	38	Puzzle	Indoor (school)	Constructivism	Situated learning, Task-based learning and Self-directed learning	Understand principle, graduated tasks
NatureAR (Alakarppa et al. 2017)	Biology	22	Treasure hunt	Outdoor (nature)	Constructivism	Challenge based learning, Goal-based learning	Feedback, problem, creativity play

1.5.1 *Studies by Years*

When sorting selected papers by year (see Fig. 1.4), we can observe an increase in the number of educational AR game studies from 2006 to 2013, while there is a drop in 2015. The increase might be related to the wide adoption of mobile handheld devices such as smartphones and tablet computers, and readily available AR libraries such as Vuforia,[3] both making it easier to develop and distribute AR application. With a recent release of Apple's ARKit[4] API and Google's ARCore[5] API we might be seeing further increase of AR games studied in educational environments.

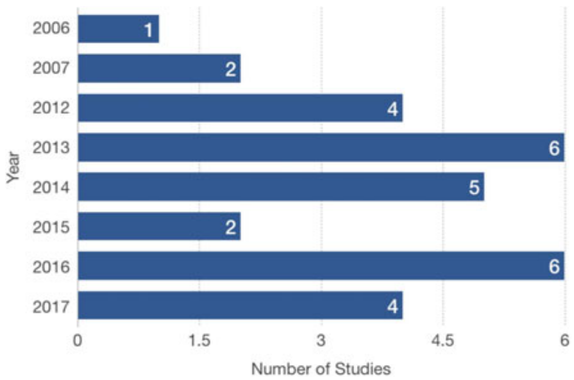

Fig. 1.4 Distribution of AR game studies by years

[3]Vuforia Software Development Kit https://www.vuforia.com/.
[4]Apple ARKit https://developer.apple.com/documentation/arkit.
[5]Google ARCore https://developers.google.com/ar/.

1.5.2 School Subjects

Looking at Table 1.6 we can see that AR games are used in a variety of school subjects. Biology (including ecology and medicine) is the leading field in this regard (30%). Taking all natural sciences into consideration along with physics (6.7%) and chemistry (6.7%), this branch of science is most often explored. Further division into topics reveal even more diversity: ecology (Squire and Jan 2007; Squire and Klopfer 2007; Furio et al. 2013a; Kamarainen et al. 2013; Hwang et al. 2016), electronics (Echeverria et al. 2012), electromagnetism (de Sainte-Foy 2015) and periodic table (Boletsis and McCallum 2013).

AR games are also used in mathematics (10%), history (10%) and language learning (10%). In addition to educational content described in school curricula, AR games are also employed for example in art (Rogers et al. 2015) and library education (Fitz-Walter et al. 2012). AR games are also employed in fields such as physical education (3.3%) and psychology (3.3%). Other studies cover 13.3% (library education, navigation and general content) (Fitz-Walter et al. 2012; Eishita et al. 2014; Rogers et al. 2015; Pombo et al. 2017). This finding shows that AR games can be employed in education and training of very diverse areas and cover various subjects from natural, social and other sciences.

1.5.3 Research Methods

A mix of qualitative and quantitative methods was used in 40% of the studies (see Appendix 1 and Fig. 1.5). Combining qualitative and quantitative methods is beneficial and allows for better understanding of AR games usage. This trend is also noticeable in Human-Computer Interaction (HCI) studies, since complementing subjective and objective methods can lead to better understanding of design problems

Table 1.6 AR Game studies by learning content

Learning content	Count (30)	%
Biology	9	30
Other	4	13.3
Mathematics	3	10
Culture and history	3	10
Language learning	3	10
Physics	2	6.7
Chemistry	2	6.7
Geometry	2	6.7
Physical education	1	3.3
Psychology	1	3.3

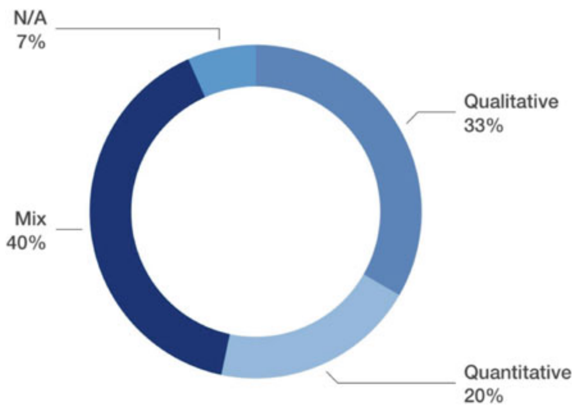

Fig. 1.5 AR Game studies by research methods

Table 1.7 Game genres used in AR games

Game genre	Count (30)	%
Treasure hunt	9	30
Puzzle	7	23.3
Simulation	6	20
Adventure	4	13.3
Role-playing	2	6.7
Action	2	6.7
Strategy	0	0

(Assila et al. 2014; Kjeldskov and Paay 2012). In our sample, qualitative only studies account for a third of all studies (33%) while quantitative only studies are reported by 20% of the papers. The remaining 7% are two papers without a study as explained in the Method section (Santoso et al. 2012; Hodhod 2014). These findings highlight the need for more quantitative studies or combination of both methods.

1.5.4 Game Genres

Among selected papers, the most common game genre is treasure hunt games (30%) and the least common is action games (6.7%) and role-playing games (6.7%) (Table 1.7). A considerable number of educational AR game studies also involved puzzle games and simulations games (23.3% and 20% respectively). Remaining game genre include adventure games (13.3%).

It has been pointed out by (Rapeepisarn et al. 2008) that game genres are not often considered when designing for a particular learning style. They also stress that different students have different styles of learning and that each student might have more than one style of learning. This means that in some learning situations, some students may prefer active engagement while others may prefer a more pragmatic learning approach. While game genres play an important role in game design, other factors such as pedagogy and literacy need to be taken into account as well.

1.5.5 Technologies Used

All selected AR games were developed for handheld devices such as PDAs in early studies, and later smartphones and tablet computers. The technology used is very dependent on what is currently available on the market and on the state-of-the-art in consumer electronics. This will change in the future when novel technologies will become available and socially acceptable (e.g. AR glasses) and when computational capabilities will increase. Currently, AR is positioned in the “Trough of disillusionment” phase in the Gartner Hype Cycle[6] for emerging technologies. Based on for example Google’s investment in AR technologies in education[7] AR is likely to progress into the “Slope of enlightenment” phase in the near future, when technology becomes widespread and easily accessible. The example of Google might also contribute to a more widespread use of Head Mount Displays (HDM). Currently, educators can take advantage of BYOD concept (bring your own device), to reduce the cost of introducing AR games in the learning process.

1.5.6 Learning Environment

The majority of the educational AR game studies were conducted in indoor learning environments, i.e. in classrooms, museums, science centers, cultural centers, libraries, living rooms, swimming pools and at summer schools (60%) (Table 1.8). Majority of these indoor learning environments include more formal setups such as settings of the classrooms, museums, science centers, cultural centers and libraries. Some of indoor learning environments also include informal setups like settings of a living room or a swimming pool. A considerable number of educational AR game studies were also conducted in outdoor learning environments such as in gardens and parks (33.3%) and just a few studies were conducted in both indoor and outdoor learning environments (6.7%).

According to Table 1.9 the majority of AR game studies were conducted in indoor learning environments and have used a puzzle genre (6 games), which is a genre that can be easily implemented in indoor formal learning setup because it often requires players to sit and solve problems that can involve logic exercises, memory and pattern matching, etc. Among the games that were used outdoors, the treasure hunt games

[6]Gartner Hype Cylce for emerging techhnologies 2018, https://www.gartner.com/smarterwithgartner/5-trends-emerge-in-gartner-hype-cycle-for-emerging-technologies-2018/.

[7]Google expeditions: https://edu.google.com/products/vr-ar/?modal_active=none.

Table 1.8 AR game studies by learning environment

Learning environment	Count (30)	%
Indoor	18	60
Outdoor	10	33.3
Indoor/Outdoor	2	6.7

Table 1.9 The number of AR games in relation to game genre, learning paradigm and theories

#	Game genre	Learning environment
6	Puzzle	Indoor
4	Treasure hunt	Indoor
3	Simulation	Indoor
3	Adventure	Indoor
2	Action	Indoor
4	Treasure hunt	Outdoor
2	Simulation	Outdoor
2	Role-playing	Outdoor
1	Puzzle	Outdoor
1	Adventure	Outdoor
1	Simulation	Outdoor/Indoor
1	Treasure hunt	Outdoor/Indoor

were mostly used as they encourage players to search for hidden objects in the environment by following a trail of clues.

1.5.7 Learning Paradigms, Theories and Activities

As seen in Table 1.5, we have categorised the majority of the AR games in constructivism and some in the humanism paradigm. This might suggest that behaviourism, cognitivism and connectivism are less explored learning paradigms in educational AR games. However, while each analysed prototype might focus mainly on one paradigm, we can find traces of other paradigms as well. For example in Electric Agents (Revelle et al. 2014), which is a transmedia action game to learn vocabulary by interacting with a TV show through AR and mobile device sensors, and EduPARK (Pombo et al. 2017), a treasure hunt AR game for a smart urban park.

According to Fig. 1.6, educational AR games were designed based on many learning theories and models. Challenge-based learning is the foremost model in this regard (43%). Educational AR games are often designed based on situated learning (20%) and experiential learning (17%). In addition to these models, educational AR games are also designed upon scaffolding (7%), problem-based 7%), collaborative (3%) and contextual (3%) learning models. The reason why challenge-based learning is mostly used in educational AR games may be related to the compensations of gamification and game-based learning.

The results from Table 1.5 shows that possible game genres for the situated learning can be simulation or role-playing games. And these game genres relate to the practice, immersion, and imitation learning activities. At the same time, it shows that the possible game genres for experiential learning can be adventure or treasure hunt games that relate to the practice and interaction learning activities. The same results can be found in (Rapeepisarn et al. 2008) study on relationship between learning techniques, learning activities and possible game genres.

We could not find any relation between game genres and learning paradigms (see Table 1.10) since for example we classified treasure hunt, simulation and adventure style games in both constructivism and humanism. The same is true for the relation between game genre and learning theories and for learning paradigms and theories in relation to learning environment.

1.5.8 Target Group(S)

Table 1.11 presents the distribution of educational AR game studies based on participants' age. The majority of the studies were conducted with primary school students (56.6%), followed by high school students (20%), and undergraduate students (6.7%).

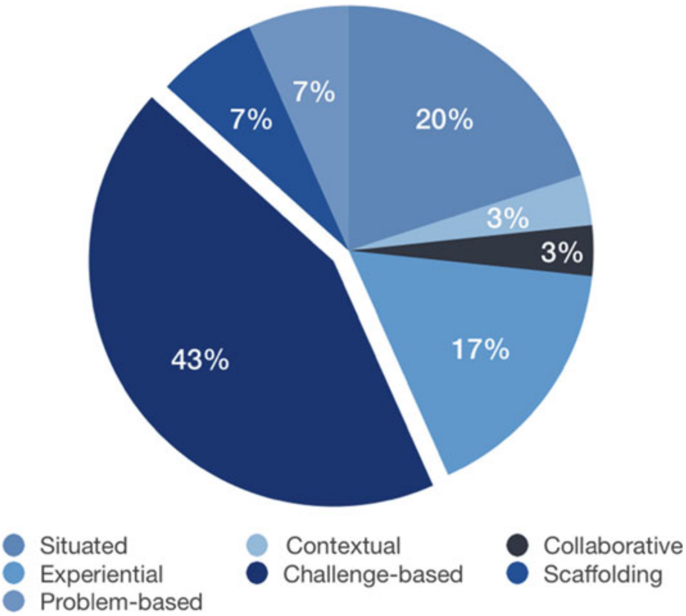

Fig. 1.6 AR game studies by learning theories

Table 1.10 The number of AR games in relation to game genre, learning paradigm and theories

#	Game genre	Learning paradigm	Learning theories
6	Treasure hunt	Constructivism	Challenge-based learning
2	Treasure hunt	Humanism	Experiential learning
1	Treasure hunt	Constructivism	Contextual learning
5	Puzzle	Constructivism	Challenge-based learning
2	Puzzle	Constructivism	Situated learning
3	Simulation	Constructivism	Situated learning
1	Simulation	Constructivism	Collaborative learning
1	Simulation	Constructivism	Problem based learning
1	Simulation	Humanism	Experiential learning
2	Adventure	Humanism	Experiential learning
2	Adventure	Constructivism	Goal-based learning
1	Role-playing	Constructivism	Situated learning
1	Role-playing	Constructivism	Scaffold of learning
1	Action	Constructivism	Scaffold of learning
1	Action	Constructivism	Challenge-based learning

Table 1.11 Target groups used in AR games

Target group	Count (30)	%
Primary school students	17	56.6
High school students	6	20
Educators	2	6.7
Any	2	6.7
Undergraduate students	2	6.7
Special education	1	3.3

The percentage of studies conducted with undergraduate students and teachers were the same (6.7%). The data also shows that AR game studies have a low percentage of students with special needs (3.3%).

Table 1.12 Sample size used in AR games

Min	Max	Mean	Median	Standard deviation
5	160	45	36	35

The results are not surprising since game-based learning might be more suitable for primary and secondary education. For example, the UNESCO report on "Games and Toys in the Teaching of Science and Technology" focuses entirely on primary and early secondary education (Lowe 1988).

We also found that the mean sample size in educational AR game studies was 45 participants (Table 1.12). The minimum sample size was 5 and maximum 160. The median value of the sample is 36 (standard deviation = 35). We can see that the majority of the presented papers have more than 30 participants. Only seven studies have less than 30 participants (21, 28, 20, 7, 5, 29, 22) and only two studies less than 20 participants. For five studies this information is not available. Table 1.5 has all the papers sorted by year and looking at the number of participants in each no pattern could be found.

1.6 Guidelines for Designing AR Games for Education

Here we present four design guidelines that emerged through our literature reveiw and should be applied as early as possible in the design and development of AR games intended for use in an educational context.

1.6.1 Design the Feedback in an Appropriate, Guided and Meaningful Manner

Feedback has been considered seriously in all of the analysed games (see Learning Activities row in Table 1.5). When designing for feedback in educational AR games, options should be considered in terms of the positive reinforcement, the timing of presentation, and of how the interpretation of feedback can help learners to build and enhance their mental models. Positive reinforcements and their timing influence the different aspects that the learner can consider in their mental model. For example, in the AR game EduPARK (Pombo et al. 2017) the virtual agent supports learners throughout the game by providing guidance about the path needed to be traversed, educational content relevant for answering questions (images, audio, videos, and augmented reality content), and feedback to given answers. Generic feedback or feedback which is not sensitive to the current learning context should be avoided as only meaningful feedback supports the learning process.

1.6.2 Create Collaborative Shared Experiences When Possible

Collaboration is a topic of several learning paradigms (e.g. constructivism and connectivism) and some AR games we have analysed have taken it into account. When a task or a learning activity is best handled through a group work AR games for education should allow learners to work together. Collaborative shared experiences provide a shared cognitive set of information between players and ensure that they build their own mental models to construct new knowledge. For example, Environmental Detectives (Squire and Klopfer 2007) engaged high school and university students in a real-world environmental consulting scenario. The scenario was built to immerse players in the practices of environmental engineers, giving them a "virtual practicum" experience, similar to working on an environmental research team. In the scenario players work in teams of two or three, and attempt to identify the contaminant, chart its path through the environment, and devise possible plans for remediation if necessary. The main focus of the game was on planning an effective investigation that balanced quantitative and qualitative data.

1.6.3 Use Elements from Real Environment to Enhance Experience

AR games do not have to focus exclusively on digital technology. For example, in the Astrid Lindgren Landscape (Nilsson et al. 2012) players need to use a real paper map where hidden information about interesting sites is displayed when viewed through the mobile phone. This concept can also be extended to include support for real elements such as cups, glasses and other objects within the game, for example using computer vision or radar (Yeo et al. 2018) to detect when users have collected such items.

In addition, in the Astrid Lindgren Landscape (Nilsson et al. 2012) game there are large distances between different AR elements, thus possibly leading to players becoming bored. This problem was partially avoided by ensuring that players make full use of the real world space. For example, selecting interesting routes in the environment, which can be used to increase the senses (e.g. dark streets leading to mystery locations), or leading players to have a coffee in a real café as part of the game (e.g. in location-based street games).

1.6.4 Design the Game Model as a Representative of the Real Phenomena

This is especially important in simulation-based games; however, it is an aspect that was considered in other games as well to make the experience as realistic and immersive as possible. To represent a real phenomenon of a learning context the game should be designed to model that phenomenon by including a set of aspects that characterize it. The learner builds their mental model by interacting with a process which executes the game model. If the game model is not representative of the real phenomenon, the experience will not help the learner to build a mental model in accordance with the real phenomenon [i.e. First Colony (Echeverria et al. 2012)]. In addition, representing the real phenomenon may influence the engagement of learners as realism is one of the characteristics of AR games that capture the attention [i.e. AREEF (Oppermann et al. 2016)].

By considering the feedback, collaborative opportunities, real world engagement and connection to real phenomena game designers and developers can enhance the engagement and pathways for adoption of AR games in education.

1.7 Conclusion and Discussion

This chapter examined thirty educational AR game studies that were presented in peer-reviewed journals and conferences. Selected studies were coded according to the following criteria: year of publication, school subject, research method, game genres, AR systems, learning environment, learning paradigms and theories, target group(s) and study sample size. Data was analysed to identify how AR games can be used to benefit the educational process in the context of different theoretical paradigms and models used in learning.

The number of educational AR game studies has increased over the years. It is foreseen that educational AR games will be more widespread in the future along with recent advancement of novel technologies.

Results reveal that AR educational games are used across diverse fields. Biology, mathematics, history and language learning are just some of the subjects, showing that a variety of fields are suitable for AR educational games. Nevertheless, the majority of studies focused on natural sciences, the area that can be easily enhanced with game components because it is often based on problem-solving tasks.

Furthermore, this review showed that the educational AR games have used various learning theories as a design principle, with challenge-based learning (constructivism paradigm) being the most common. Another interesting point is that AR games can be applied in any learning indoor and outdoor environment. Indeed, the use of AR games in appropriate settings enhances active and authentic learning in the real wold, creates an opportunity for exploring experiential student-centred learning rather than the typical educator-centred learning, and supports consolidation from working to long-term memory system through learning activities.

The results also revealed that the technology used is very dependent on what is currently available to the wider research community. While technology presents certain limitations, it is changing fast and handheld devices might soon be replaced by other technologies such as projections or head mounted displays.

One of the results revealed by our analysis is also the fact that AR games are not commonly used for teaching students with special needs. Games and gamified tasks are often used in rehabilitation or for maintaining or inhibiting certain conditions and diseases. This opens another interesting avenue for future developments.

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Appendix 1: AR Games in Education

https://docs.google.com/document/d/1-RsE1C-AoPOnnAe9FfDQaRG18HCLyB14QD31vfKmDes/edit?usp=sharing

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