Using Mobile Augmented Reality Games to develop key competencies through learning about sustainable development

IO2_A2
Analysis and synthesis of the literature on learning design frameworks and guidelines of MARG

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WHAT IS AUGMENTED REALITY?

The ways in which the term "Augmented Reality" (AR) has been defined differ among researchers in computer sciences and educational technology. A commonly accepted definition of augmented reality defines it as a system that has three main features: a) it combines real and virtual objects; b) it provides opportunities for real-time interaction; and, c) it provides accurate registration of three-dimensional virtual and real objects (Azuma, 1997). Klopfer and Squire (2008), define augmented reality as "a situation in which a real world context is dynamically overlaid with coherent location or context sensitive virtual information" (p. 205). According to Carmigniani and Furht (2011), augmented reality is defined as a direct or indirect real-time view of the actual natural environment which is enhanced by adding virtual information created by computer. Other researchers, such as Milgram, Takemura, Utsumi and Kishino, (1994) argued that augmented reality can be considered to lie on a "Reality-Virtuality Continuum" between the real environment and virtual environment (see Figure 1). It comprises Augmented Reality AR and Augmented Virtuality (AV) in between where AR is closer to the real world and AV is closer to virtual environment.

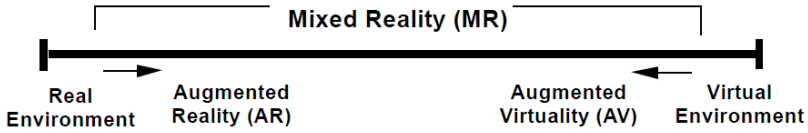

Figure 1. Reality-Virtuality Continuum (Milgram et al., 1994, p. 283).

Wu, Lee, Chang, and Liang (2013) discussed how that the notion of augmented reality is not limited to any type of technology and could be reconsidered from a broad view nowadays. This paper focuses on augmented reality games, which are embedded on mobile devices technology and especially on personal digital assistants (PDA), smart phones and tablets. According to Squire and Jan (2007), "augmented reality games are games played in the real world with the support of digital devices (PDAs, cellphones) that create a fictional layer on top of the real world context" (p. 6).

FEATURES, SYSTEMS AND APPLICATIONS OF AUGMENTED REALITY

The main devices utilized for augmented reality are displays, input devices and tracking, and computers (Carmigniani & Furht, 2011). The major types of displays that could be used are head mounted (Head Mounted Displays, HMD), the displays of mobile devices (e.g., Smart-Phones, PDAs and Tablet PCs) and the spatial displays (e.g., optical elements, holograms, radio frequency tags). In order to use the input devices users usually use gloves and wireless bracelet. Moreover, the tracking devices consist of digital cameras and/or other optical sensors, GPS, accelerometers, compasses, wireless sensors, etc.

A review of the literature indicates that augmented reality is not limited to a particular device (Broll, Lindt, Herbst, Ohlenburg, Braun, & Wetzel, 2008; Johnson, Levine, Smith, & Haywood, 2010) but a combination of technologies and devices. Devices can be used to enhance individuals' senses, such as enhancing audio messages for blinds or individuals who have low vision, deaf or hearing impaired.
The augmented reality systems are divided into image-based and location-based systems (Cheng & Tsai, 2013; Pence, 2011). As Wojciechowski and Cellary (2013) described, "the image-based augmented reality is focused on image recognition techniques used to determine the position of physical objects in the real environment for appropriate location of the virtual contents related to these objects" (p. 572).

Nowadays, with the new advances in technology, an increasing amount of augmented reality applications are developed especially with mobile applications. These applications have several different uses from advertising to education. Table 1 shows some of these applications that can

be applied to educational purposes. These applications are dependent on mobile technology (e.g., smart phone or tablet) available to the user and the type of operating system (e.g., Android, iOS, Windows Phone).

Table 1. Examples of Augmented Reality (AR) applications

Application/Website	Description	Mobile operating system
Designboom (*http://www.designboom.com/technology/street-tag-iphone-app*)	Creates virtual graffiti in various places.	iOS
FETCH! LUNCH RUSH *(http://pbskids.org/apps/fetch-lunch-rush.html)*	Lunch Rush is an AR app to teach math skills to elementary students through the use of visualization.	iOS
Butterfly Burst *(https://play.google.com/store/apps/details?id=uk.co.Armaze.Butterfly)*	Application where the user can see butterflies around and play a game with them.	Android
ARBasketball *(https://itunes.apple.com/us/app/arbasketball-augmented-reality/id393333529?mt=8)*	Game about basketball.	iOS
Arsoccer *(https://itunes.apple.com/us/app/arsoccer-augmented-reality/id381035151?mt=8)*	The user can "kick" the ball with her/his feet.	iOS
Zoo-AR *(https://edshelf.com/tool/zoo-ar)*	Zoo-AR is an AR application with a variety of animals and insects available for viewing in 3D.	iOS
Anatomy 4D *(https://play.google.com/store/apps/details?id=com.daqri.d4DAnatomy)*	Provides a virtual tour of the human body.	Android, iOS
Geometry101 (*https://edshelf.com/tool/geometry101*)	Provides activities for geometry.	iOS
ZooBurst *(http://www.zooburst.com)*	Digital storytelling tool that creates books with three-dimensional objects.	iOS
Word Lens *(questvisual.com)*	Translates words from one language to another.	Android, iOS
SkyView *(http://www.terminaleleven.com/skyview/iphone)*	Application for the exploration of the universe.	iOS
Transparent Earth *(http://www.hogere.com/transparentearth)*	Application that shows geographic information for earth and for various cities. E.g. we could see the other side of the world under our foot.	iOS
Spacecraft 3D *(https://play.google.com/store/apps/details?id=gov.nasa.jpl.spacecraft3D)*	Interact with a variety of spacecraft used to explore our solar system, to study the Earth, and to observe the universe.	Android
Popar Toys *(https://popartoys.com)*	Various AR games.	Android, iOS
SatelliteAR *(http://spacedata.agi.com/MobileApps/about.htm)*	Information about the satellites that are around us, in the sky.	Android

GUIDELINES FOR MARG DESIGN

The educational mobile augmented reality applications have been an active topic among educational technology researchers (Laine, 2018) and the number of reviews and case studies is rapidly growing. The majority of these reviews aim to establish what is needed to create good mobile augmented reality games and what causes them to fail (Ardito et al., 2010). Findings are often presented as guidelines to support designers to create games that offer an engaging experience (Ardito et al., 2010). In this paragraph we present an overview of guidelines from existing literature divided in the five categories: pedagogy, gameplay, game scenario, social interacting and technology.

Guidelines regarding pedagogy

The Oxford dictionary defines pedagogy as 'the theory or principles of education or a method of teaching based on such a theory'. In this section we summarize a list of guidelines regarding pedagogy that frames the design of AR games. To do that, we draw upon eight recent studies. A summary of the guidelines from these studies regarding pedagogy is given in Table 2.

The oldest study that we used in this literature review is the study of Fotouhi-Ghazvini, Earnshaw, Robison and Excell, and took place in 2009. The authors reviewed four AR games and defined guidelines for future AR game designers. The studies of Ardito et al. (2010) and Stefan & Moldoveanu (2013) both reviewed three AR games. In 2014 Dunleavy and Dede performed a literature review and defined guidelines based upon 17 reviewed AR games. There work was followed by that of Li, Spek, Feijs, Wang and Hu in 2017 who also performed a literature review and defined their guidelines based on 27 available reviewed AR games. The most recent work is from Laine, 2018, and Laine and Suk, 2019. Both studies performed analysis on two case studies, and compared the results. Based on their comparison they provided guidelines for designing AR games

Table 2. Summary of guidelines regarding pedagogy

Research	# reviewed AR games	Guidelines regarding pedagogy
Stefan & Moldoveanu (2013)	3	• Directly support social learning, in online scenarios. • Implement iteration which refers to the ability of the game to repeat some activities or replaying the entire game to attempt alternate strategies, and encourage experimentation, hypothesis testing, and synthesis • Reflection • Implement scaffolding which refers to discussion outside the gameplay about playing strategies, in case of complex games. • Support situated and true learning contexts, pervasive learning. • Teacher's role in the case of an AR educational game is that of a coach or a learning facilitator.

Fotouhi-Ghazvini, Earnshaw, Robison & Excell (2009)	4	• The learning objectives must be integrated into the game rules, story and different levels. • As the game progresses, the teacher must focus the group in the right direction. • Learning through enquiry and exploration • The essence meta-cognition (i.e. self-monitoring and evaluation) • The cognitive process hierarchy must be implemented fully and sequentially (Bloom's Taxonomy and Gagne's nine events of instructions)
Dunleavy & Dede (2014)	17	• Try to cope with learners' cognitive level and avoid cognitive overload due to too much information.
Dunleavy (2014)	6	• Scaffold each experience explicitly at every step to achieve the desired experience/learning behavior
Li, Spek, Feijs, Wang & Hu (2017)	26	• When designing an AR learning game, the designers should always involve the target learner groups into the design process, asking for their preferences and feedback for the game concepts, and taking their player types, learning skills and knowledge level into consideration. • The clear educational objectives are essential for the design of an effective AR learning game. Only when the educational objectives are clear, the proper game elements and AR features can be selected, and effective AR learning games can be designed.
Ardito, Sintoris, Raptis, Yiannoutsou, Avouris & Costabile (2010)	3	• Include a pregame activity to prepare players, as an ice-breaking activity in the classroom. • Vertical or horizontal exploration of a place or topic, deeply exploring a limited space and -superficially exploring a broad space. • Players should be required to link areas, locations, physical objects to concepts and topics. • Balance between competition and knowledge acquisition to avoid negative impact. • Include a debriefing phase after the game to permit players to reflect on their experience. • It can be either an individual activity or a collaborative one which aims to support players to clarify and consolidate their experience. • Depict life-long learning in informal settings when embedded in places of high information. • The game should be based on learning objectives such as competition used to increase motivation.
Laine & Suk (2019)	2	• Identify the players' skills level and adjust the difficulty of challenges and other parts of the game content accordingly. • Avoid overemphasizing pedagogy which can cause the reduction of the fun factor of the game. • Strive for seamless integration of learning content and game mechanics. • Ensure the connection between the game session length and the intended pedagogical setting. • Allow continuing the game-play at a later time. • Be fair when players make mistakes.

		• Nurture understanding of the player on how the game and pedagogical content can be of use in the real world. • Provide challenges based on understanding facts. • Provide positive disturbances to challenge the players' ideas.
Laine (2018)	2	• Show abstract concepts as concretized ones, allowing hands on experiment • The Game and the learning content should be based on an appropriate learning theory or framework • Involve the context as a learning resource.

Although the literature used in Table 2 all examine different games, there exist similarities between the guidelines. The guidelines are defined to benefit the effectiveness of the learning aspects of an AR learning game. Research suggests that integrating **clear educational objectives** into various elements of the game, such as rules and stories will contribute to the educational aspect of an AR game (Ardito et al., 2010; Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009 ; Laine, 2018; Li, Spek, Feijs, Wang & Hu, 2017). Therefore, clear learning objectives have to be defined at the beginning of the design process.

To achieve the learning objectives in a game, traditional learning methods can be implemented such as scaffolding (Dunleavy, 2014; Stefan & Moldoveanu, 2013). This will create desired learning behavior of the users by **creating challenging exercises** or puzzles for the users from which they will learn (Laine & Sui, 2019). Another learning method that should be included is **reflectio**n (Ardito et al., 2010; Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009; Stefan & Moldoveanu, 2013). This will provide users with the opportunity to reflect on what they have learned, experienced and helps them self-monitor on their process.

Another guideline is to **make use of the context and environment** as a learning resource. The literature advices games to make explicit links between the real and virtual environment, by integrating the real world in educational concepts and topics (Ardito et al., 2010; Laine, 2018). Moreover, the AR technology can be used to visualize abstract concepts as real ones (Laine, 2018), illustrating the benefit of using AR technology.

Lastly, the guidelines also suggest an **explicit role for the teacher** as a facilitator during the game, helping and coaching the learners when needed (Fotouhi-Ghazyini, Earnshaw, Robison & Excell, 2009; Stefan & Moldoveanu, 2013).

Guidelines regarding gameplay

The oxford learner's dictionary defines the gameplay as 'the features of a game, such as its story or the way it is played, rather than the images or sounds it uses'. In this literature review we refer with gameplay to the way the game is played. This section serves as a summary of the guidelines regarding gameplay that frames the design of AR games. The guidelines provided in this section are based on the the guidelines provided by eight recent studies. An overview of the guidelines can be found in Table 2.

Table 2. Summary of guidelines regarding gameplay

Research	# reviewed AR games	Guidelines regarding gameplay
Wetzel, McCall, Braun, & Broll (2008)	3	• Role play, resolving several tasks • Use a combination of real and virtual elements such as paper maps.

		• Make use of the real world location, beyond simply locating virtual elements in a real space. • Use potential technical problems as elements within the gaming experience • Choose your tracking wisely • Enhance user experience and encourage exploration.
Stefan & Moldoveanu (2013)	3	• Playbility: "the amount of satisfaction a player gets out of interacting with a game", • Players contribution" A player adds its own contribution to the game, by using its skills, taking decision, handling the interface, concentration, attention • Create a mixed-reality environment, by combining real and virtual information and visualization • player-oriented game, based on a dynamic environment, dependent on the user and device orientation • provide a sense of immersion;
Fotouhi-Ghazvini, Earnshaw, Robison & Excell (2009)	4	• The game model must be close to the real world • each team member must have distinct roles • resources must be constrained • role playing • Rules are constraints or controls in the playing environment. • These rules must be fixed, repeatable, explicit, unambiguous and shared by all players at the same time by means of mobile technology, e.g. GPS or WiFi. • The use of the body in the learning activities is critical • the game play area must be easily configurable. • The navigation through the game was by simple physical navigation • Characters could be both real and virtual. • Instead of making the game into one big puzzle, it can be divided into small puzzles in different game levels.
Dunleavy & Dede (2014)	17	• If authentic environmental observation and interaction are part of the learning objectives, then a place-dependent model is optimal, as the designers can scaffold experiences that require the users to observe and manipulate the physical environment (e.g., sampling water, observing topography, collecting leaf samples) to accomplish a specific experience-based task. If not, consider place-independent model. • Choosing a location that students know conceptually or physically (e.g., a zoo)may provide familiar mental and physical models, thereby decreasing some of the inherent complexity and subsequent cognitive load for the participating users.
Dunleavy (2014)	6	• Create a simplified experience structure initially and increase complexity as the experience progresses • Replace text with audio • Use videos containing narrators as "guides" that are the same age as the students

Li, Spek, Feijs, Wang & Hu (2017)	26	• Designers should use different game elements (quizzes, timer, score, feedback) to improve the learning achievements and motivation
Ardito, Sintoris, Raptis, Yiannoutsou, Avouris & Costabile (2010)	3	• Players should be free to switch between different tasks • Players can/ cannot correct their mistakes, as an evaluation of the consequences of their actions • Help or hint mechanisms should be provided • Increase difficulty of the levels by automatic adaption or human-generated adaption • Prevent rule breaking by discouraging it or by incorporating cheating into the game; • Make clear game goals such as earning points, completing tasks etc. • Clear game ending conditions such as maximum time, target score, end of resources etc. • Provide alternative ways for performing tasks or completing the game; • Exploit role-playing and link to the tasks; • Provide immediate feedback about task execution showing its impact on the game; • Players should be allowed to practice different skills included in a variety of tasks - perform a quest, identify certain locations; shoot a picture from a specific angle, videotape a route; identify physical marks, answer questions, collect and classify materials;
Laine & Suk (2019)	2	• Opportunities for competition and collaboration; • Allow player co choose the preferred game-play mode; • Encourage world exploration by physical movement; • The extent of movement matches with the requirements of pedagogical setting; • Provide per-player customization option; • Allow players to use navigational skills and provide appropriate level of guidance if they are not able to find the place; • Avoid repeating similar content and activities for a long time; • Nurture engagement through tension; • ensure a relaxing experience for the player; • Provide a way for the player to find hidden and surprising things in order to go further.
Laine (2018)	2	• Combine game genres, making the game interesting and suitable for many players; • Get a skilled designer to create the content and game appearance; • Use a game-play model to design different components and keep the player engaged (e.g. game bricks); • Treasure hunt; • Use of educational prizes; • Use of map, bomb and locations; • Use of a great variety of interaction tools; • Use of obstacles; • Scaffolding hints.

The design of the gameplay is of great importance to the motivation and engagement of users. The gameplay regards different mechanisms of the games available to the learners. Various studies showed

the importance of creating a '**mixed-reality'** in which the story line interacts with the real environment and makes use of real objects in order to give the learners a sense of real experience (Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009; Stefan & Moldoveanu, 2013; Wetzel, McCal, Braun & Broll, 2008). By including **both a virtual and a real environment**, users are asked to engage physically in the game as well. It asks for body movements from the users, who need to walk towards real-life objects for example, in order to get the next challenge, puzzle or assignment. This use of the body is critical learning activities (Laine & Suk, 2010).

In terms of learning experiences, the guidelines suggest to **integrate several levels**. The learner will start at the lowest level, but as the learner progresses through the game, the level will increase with an appropriate pace. By increasing the difficulty of the game, users will keep be challenged, while preventing frustration by receiving questions which are too hard at the beginning of a game (Ardito et al., 2010; Dunleavy, 2014; Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009).

To support learners during the game various methods can be applied. Adito et al. (2010) propose using **scaffolding hints**, to help users when needed. Another option proposed by the literature is the implementation of a virtual guide, preferably in the form of a character that fit the story line and are of the same age as the users. Such a guide can coach users navigate through the game, can give hints or can answer basic question that users might have. Such coaching may prevent frustration and confusion (Dunleavy, 2014; Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009; Laine & Suk, 2019).

Lastly, the guidelines for gameplay stipulate the importance of a **clear set of rules**, that are fixed, repeatable, explicit, unambiguous and shared by all players at the same time (Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009).

Guidelines regarding game scenario

The game scenario regards the scenario in which the game is situated. This section provides a summary of the design guidelines for AR games regarding game scenarios. This section draws upon the guidelines regarding game scenarios defined in nine different studies that all reviewed multiple AR games. Table 3 provides a summary of the studies and their defined guidelines regarding game scenario.

Table 3. Summary of guidelines regarding game scenario

Research	# reviewed AR games	Guidelines regarding game scenario
Wetzel, McCall, Braun, & Broll (2008)	3	• Keep it simple • Show Reality • Do not simply convert a game to augmented reality • Create meaningful content
Stefan & Moldoveanu (2013)	3	• Challenge: offer varying levels of difficulty, hidden information, and a random behavior • context-aware, so called outdoor games;
Fotouhi-Ghazvini, Earnshaw,	4	• challenges must be used throughout the game system. • puzzles fit naturally into the story and give the players the opportunity to learn more about the people, the setting, and the world they are exploring.

Robison & Excell (2009)		• role-play real life. • Strategy-based adventure games • try to be as close as possible to real life and to the environment where it is taking place, or the environment it is simulating.
Dunleavy & Dede (2014)	17	• Use Inquiry based simulations as scenario with a definitive ending solution rather than an open-ended ending. • Designers must provide ways that users can subsequently construct story "pieces" into a synthesized whole, to give the participants a complete view of the problem or narrative. • Structure the AR experience in a way that prevents the students' natural inclination to "race" through the experience in an effort to "beat" their classmates by being the first ones to finish. • Design a nonlinear path with an entry point "gatekeeper" that triggers all the remaining digital objects that students needed to encounter. The students then choose their own paths and are therefore less likely to see themselves as ahead or behind their classmates. .
Dunleavy (2014)	6	• The story or narrative provides the structure and rationale for the AR experience, and it has a profound impact on the quality of the experience. • Combine gamification elements, such as scoring systems or fail states, to an immersive narrative.
Li, Spek, Feijs, Wang & Hu (2017)	26	• Designers should design motivational game scenarios such as treasure hunts, secret missions.
Ardito, Sintoris, Raptis, Yiannoutsou, Avouris & Costabile (2010)	3	• Exploit metaphors from real-life activities and stories; • Minimize the changes to the physical places; • Include social conventions of the place; • Include activities that are not part of the game, but happen in the real world; • Include a game master to enforce rules or narrate the story; • Integrate back-story that is the basis of the tasks; • Contextual cues linked to specific places or events to convey additional information; • Allow players to interfere to competitors; • Include rewards to improve satisfaction - provide multimedia information as a prize; • Tune the level of awareness of other players' activities - hide/ provide/ delay information.
Laine & Suk (2019)	2	• Show the progress of the game-play for the player; • Provide a sufficient level of realism, fantasy and immersion; • Give the player the chance to become the hero; • Provide a well-written story that connects the game components and help the player feel the experience; • Connect the story to the well-known experience and environment of the player.

Research shows that it is important to create a scenario that entails a story or narrative that motivate players to engage such as treasure hunts or secret missions (Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009; Li, Spek, Feijs, Wang & Hu, 2017). Dunleavy and Dede (2014) added that the **narrative preferably has an definitive ending** rather than an open-ended ending. The story must be well-written to increase engagement and all the other game components must be integrated into this story which will help the player to feel the experience (Ardito et al., 2010; Laine & Suk, 2019). To ensure users have a full understanding of the scenario, learners must be able build or construct story 'pieces' of this narrative during the game through assignment or challenges (Dunleavy, 2014; Dunleavy & Dede, 2014).

Wetzel, McCal, Braun and Broll (2008) state that **showing reality** in the game will strengthen the experience of the narrative for the users. The literature advices to stay as close as possible to real life and the environment where the game is taking place and minimize the changes to the physical places . This can be done by integrating virtual details of real locations, peoples, animals or objects (Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009). This encourages the identification of users with characters or context of the game. Adito et al. (2010) and Dunleavy (2014) proposed various game elements such as **scoring systems and rewards** to increase engagement even further.

Guidelines regarding social interaction

The American Psychological association defines social interaction as 'any process that involves reciprocal stimulation or response between two or more individuals. This section offers a summary of the design guidelines regarding social interaction. These guidelines are based on the nine studies this review draws upon.

Table 4. Summary of guidelines regarding social interaction

Research	# reviewed AR games	Guidelines regarding social interaction
Wetzel, McCall, Braun, & Broll (2008)	3	• Create Sharable Experiences • Use Various Social Elements
Stefan & Moldoveanu (2013)	3	• EMOTIONAL APPEALING: The game must create emotions to players by means of virtual and physical surroundings. • INTERACTIVITY

Fotouhi-Ghazvini, Earnshaw, Robison & Excell (2009)	4	• communication capabilities • players freely communicate with each other • Playing in a team and communication among the players • Factors that increased the level of game customisation for learners were: simplicity, loosely defined game structure, familiar physical locations and real objects, each groups' intelligence homogeneity, friendship, gender-division, familiarity with playing digital games and mobile devices.
Dunleavy & Dede (2014)	17	• Create differentiated role-based AR experiences that use a combination of jigsaw pedagogy and interdependent roles to give students a complete picture of problem or experience space • Allow teamwork • Enable communication channels through playing devices (i.e.chat)
Dunleavy (2014)	6	• Create' teams of players consisting of pairs or more. • Create the game in a way that students need each others' contribution to solve a puzzle
Li, Spek, Feijs, Wang & Hu (2017)	26	• Designers should keep the social advantage of AR in the AR learning games such as roles, trying to design social functions that can lead to better social effects in real life.
Ardito, Sintoris, Raptis, Yiannoutsou, Avouris & Costabile (2010)	3	• Team players should be selected based on the pre-existent social relations or according to their skills; • Assignment of responsibilities and tools among the team to induce collaboration; • Permit, force or neglect competition among the team members.

The social interaction that users engage in can be stimulated in various game designs. Three themes have arisen in the literature to support social interaction: **teamwork, role play and communication channels**. Guidelines throughout the literature agree that teamwork should be allowed in the game design (Ardito et al., 2010; Dunleavy, 2014; Dunleavy & Dede, 2014; Fotouhi-Ghazvini, Earnshaw, Robison & Excell, 2009). Ardito et al. (2010) suggest that the team players should be selected based on the pre-existent social relations, hence their network of friends, to ensure optimal social interaction and teamwork between players.

Another way to increase the social interaction is to integrate the **necessity of teamwork** and communication along the players is to create the game in a way that students need each other's contribution to solve puzzles (Dunleavy, 2014). This can be done by defining different role plays users can fulfill in the game scenario (Dunleavy & Dede, 2014; Li, Spek, Feijs, Wang & Hu, 2017). Each role will have their own assignment of responsibilities and tools among the team that are necessary for puzzles. This forces users to work together on puzzles. Creating such social roles in the game can lead to better social effects in real life (Ardito et al., 2010).

Dunleavy and Dede (2014) provide a last guideline which proposes to implement various communication channels such as a chat.

Guidelines regarding technology

The oxford learner's dictionary defines technology as 'scientific knowledge used in practical ways in industry, for example in designing new machines. In this section we focus on the possible AR technologies that are used in practical ways in AR games, for example the AR technology to make virtual artifacts or introduce virtual characters. This section presents a list of guidelines regarding technology that frames the design of AR games. The guidelines presented in Table 5 are based on nine different studies, who each reviewed multiple AR games and defined guidelines based on their findings.

Table 5. Summary of guidelines regarding technology

Research	# reviewed AR games	Guidelines regarding technology
Wetzel, McCall, Braun, & Broll (2008)	3	• "Magic Lens Box" is based on the MORGAN AR/VR Framework (Ohlenburg, Broll, & Braun, 2008). • ARToolkitPlus library • Experiences First, Technology Second • Select technologies which are relevant to aspects such as time period and ambience
Stefan & Moldoveanu (2013)	3	• point-and-click interface and a natural (gesture-based) human-computer interaction • combines graphics and sounds with user mobility; • support multimedia-based content and storylines; • can integrate user created content;
Fotouhi-Ghazvini, Earnshaw, Robison & Excell (2009)	4	• The technology plays a significant role in controlling the game and the distance proximity between players; game characters and the game objects must be decided by GPS, WiFi, Bluetooth or infrared. • designers need to add menus for room location, area maps, list of virtual or real items or resource collections, with options to collect environmental data, control GPS, access Bluetooth or Infrared and message other peers are necessary.
Dunleavy & Dede (2014)	17	• Utilize the handheld to foster interaction with the context rather than to present extensive information independent of context.
Dunleavy (2014)	6	• While location based AR can provide powerful and compelling experiences, it is critical that designers do not create experiences where the technology becomes a barrier to the environment. Rather the technology needs to drive the students deeper into the authentic observation and interaction with the environment and with each other if AR is to grow beyond a novelty technology.
Li, Spek, Feijs, Wang & Hu (2017)	26	• Designers should Identify the effects of each AR feature. AR technology compasses various features, and basically divided into location-based AR and image-based AR. While other forms included the use of an AR avatar, physical objects, extra instructional materials (e.g. video, audio, text etc.), and so on. But, does the AR avatar help students engage in the study, or does it distract the students' attention? Identifying the different outcomes and effects of each feature will make the design of AR technology better help students to achieve their goals.
Ardito, Sintoris, Raptis, Yiannoutsou,	3	• Let players get familiarized with the equipment and game rules;

Avouris & Costabile (2010)		• Facilitate game learnability such as tasks, rules, constraints, which should be easy to understand and to learn; • Create a multidisciplinary design team including HCI, domain experts, site experts, educational experts; • Perform formative evaluations and pilot studies to check if tasks' difficulty is appropriate for the target players; • Extend the game experience beyond the game session such as including a participation to web community; • Minimize the interaction with the game tools.
Laine & Suk (2019)	2	• Use rich media content that facilitates immersion in the game experience; • Apply state-of-the-art technologies; • Create and undergo plans for technical usability tests to ensure that the technology and content work in a different range of situations; • Allow customization of game-play experience by the player and by the teacher - story creation, challenge creation, changing preferences; • Allow the player control and manipulate the game world - include characters and game objects; • Allow the player practice AR interaction before playing the game; • Provide an in-game tutorial to present the essential features of the game; • Provide clear instructions of the objectives and how to reach them;
Laine (2018)	2	• Use a well-established and free platform with good support resources (e.g. ARIS, Aurasma, Bilbbar, Vuforia SDK, ARToolkit); • Choose a target tracking method according to the location and maintenance resources; • Define unambiguous core concepts; • Use all the versatile ways of AR and adopt those which suits; • Provide different ways of interaction (e.g. touchscreen, marker manipulation, sensor-based gestures, eye tracking, speech recognition); • Provide 3D models, 2D pictures, videos, animations, annotations, sounds; • Provide an easy method to modify and add game content.

There exist many platforms on which AR applications can be created and Laine (2008) identified a handful of platforms which seemed, based on her literature review, to be the most commonly used. Platforms such as ARIS, Vuforia SDK and ARToolkit were very popular among education augmented reality designers. Her guideline is to choose a well-established and free platform with good support resources. Ardito et al. (2010) focus on not only the design platform, but the design team as well. They suggest creating a multidisciplinary design team including HCI, domain experts, site experts and educational experts.

However, although the technology and design teams are very important, the guidelines also suggest that it is not the most important aspect of an AR game. The focus should lay on the **experience of the game** and the technology must complement this experience and not the other way around (Wetzel, McCall, Braun & Broll, 2008). Hence, instead of using all the technologies available, design teams should familiarize themselves with all the different options such as avatars, physical objects, extra instructional material et cetera. After familiarization, the technologies which are the most relevant to the story line,

time period or environment can be selected (Laine, 2018). Li, Spek, Feijs, Wang & Hu (2017) point out that different outcomes of AR technologies such as avatars, physical object and so on, should be identified. For example, is a virtual guideline helpful or merely a distraction towards players? Guidelines have arisen by reviewing and analyzing existing games, but the actual support of different AR technologies for students to achieve their goals, have not yet been established.

In line with the guidelines for gameplay and the game scenario, the design guidelines for technology also suggest that the **AR must not become a barrier to the environment**, but instead drive the students deeper into the authentic observation and interaction with the environment (Dunleavy, 2014). Hence the technology must find a balance between the virtual world and the real environment and let both worlds work together.

Regarding interaction between players and the game, the AR technologies that are often used are visualizing virtual content and using the touch screen of a mobile device to interact with the content (Laine, 2018). Laine (2018) suggest that this must be diversified and advices game designers to include AR technology that make interaction more natural. Laine suggest several examples of such technologies referring to Ducher's review on interaction methods in AR with a specific focus on natural interaction. These interaction methods include haptic user interfaces, gesture recognition, gaze-tracking and speech recognition.

Moreover, **multimedia-based content** and **storylines** are advised in the guidelines (Laine, 2018; Stefan & Moldoveanu, 2013). Multimedia-based content can be ensured by varying between 3D models, 2D pictures, video's, animations, sounds, and text during the story, puzzles and challenges (Laine, 2018).

Besides guidelines focusing on the implementation of AR technology into the game, there are also guidelines to support users in using the AR technology. Various research defined guidelines which mention some sort of **practice environment** in which players should be able to familiarize themselves with the essential features of the game such as equipment, AR interaction and game rules (Ardito et al., 2010; Laine & Suk, 2019). This environment can for example be an introductory phase of the game or an in-game tutorial.

Lastly, the guidelines propose pilot studies to check if the AR technology works in **different settings** and a range of situations and to test if the tasks' difficulty is appropriate for the target players (Ardito et al., 2010; Laine & Suk, 2019).