



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

IO2_A1

Analysis and synthesis of frameworks on learning design frameworks and guidelines of MARG

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THEORIES OF LEARNING

Squire and Jan (2007) grounded the design of their research within the *game-based learning theory*. Based on this theory they aimed 1) at encouraging players to inhabit professional roles with specific professional identities and perspectives, 2) challenging players through multiple layers of narratives and tasks, 3) situating the game in a local/physical place, 4) facilitating learning through multiple representations, and 5) creating social interactions that promote collaboration, competition, and reflection in action. Squire and Klopfer (2007) used *situated learning* as a base for designing an analytic program about conducting research in environmental science. Specifically, they used augmented reality to position students into a complex problem-solving framework within the physical world. Moreover, situated learning theory was adopted by augmented reality game regarding environmental concepts. Rosenbaum, Klopfer and Perry (2007) used *authenticity* to frame their research, which is related to constructivism, situated learning and practice communities. According to the researchers, the question of authenticity is dependent upon the framework in which the game can be perceived as authentic. In Echeverría et al.'s (2012) study the use of *Computer Supported Collaborative Learning*, was used to frame the design. This pedagogical approach stems from constructivism. In a collaborative learning activity, students work as a group in a coordinated effort to achieve a specific educational goal. On the other hand, Furió et al. (2013a) and Furió et al. (2013b) developed the games relying on two learning theories. The first one was Gardner's theory of multiple intelligences and the second one was Kolb's theory that perceives learning as a continuous process named "Kolb Learning Cycle".

ANALYSIS AVAILABLE AR GAMES

The possibilities of AR technology are rapidly growing and the variation in game design in available AR games can be enormous due to large amount of design options. The guidelines, as previous discussed, offer designers support in the design process to ensure the AR games becomes as engaging experience for the players. This section focuses on certain design aspects of the game such as the gameplay, game scenario, levels and character. Additionally, this section examines the learning opportunities that are provided by the game design. We discuss learning opportunities for developing skills regarding collaboration, problem-solving, leadership, social interaction, active citizenship, data and information literacy, critical thinking and applying scientific knowledge to everyday life.

In this section, we draw upon 12 studies which all developed and evaluated an educational AR game. O'Shea, Mithcell, Johnston and Dede (2009) most of the studies describe the design process and choices used during the initial development of the AR game and provide results from formative evaluations of the AR game (O'Shea, Mitchell, Johnston, & Dede, 2009). Likewise, Pombo, Marques, Afonso, Dias and Madeira (2019) present the EduPARK project's first cycle of design-based research for the development of a mobile AR game-like ap that aims to promote learning in urban park and experiences of students using it in loco (Pombo, Marques, Afonso, Dias, & Madeira, 2019). Furió, González-Gancedo, Juan, Seguí and Rando (2013) present an initial study to determine the subject preferences for educational computer games for children. Based on their findings, they developed an iPhone game for transmitting knowledge as part of multiculturalism, solidarity and tolerance. A second study evaluated the iPhone game and examined if the game has better learning outcomes than a traditional game. Their findings showed that there is no different in learning outcomes between the iPhone game and a traditional game, however the majority of the students, 90 percent, preferred the iPhone game over the traditional one. Such studies, which include both the design process and the evaluation of the game are the fundament of this section in which we aim to identify the learning opportunities users receive for developing various skills related to learning objectives.

AR games and relevant school subject

An AR game is relevant to a certain school subject when it covers learning objectives of that specific school subject. AR games are not necessarily restricted to one specific school subject, in fact AR technologies can promote interdisciplinary learning, by discussing a certain topic through various points of views. For example, the game EduPARK teaches players about symmetry axis using flowers, combining biology and math concepts (Pombo, Marques, Afonso, Dias, & Madeira, 2019). Table 6 provides an overview of the examined AR games and their related school subjects.

Table 1. Summary of the games and their related school subjects

| Authors | Name of the game | School Subject |
|---|---------------------------------------|---|
| Pombo, Marques, Afonso, Dias, & Madeira, 2019 | EduPARK | <ul style="list-style-type: none"> • Biology • History |
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | <ul style="list-style-type: none"> • Environmental education |
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | <ul style="list-style-type: none"> • Geography • Literacy • History • Foreign languages |
| Gariepy et al., 2018 | (No specific name) a mobile videogame | <ul style="list-style-type: none"> • Biology • Health Education |
| O'Shea, Mitchell, Johnston, & Dede, 2009 | Alien Contact! | <ul style="list-style-type: none"> • Mathematics • Literacy |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | <ul style="list-style-type: none"> • History |
| Squire & Jan, 2007 | Mad City Mystery | <ul style="list-style-type: none"> • Environmental Science |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | <ul style="list-style-type: none"> • Sustainable development |

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| Schrier, 2006 | Reliving the Revolution (RtR) | <ul style="list-style-type: none"> History (middle school and high school) |
| Klopher & Squire, 2007 | Environmental Detectives | <ul style="list-style-type: none"> Advanced introductory (late high school and early college) |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | <ul style="list-style-type: none"> Biology (basic of epidemiology) |
| Kamarainen et al., 2013 | EcoMOBILE | <ul style="list-style-type: none"> Biology |

Game scenarios

The oxford dictionary defines a game scenario as a written outline of what happens in the game. In this section, we provide a summary of the game scenarios of the twelve analyzed AR games from the reviewed literature. An overview is given in Table 7.

Table 2. Summary of the game scenarios in terms of their objectives

| Research | Name of the game | Game scenario in terms of its objectives |
|---|----------------------------------|---|
| Pombo, Marques, Afonso, Dias, & Madeira, 2019 | EduPARK | <ul style="list-style-type: none"> Support user learning in a particular outdoor setting and identify multidisciplinary issues (e.g., integrating Biology and History) that might be explored in the selected park. The identified issues should be used to create four interdisciplinary educational guides, or quiz games, for the app. It should promote learning contextualized in the park, e.g., related to the botanical species or with the historical monuments in the park; It should promote interdisciplinary learning, e.g., using flowers to teach about symmetry axis; |
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | <p>The scenario of the game asks students, in groups of five, to save a small sea turtle, Elli, from a wicked scientist whose purpose is to destroy the environment of Santorini. The purpose of the game:</p> <ul style="list-style-type: none"> Explore the environmental problems of the island of Santorini. Adopt positive attitudes toward environmental issues on the island Propose solutions for improving the quality of life and the development of their land |

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| | | <ul style="list-style-type: none"> • Develop ways and skills of intervention in their immediate social environment to address the problems of the wider environment. |
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | <p>The subject of the game is multiculturalism, tolerance, and solidarity. The game focuses on transmitting knowledge about three of the world's poorest continents (Africa, Asia, and Central and South America).</p> <ul style="list-style-type: none"> • To cover the solidarity aspect, the mission of the game is to collect food from these continents to distribute it among poor people. • To cover the multiculturalism aspect, while playing, the players learn about the food, animals, monuments, and meteorological phenomena that are typical of these continents. • To cover the tolerance aspect, the game indirectly tries to promote respect for other people of different cultures (like the Africans) by helping them with different tasks. |
| Garipey et al., 2018 | (No specific name) a mobile videogame | <p>A mobile videogame intervention to decrease high-risk sexual behavior in black and Hispanic adolescents.</p> <p>High-risk sexual behavior (e.g., vaginal intercourse without condoms, multiple sequential or concurrent sexual partners, and intercourse under the influence of alcohol or drugs)</p> |
| O'Shea, Mitchell, Johnston & Dede, 2009 | Alien Contact! | <p>In Alien Contact! the students are presented with the following scenario: Aliens have landed on Earth and seem to be preparing for a number of actions, including peaceful contact, invasion, plundering, or simply returning to their home planet, among other possibilities.</p> <ul style="list-style-type: none"> • Working in teams (four pupils per team), the students must explore the augmented reality world, interviewing virtual characters, collecting digital items, and solving mathematics and literacy puzzles to determine why the aliens have landed. • Each team has four roles: chemist, cryptologist, computer hacker, and FBI agent. Depending upon his or her role, each student will see different pieces of evidence. In order to successfully navigate the augmented reality environment and solve various puzzles, the students must share information and collaborate with the other members of their team. • As students collect this data, they will discover different possibilities for why the aliens may have landed. It is up to the students to form hypotheses |

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| | | based upon the data collected. At the end of the unit, the students orally present their findings as a team to the class and support their hypothesis with data collected in the field. |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | <p>According to the plot of the game, the player is a ghost hunter in our days who tries to catch a ghost of a knight who belonged in the Order of the Knights Hospitaliers of Saint John of Jerusalem who came to Rhodes in 1300 A.C.</p> <ul style="list-style-type: none"> • The ghost hunter is wandering inside the medieval city and the player collects data from scared virtual characters who admit that they have seen it. The player visits places in the city with cultural interest where the ghost was supposed to be and gathers information. • At each location the player has to solve historical puzzles in order to move to the next challenge. • The final scene of the game is in municipal garden of Rhodes where a special video audio theater performance without actors is performed. There he/she realizes that the ghost is actually a trick of a sneaky bad guy, special effect technician of the theater whose gang wants to frighten the locals and the tourists and depose the current mayor, in order to avenge his dismissal from the municipal theater. |
| Squire & Jan, 2007 | Mad City Mystery | Mad City Mystery is a murder mystery game set in around Lake Mendota Madison, Wisconsin. Students investigate an untimely death caused by a murder, suicide, or the combination of several interacting toxic chemicals that are commonly found in the region. The game itself begins with the revelation of Ivan's mysterious death. From there, players must interview virtual characters, gather quantitative data samples, and examine government documents to piece together an explanation. |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | In Sète, a small French southern town nearby the Mediterranean Sea, six companies are competing to implement new energies into the city. The companies are specialized in different "green" energies: heat pumps, windmills, ocean wave energy, photovoltaics and methanization. Each of them has to convince the committee tender responsible for the call for project that their project is the best for a sustainable development of the city. But they |

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| | | <p>have to face cons from an active local association of citizens before they vote to choose the best project. The debate is tricky and the competition is merciless. Each one is aware of the importance of the stakes and is deeply involved in the struggle... but this is “only a game”.</p> <p>The “mayor of the city” is a secondary teacher. The “companies”, the “committee tender” and “association of inhabitants” are the different characters playing by secondary students. Each company has two weeks to design a pre-project. They present the pre-project to other companies, to the committee tender and to the citizens association who provide opinions and recommendations. Then, the companies have two more weeks to improve their project according to the feedback that they get after their presentation. At the same time, the committee tender and the citizens association verify the coherence of the different projects by gathering data on the field.</p> |
| Schrier, 2006 | Reliving the Revolution (RtR) | <p>RtR takes place in Lexington, Massachusetts, the site of the Battle of Lexington of the American Revolution (British vs. American). The game is structured into two 30-minute periods: Time 1 simulates the moment before the Battle of Lexington has begun and the first shot has been fired, and Time 2 recreates the moment immediately after the Battle ends. The goal of the game is for the players to “re-enact” the events of April 19, 1775, and decide who they think fired the first shot at the Battle of Lexington, which remains a mystery today. In addition to this primary goal, there are two other character-specific mini-objectives that help guide, direct, and check one’s progress in the game and, furthermore, also help the participants address systematically the more complex historic question, because they highlight different hypotheses as to who fired the first shot. Thus, while playing RtR, participants can focus on smaller specific subtasks, rather than just the larger goal and, by fulfilling these mini-objectives, they can have a better grasp of their progress in the game and a larger picture of what happened in Lexington.</p> <p>Basically, the game scenario is set in present-day Lexington Common and allows the players the chance to inspect the physical buildings and structures that were involved in the Battle of Lexington. The main coordinate of the game is the search for virtual historic figures (NPCs) and game items triggered by GPS.</p> |

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| Klopher & Squire, 2007 | Environmental Detectives | <p>In the prototype version of the game, the players are described as environmental scientists responding to a call from the President of their University, who has recently been notified that a toxin has been discovered in the campus groundwater during routine tests on a construction site. The players must report back to the President in 90 minutes with a description of the problem, a list of possible causes and culprits, and, more importantly, recommendations for solving the problem. In order to do that, the participants navigate a physical location and use handheld and GPS devices to gather information from virtual game characters and take virtual toxicity analyses at specific GPS coordinates.</p> <p>Specifically, the objectives of the game scenario are to help students learn the importance of balancing desktop research and fieldwork, understand that investigations are a social enterprise, constrained by time and budgets (rather than “purely” scientific enterprises), and that no one solution to an environmental disaster is ideal.</p> |
| Rosenbaum, Klopper & Perre, 2007 | Outbreak @ The Institute | <p>The action of the game takes place on a university campus where an international robotics competition is held. The participants come exactly from those countries where several cases of Bird Flu were reported.</p> <p>The game does not mention a specific set of objectives to be achieved, being the players the ones who set up their goals throughout the game. Despite this freedom of choice, they are assigned with the tasks of collecting scientific information about Bird Flu and finding methods of limiting the spread of the disease or stopping it. Another task consists in identifying the first virtual characters that were infected. In order to be able to fulfill the above mentioned tasks, players should prevent themselves from getting sick.</p> <p>A major challenge for the players is to differentiate the characters infected with Seasonal Flu from those displaying symptoms of Bird Flu because they are quite similar in manifestation.</p> |
| Kamarainen et al., 2013 | EcoMOBILE | <p>The game scenario consists in students finding several “triggers” meaning virtual spots placed on the map of a real area which become active when the physical locations are reached.</p> <p>Throughout the field trip, students are divided into pairs. Once arrived at the first trigger location, they are provided with introductory notions about the organisms living around</p> |

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| | | <p>the pond and are asked to establish their role in the ecosystem. Then, students are guided how to measure two water quality variables and are also taught to interpret the values obtained. The above described process repeats at a second location. Navigating to another trigger or hotspot, students are asked to make a sketch of a previously noticed organism. The following two locations offer visual overlays, 3D models, videos and additional information regarding the classification of organisms. Moreover, the level of comprehension of the children is checked by posing them a series of questions. At the end of the game, students meet with another pair of fellows who had to measure the other two water quality variables and compare their results.</p> |
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The 12 AR games each have an original game scenario, but they all seem to serve the same purpose: letting the users explore both the AR world and real environment. The stories of the game scenario's sketch the AR environment which the users will be exploring. For example, Schrier (2006) examined the game *Reliving the Revolution* which situates the players in the present-day Lexington Common and allows the players to inspect the physical buildings and structures that were involved in the Battle of Lexington. Likewise, *Save Elli! Save the environment!* invites the users to investigate the real environment by sketching a story in which a wicked scientists wants to destroy the environment of Santorini, which is the home of Elli the sea turtle. The users are asked the explore the environmental problems of Santorini. *Outbreak @ the Insitute* shares a story in which there is an outbreak of the Bird Flu at an university campus right after hosting an international robotics competition in which participants from countries with cases of Bird Flu participated. These stories, which are provided as an introduction of the game, sketch the environment which the learners will be exploring.

Some game scenarios define a specific assignment and goal for the users. For example, both *Rhodes K-nights* (Markouzis & Fessakis, 2016) and *Mad City Mystery* (Squire & Jan, 2007) have a quest-like game scenario in which the users need to solve a mystery. In *Rhodes K-nights* users are ghost hunters that have to catch a ghost and in *Mad City Mystery* users need to solve a murder. Both scenarios explicitly frame the assignment users have during the game.

On the contrary, there are game scenarios which mainly describes the environment and ask users to explore the world, but without giving them a specific goal. Games like *EduPARK* (Pombo, Marques, Afonso, Dias, & Madeira, 2019)and *EcoMOBILE* (Kamarainen et al., 2013) invite the users to explore the environment and find certain AR objects that will become visible when users are nearby a certain location. This type of game scenario still invites the users to explore the environment, but without an overall purpose.

Furió, González-Gancedo, Juan, Seguí, and Rando (2013) investigated an iPhone AR game that aims to transmit knowledge about three of the world's poorest continents and aims to increase tolerance and solidarity within the users. The game scenario of this game directly serves this learning objective. The scenario of the game is that users have to collect food from these continents to distribute it among poor people. This is an example of how game scenarios can directly support learning objectives.

In most cases the game scenarios serve the learning objectives more indirectly, by providing an environment in which assignments and puzzles can be easily integrated in such a way that the AR technology is well synthesized with the real environment. By doing so these AR games promote contextualized learning (Pombo, Marques, Afonso, Dias, & Madeira, 2019)

Levels of AR games

Table 3. A description of different game levels in the AR games.

| Research | Name of the game | Description of different game levels |
|---|------------------|---|
| Pombo, Marques, Afonso, Dias, & Madeira, 2019 | EduPARK | Three quizzes are intended for different levels of the Portuguese Education System: (1) the 1st Cycle (for 6 to 9 years-old students); (2) the 2nd (for 10 and 11 years-old students) and 3rd Cycles (for 12 to 14 years-old students) of Basic Education; (3) the Secondary (for 15 to 18 years-old students) and Higher Education; and (4) one quiz is intended for any ordinary citizen visiting the park. For the app prototype development, the project team decided to develop just two quiz-based educational guides: for the 1st and the 3rd Cycles of Basic Education. |

EduPARK (Pombo, Marques, Afonso, Dias, & Madeira, 2019) is the only game, out of twelve games analyzed AR games, which included different game levels in the game. Each game level is customized to another target group. The first level is for 6 to 9 years-old students. The second level for 10 and 11 years-old students and the third level is for 15 to 18-years old, and higher education, students. The game level has a quiz appropriate for the target group. Additionally, the game has one quiz intended for any ordinary citizen visiting the park in which this game takes place. By implementing these different levels, the target audience of this game is very broad, ranging from 6 to 18 years-old students and passers-by.

Game characters

The oxford dictionary defines a game character as a person or animal in a game. Except for EduPARK, every AR game, based on the nine studies we draw upon, has multiple characters. There are three types of characters than can be present in games. The first type of character is the role that players fulfill during the game. Various games provide the players with multiple options in terms of game characters. The second type is the virtual guide that supports and informs players and the last type of characters is the virtual character that is present in the game and with whom players can interact.

Mad City Mystery, RtR, Environmental detectives and Outbreak @ The Institute all have different roles that players fulfill. Each role comes with different tools that can be used to retrieve evidence. Hence, each role retrieves distinct evidence (Schrier, 2006). Players must work together and combine their collected evidence to find answers or solutions (Squire & Jan, 2007). For example, Outbreak @ The Institute offers players three options in terms of game characters: medical doctors, field technicians and public health officials. In this game medical doctors are in charge with treating players and virtual characters. The mission of the field technicians is to diagnose diseases while public health officials are entitled to quarantine virtual characters if they are infected (Rosenbaum, Klopfer & Perre, 2007). Hence, each players has its own role in the game. Garipey et al. (2018) analyzed an AR game in which players could choose their own avatar to play with, however, these avatars didn't necessarily come with different tools or roles. They merely are a representation of individual players.

Virtual guides are seen in EduPARK and the iPhone AR game analyzed by Furió, González-Gancedo, Juan, Seguí and Rando (2013). In EduPARK the guide is there to guide the players and give them immediate formative feedback during the game (Pombo, Marques, Afonso, Dias, & Madeira, 2019). In the iPhone AR game the guide character presents some information about the continent to be visited

(Furió, González-Gancedo, Juan, Seguí, & Rando, 2013). Hence, the guides serve as a source of information and support for the players.

Lastly, there are virtual characters such as the female monkey in EduPARK, the little sea turtle Elli in *Save Elli! Save the Environment!*, or citizens of the medieval city, shop keepers and tourists in the game Rhodes K-nights (Markouzis & Fessakis, 2016). Players can interact with these virtual players to collect information that helps players to solve mysteries, puzzles or to reach their goal in the game.

Table 4. A summary of different game characters in 12 AR games

| Research | Name of the game | Different game characters |
|---|---------------------------------------|---|
| Pombo, Marques, Afonso, Dias, & Madeira, 2019 | EduPARK | <ul style="list-style-type: none"> • A female monkey that lived in a cage in the park, for several decades. • The mascot is being used in the app to guide the players and give them immediate formative feedback after answering; e.g., when an incorrect answer is given, the mascot explains the right answer. |
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | <ul style="list-style-type: none"> • Small sea turtle named Elli |
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | <ul style="list-style-type: none"> • The guide character presents some information about the continent to be visited (e.g. there are several spoken languages). |
| Gariepy et al., 2018 | (No specific name) a mobile videogame | <ul style="list-style-type: none"> • Adolescent players choose an avatar and go to a house party as that avatar. |
| O'Shea, Mitchell, Johnston & Dede, 2009 | Alien Contact! | <ul style="list-style-type: none"> • The game includes six different virtual characters which provided clues to help solve a mystery, guiding the students through a process of inquiry and evidence building. |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | <ul style="list-style-type: none"> • Single role for the players, that of a ghost hunter • Many agents (virtual characters), who are citizens of medieval city, shop keepers and tourists. Player interviews them to collect information and objects which are stored in his/her inventory. |

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| Squire & Jan, 2007 | Mad City Mystery | <p>Players take on one of three roles:</p> <ul style="list-style-type: none"> • Medical doctor • Environmental specialist • Government official <p>These roles are each capable of decoding and retrieving information in different ways, as mediated by tools; for example, the Medical Doctor may diagnose Non-player characters (NPCs) and retrieve their medical history during the game. Players must work together, however, as the medical history is of little use without an understanding of local toxins (provided in documents to the government official), and vice versa.</p> <p>These roles were constructed to map to play styles identified within popular games and past research, namely the government official (appealing to those affiliating with power, i.e. the warrior), the environmental scientists (appealing to those affiliating with nature, i.e. the hunter), and the medical doctor (appealing to those who desire to help people)</p> |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | Six companies (6 pairs of students) have to design a project for implementing new energies in the city of Sète (south of France). |
| Schrier, 2006 | Reliving the Revolution (RtR) | <p>There are 4 possible characters based on actual historic figures from the Revolutionary War period:</p> <ul style="list-style-type: none"> • Prince Estabrook (African-American slave/Minuteman soldier) • John Robbins (free/Minuteman soldier) • Ann Hulton (Loyalist/ townspeople) • Philip Howe (Regular (British) soldier). <p>Working in pairs, participants collect distinct evidence based on their role.</p> |
| Klopper & Squire, 2007 | Environmental Detectives | The game includes differentiated roles - players take on distinct roles that change their capabilities and the information that is given to them by the non-player characters. For instance, in one iteration of the game, |

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| | | there are detectives that search for information, nurses that interview characters who have fallen ill as a result of the contamination and experts that try to provide explanations for the phenomenon. |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | <p>Outbreak @ The Institute offers players three options in terms of game characters:</p> <ul style="list-style-type: none"> • Medical Doctors • Field Technicians • Public Health Officials <p>Each of these roles presents a certain series of abilities and competences in the game. Medical Doctors are in charge with treating players and virtual characters. The mission of the Field Technicians is to diagnose diseases while Public Health Officials are entitled to quarantine virtual characters if they are infected.</p> <p>Throughout the game, several virtual characters appear in different locations and players have to interact with them so as to find as many information as possible about their health state and country of origin. This type of inquiry leads to a better understanding of the disease and helps players carry out effective strategies for stopping the outbreak.</p> |
| Kamarainen et al., 2013 | EcoMOBILE | There are no other characters than the player |

Understanding and diversity

The Oxford learner's dictionary defines diversity as 'a range of many people or things that are very different from each other', included different opinions, views et cetera. This section offers a summary of the opportunities for developing understanding and respecting diversity. To do that, this section draws upon twelve different studies. An overview of the learning opportunities regarding understanding and diversity is given in Table 5.

Table 5. A summary of opportunities for developing understandings and respecting diversity

| Research | Name of the game | Opportunities for developing understandings and respecting diversity |
|---|-------------------------------|--|
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | A game for transmitting knowledge as part of multiculturalism, solidarity and tolerance. The game is based on this: To know, understand and respect different cultures and differences between people, |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | Our observations of students show that most of them are deeply involved into the game even if a few minorities of them have difficulties to deal with the freedom offered by the situation. Everybody wants to express his/her opinion and need to understand and respect the arguments of the others. |
| Schrier, 2006 | Reliving the Revolution (RtR) | The historic event that is the centre of the game narrative is a conflict between 2 nations, therefore the idea of diversity, of "otherness" cannot be held absent from the picture. The game trials suggested that participants started to be more aware and tolerant of others' opinions and points of view. According to the author, one of the participants declared: "I learned about all the different sides. Normally you would just think of the American soldiers and the British soldiers, slaves, the wives, the Minutemen, there are people frustrated here for personal reasons, patriotic reasons. But you get a sense of the different roles of that time period." Another participant noted that reading the diverse historic figures' testimonials "gives you a larger point of view about what happened." The game, thus, proposes a complex and nuanced understanding of the various points of view regarding the historic moment of the Lexington Battle, which is not to be conceived in terms of a |

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| | | simple dichotomy, but rather as a multiple-alternative (or multi-dimensional) event. |
| Klopher & Squire, 2007 | Environmental Detectives | The game scenario relies heavily on developing the players' capacity of understanding the mechanisms behind finding a solution to an environment disaster and on respecting the others' decisions/actions. |
| Rosenbaum, Klopher & Perre, 2007 | Outbreak @ The Institute | The game provides opportunities for developing understanding and respecting diversity by creating characters who possess distinct abilities and traits of character that make them react differently when they are confronted with critical situations. In addition to this, diversity manifests through the range of strategies that can be adopted by players during the game in order to accomplish their goals. As there are not mentioned specific criteria for winning the game, students are offered the freedom to devise their own purposes based on their previous experience and knowledge about the topic of the game. |
| Kamarainen et al., 2013 | EcoMOBILE | The game provides opportunities for developing understanding and respecting diversity by showing aspects of the natural world that are not perceivable by the human eye without the aid of technology. By means of certain visual representations or 3D models, very small organisms are presented in a larger size for closer inspection. In this way, students become more aware of their importance in the ecosystem in spite of being imperceptible. In addition to this, the game puts a strong emphasis on the relationship between abiotic and biotic factors namely between water in the pond and the organisms living in its proximity by providing supplementary information about their interdependence. A deeper understanding of the essential role of each type of organism in an ecosystem also derives from the dialogue between classmates who have to join their efforts in order to fulfill the given tasks. |

There are two games in which opportunities to learn about, understand and respect diversity, are central. The learning objectives of the iPhone AR game, analyzed by Furió, González-Gancedo, Juan, Seguí and Rando (2013) is based on providing opportunities to understand and respect different cultures and

differences between people. Hence, the game itself provides an opportunity for developing understandings and respecting diversity. Likewise the game scenario of RtR, analyzed by Schrier (2006), lets player embrace diversity and understanding. The narrative of the game is a conflict between two nations and the players are asked to find out who started the conflict by firing first. In order to do so, players have to search for different sides of the stories. The game trials of this AR game suggested that participants started to be more aware and tolerant of others' opinions and points of views (Schrier, 2006).

Kamarainen et al. (2013) analyzed EcoMOBILE, a game which uses AR technologies to create opportunities for developing understand and respecting diversity. During the game aspects of the natural world, that are not perceivable by the human eye without the aid of technology, are made visible by using AR technology. By giving for example small organisms a visual representation, students become more aware of their importance in the ecosystem in spite of being imperceptible (Kamarainen et al., 2013).

The games Outbreak @ The Insitute and Environmental detectives provide opportunities for developing understand and respecting diversity by creating characters who possess distinct abilities and traits of character that make them react differently when they are confronted with critical situations (Rosenbaum, Klopfer & Perre, 2007). Moreover, diversity manifests through the range of strategies that can be adopted by players during the game in order to accomplish their goals (Rosenbaum, Klopfer & Perre, 2007). Individual players have their own approach and players need to respect others' decisions and actions in order to find a solution or answer to their given puzzles or assignments (Klopfer & Squire, 2007).

Collaboration skills

The oxford learner's dictionary defines collobartion skills as one's ability to work together with another person or group of people to create or produce something. Mobile AR games provide a useful platform to create opportunities for developing collaboration skills. Drawn upon the 12 studies, reviewed for this literature, ten out of the twelve AR games provide such opportunities. There are various game designs which stimulate users to collaborate. An overview of these opportunities is provided in the following Table.

Table 6. A summary of opportunities for developing collaboration skills

| Research | Name of the game | Opportunities to develop collaboration skills |
|---|----------------------------------|--|
| Pombo, Marques, Afonso, Dias, & Madeira, 2019 | EduPARK | It should be used in groups of users, so the app's educational challenges can promote collaborative discussion of ideas; |
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | Students play the game in groups of five and try to find solution all together. |
| O'Shea, Mitchell, Johnston & Dede, 2009 | Alien Contact! | There are multiple roles given to students. To infuse this situation with challenge and invite curiosity, each student's differentiated role is presented with an alternate, incomplete view of the game space. For example, when presented with a piece of alien spacecraft debris, each team member is given a different dimension of the wreckage to measure or a unique clue as to how to measure it. If the students do not collaborate, they |

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| | | will not be able to solve the problem and advance to the next stage of the game. |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | The answers showed that the main reason of collaboration was decision making about the game, e.g. to select the correct answer to a question or to select a virtual character to talk with. However, the recordings reveal that the players were also collaborating intensively in order to be orientated in the Medieval City, although they didn't mention it in the questionnaires. This happened because maybe they didn't realize that the correct orientation was part of the game and part of location-based Augmented Reality applications in general. All the participants believed the collaboration was necessary and they wouldn't prefer having played the game by themselves. The collaboration was face to face in front the device, students asked for a multi user version of the game so that they could collaborate through their devices. |
| Squire & Jan, 2007 | Mad City Mystery | The game roles encouraged collaboration and served as a scaffolding for reading. Specifically, they encouraged students to share information, synthesize what they read, communicate orally with their group, ask questions, and debate meanings. |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | Yes, by organizing students in teams. |
| Schrier, 2006 | Reliving the Revolution (RtR) | The physical nature of RtR increases the game's collaborative potential and provides opportunities for the development of collaboration skills since it is played in pairs and the players need to constantly communicate to each other their interpretations of the evidence they gathered, to explore hypotheses aloud or on paper, and to share testimonials and documents accessed on the handheld to support their beliefs or theories. Then, during the debate period, participants are engaged in a free verbal communication of their views, presenting their evidence and listening to other's ideas. The decisions are all made collectively by the participants after rich debates on the evidence collected. As it happens with AR games in general, RtR provides opportunity for collaborative exchanges or debates, where participants can trade theories and reflect on their own conclusions. |

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| Klopher & Squire, 2007 | Environmental Detectives | The differentiated roles were designed to promote collaboration across players, as no one player would have access to all the needed information. The players are introduced into a dynamic world in which actions have consequences and collaboration is a key to success, therefore they constantly make use of their collaborative potential. |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | <p>The game provides opportunities for the development of collaboration skills by the fact that each type of game character possesses distinct abilities and the reactions of virtual characters are also different depending on the role of the player who interviews them.</p> <p>There is an obvious interdependence of the roles as each of them needs the knowledge and reliability of the others. For this reason, players are troubled when it comes to applying the best tactics. Some of them consider it is preferable to stay together because this allows them to share information easily, but at the same time it results impossible to cover all the game areas if they do not split in smaller groups.</p> <p>In conclusion, it is of utmost importance for players to communicate efficiently in order to join their efforts in their attempt of containing the outbreak.</p> |
| Kamarainen et al., 2013 | EcoMOBILE | The game provides opportunities for the development of collaborative skills by encouraging students to work in pairs in order to cope with the challenges that await them. A member of the team is in charge with carrying the smartphone and navigating from one location to another, while his colleague uses the handheld device and environmental probes so as to collect water measurements. Thus, they depend on each other and the accuracy of the results is strongly influenced by their capacity to work together. |

The first game design that stimulates the development of collaboration skills is an AR game that should be used in groups of users like EduPARK and EcoMOBILE. This game design forces students to work together and elaborate and discuss ideas. For example, the AR game EcoMOBILE suggests users work in pairs. One member of the team is in charge with carrying the smartphone and navigating from one location to another, while his colleague used the handheld device and environmental probes so as to collect water measurements. Both players depend on each other and the accuracy of the results is strongly influenced by their capacity to work together.

Rhodes K-nights illustrates a second game design which provides opportunities for developing collaboration skills. Rhodes K-nights is an individual player game, but the game trial showed various reasons of collaboration among players. Users tended to collaborate to select the correct answer to questions, or to select a virtual character to talk with. Moreover, it seemed that individual players worked together to be orientated in the Medieval City where the game scenario takes place.

Lastly, providing the users with different options of characters, whom each have distinctive roles to fulfill, supports collaboration learning opportunities as well. Alien Contact, Mad City Centre, RtR, Environmental detectives and Outbreak @ The Institute are all games in which players can choose their own character. Each student's differentiated role in these games, is presented with an alternate, incomplete view of the game (O'Shea, Mitchell, Johnston & Dede, 2009). This encourages students to share information, communicate orally with their group, ask questions and debate meaning (Squire & Jan, 2007). If students do not collaborate, they will not be able to solve the problem.

Problem-solving skills

The Oxford dictionary defines problem-solving as 'the act of finding ways of dealing with problems'. Except for EduPARK, each of the twelve analyzed AR games in this literature review, provide opportunities for developing problem-solving skills. These opportunities arise by either asking the users specific questions, giving them specific assignments, or introduce them to a specific problem or mystery which they have to solve. Table 12 offers an overview of these opportunities.

Table 7. A summary of opportunities for developing problem-solving skills

| Research | Name of the game | Opportunities for the development of problem-solving skills |
|---|---------------------------------------|--|
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | Students must find a solution to save Elli. By answering the questions correctly, students could discover the secret code that released Elli and successfully complete game. |
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | the players explore a room searching for the objects requested by the guide character by focusing the iPhone camera on the different markers that are distributed throughout the room. The children have to solve the problem of collecting food (logical-mathematical); the music and sound effects in the minigame allow the children to get into the gameplay and reinforce |
| Garipey et al., 2018 | (No specific name) a mobile videogame | Players must take some decisions |
| O'Shea, Mitchell, Johnston & Dede, 2009 | Alien Contact! | Through the game scenario, students were presented with a problem situation that needed solution. |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | Participants of the game are presented with a mystery that needs solution and thus they exercise their problem-solving skills. |

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| Squire & Jan, 2007 | Mad City Mystery | The game's problem, presented in the scenario, is designed to encourage students to think about interconnecting causal factors, as opposed to single cause problems; in fact, no one of the possible contaminants presented in the game would be likely to kill Ivan. The problem was constructed in this open-ended fashion for several reasons. First, we wanted a problem sufficiently complex to support complex argumentation. |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | Concepts such as actors for land use management, conflicts for space uses, energy conversion or energy efficiency are linked and embedded in a composite learning situation. As a result students are led to develop behavior and to elaborate argumentations that take into account the complexity of the problem. They are involved in a complex task. We have observed that most of what students produced is based on a multifaceted point of view of the problem to be solved which includes geography, economy, physics and environmental sciences. |
| Schrier, 2006 | Reliving the Revolution (RtR) | Throughout the game, the RtR participants had to turn into genuine problem solvers: they needed to frame the game's objectives, to deconstruct the wider problem into smaller issues, to identify and assess potential solutions, and, very importantly, to decide how to tackle new challenges. Thus, RtR provides opportunities for the development of problem-solving skills in that it enables participants to analyze realistic evidence and solve an actual question from within a historical, social and geographical context. This encouraged participants both to practice problem solving and critical thinking skills and to view their actions as authentic, thereby motivating them further and strengthening their ability to apply these tasks and conceptual frameworks to other situations. |
| Klopper & Squire, 2007 | Environmental Detectives | The Environmental Detectives provides opportunities for the development of problem-solving skills as the participants involved are supposed to research, analyze, find connections between actions, draw conclusions and make |

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| | | decisions regarding the issue of a toxin spill. In order to achieve this, the players resorted to two methods: 1. a mathematical sampling problem whose main goal was to map how the contaminant (Tri-Chloro-Ethelene) spread through the environment; 2. interviewing various experts in the field, gathering information from them and trying to find out what is the best location to drill. |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | <p>The game provides opportunities for the development of problem-solving skills by testing the capacity of the players to adapt to a completely new situation which threatens the fate of the humanity.</p> <p>Players are assigned with an enormous responsibility, that of preventing the spread of the bird flu. In order to win this battle, they have to pay attention to all the details that make part of the game such as the responses given by the virtual characters, any kind of physical sign that may indicate the existence of the virus or the way they use the diagnostic kits so as to find out who is infected or not. Players also have to take important measures for preserving public health: they quarantine those who are suspected of being infected, they administer medicines to those who are already sick and decide the steps to be followed for avoiding other people to catch the disease.</p> |
| Kamarainen et al., 2013 | EcoMOBILE | The game develops students' problem-solving skills by assigning them with various tasks such as classifying the organisms observed around the pond into producers, consumers or decomposers, using appropriately the water quality measurement tools, answering to multiple-choice questions based on information recently displayed on the smartphone. The fact that they have to deal quickly with all these requirements is aimed to improve their ability to make a decision in a relatively short period of time which represents a great advantage for any individual nowadays. |

The game *Save Elli! Save the Environment!* is the only game which asks specific questions to the users. The users can find the solutions to these questions by exploring the world in which the game is situated (Koutromanos, Tzortzoglou & Sofos, 2018).

The game EcoMOBILE develops students' problem-solving skills by assigning them with various tasks such as classifying the organisms observed around the pond into producers, consumers or decomposers. Other tasks can be answering multiple-choice questions based on information recently displayed on the smartphone or measuring the water quality with the appropriate tools. Users are stimulated to use their problem-solving skills in order to execute the assigned tasks.

The most common method to create opportunities for developing problem-solving skills is by defining the game scenario as a problem, mystery or quests for which the users need to use their problem-solving skills to find an answer (Furió, González-Gancedo, Juan, Seguí, & Rando, 2013; Klopfer & Squire, 2007; Markouzis & Fessakis, 2016; O'Shea, Mitchell, Johnston & Dede, 2009; Schrier, 2006; Squire & Jan, 2007). This type of game scenario invites learners to research, analyze, find connections between actions, draw conclusions and make decisions regarding the game scenario related issue, such as the murder in Mad City Mystery or the toxin spill in Environmental Detectives (Klopfer & Squire, 2007). Hence, providing lots of opportunities to develop problem-solving skills.

Leadership skills

The oxford dictionary defines leadership skills as the ability to be a leader or the qualities a good leader should have. Using this definition, opportunities to develop leadership skills have only been found in two games: RtR and the game Sanchez, Delorme, Jouneau-Sion and Prat (2010) analyzed. Table 8 summarizes these opportunities.

Table 8. A summary of opportunities for developing leadership skills

| Research | Name of the game | Opportunities for developing leadership skills |
|---|-------------------------------|---|
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | Students data to imagine the impact of the planned decisions. The listening of the videos who display interviews of "local inhabitants" helps them to get knowledge on the consequences of the planned projects for people (human environment).The design of the situation aims at that the students get an idea of the complexity of factors that influence the decisions of policymakers for land use management. |
| Schrier, 2006 | Reliving the Revolution (RtR) | Yes, RtR provides opportunities for the development of leadership skills - throughout the game participants can take turns as the leader and can be in charge of the pairs, but relying permanently on interaction with the other participants/pairs and on collaborative interventions. |

RtR does this in a very direct way, by letting users be the leader, making them in charge of the pairs that are playing the game. Participants take turns as the leader. However, even as leader, players are relying permanently on interaction with the other participants and, or, pairs. Hence, this game provides useful learning opportunities to develop leadership skills.

The game analyzed by Sanchez, Delorme, Jouneau-Sion and Prat (2010) lets students be a company that has two weeks to design a pre-project for a certain green energy that convinces the committee tender that their project is the best for a sustainable development of the city. In order to do this, users are required to collect data through interviews with local inhabitants. These interviews must give the students insights in the consequences for the human environment that their planned actions have. In this way, the game provides the opportunity for developing leadership skills by giving the students an idea of the complexity of factors that influence the decisions of policymakers for land use management (Sanchez, Delorme, Jouneau-Sion & Prat, 2010).

Active citizenship skills

An active citizenship is defined by LEXICO, a vocabulary provided by OXFORD, as ‘taking responsibility and initiative, as a citizen, in areas of public concern such as crime prevention and the local community’. Five of the twelve reviewed games in this literature provided opportunities for developing active citizenship skills. Table 14 present these opportunities.

Table 9. A summary of opportunities for developing active citizenship skills

| Research | Name of the game | Opportunities for developing active citizenship skills |
|---|----------------------------------|--|
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | In terms of awareness of the ecological problem |
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | multiculturalism, solidarity, and tolerance; and nature and living organisms. |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | According to Morin (Morin, 2000), the capability of citizens to think the complexity of the world is a major educational stake. To achieve this goal, students must be engaged in realistic learning situations in which they can develop complex thinking. Geotechnologies permit the teachers to design such learning situations. Citizenship encompasses both the notion of rights and responsibilities and the involvement and participation of individuals to the life of public institutions for the common good (Weinstock, 2000). We settled the rules of the game in a way that they are compatible with the democratic process of a call for project. Therefore, the different steps of the game are close to a real call for project procedures. The students have to follow the rules but they are as well, as committee tender members, responsible for the respect of these rules. It is |

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| | | expected that students get a deep understanding of the rationales in which these rules are grounded and we have observed that students have a feeling of injustice if the rules of the game are not respected. |
| Schrier, 2006 | Reliving the Revolution (RtR) | Historic(al) events are factors that may shape or strengthen one's sense of belonging to a wider community that shares the same ideals, thoughts, mentalities, therefore an AR game structured around a historic(al) event contributes actively to civic engagement. The RtR game provides opportunities for the development of active citizenship as it grows community awareness regarding the historic(al) process of a nation's becoming and encourages one to think about the consequences and historic implications of one's decisions. |
| Klopher & Squire, 2007 | Environmental Detectives | The game can be connected to the idea of active citizenship and civic participation as it relies on a matter of environment protection that is ultimately linked to public health. During the game, players see a rash of health problems and, after doing desktop research they gather data to ascertain their potential causes and, ultimately, prevent the event from happening again. |

Save Elli! Save the Environment, Environmental detectives and the iPhone AR game examined by Furió, González-Gancedo, Juan, Seguí and Rando (2013) provide these opportunities by making the players aware of environmental problems in their game scenario and the consequences for the organisms living in these environments. Moreover, they challenge the players to come up with solutions to these environmental problems. In Save Elli! Save the Environment the environmental problems are linked to the existence of certain animals, while in environmental detectives, the environment protection is linked to public health. By making players aware and letting them think about solutions, players get the opportunity to develop active citizenship skills.

Sanchez, Delorme, Jouneau-Sion and Prat (2010) analyzed the game in which players represent a company and have to design a pre-project related to a certain green energy in support of a sustainable development of the city. Sanchez, Delorme, Jouneau-Sion and Prat try to support the involvement and participation of players to the life of public institutions (e.g. citizenship) by engaging them in a realistic learning situation.

The designers of RtR state that historic(al) events are factors that may shape or strengthen one's sense of belonging to a wider community that shares the same ideals, thoughts, mentalities. Therefore centering their AR game around an historic(al) game scenario, provides users with learning opportunities regarding their active citizenship skills.

Data literacy skills

Data literacy skills refers to the ability to derive meaningful information from data.

Nine out of the twelve analyzed AR games in this literature review provide opportunities to develop data literacy skills. This section will provide a summary of those opportunities and an overview is given in Table 10

Table 10. A summary of opportunities for developing literacy skills

| Research | Name of the game | Opportunities for developing data literacy skills |
|---|-------------------------------|--|
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | The children have to hear and read the instructions that the guide character gives them in order to collect the food (linguistic intelligence) |
| O'Shea, Mitchell, Johnston & Dede, 2009 | Alien Contact! | When students come within approximately 30 feet of these digital artifacts, the AR and GPS software triggers video, audio, and text files, which provide narrative, navigation, and collaboration cues as well as academic challenges. |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | Players are encouraged to use data from different sources in order to answer the game's questions. |
| Squire & Jan, 2007 | Mad City Mystery | The game embed newspaper articles, videos, multimedia documents, encyclopedias, and texts (even books!) in the environment for players to read in order to gain more background information, clues, and richer context for play. Websites, manuals, and FAQs provide players extra information that is mobilized in game play. |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | Students are encouraged to use data from different sources in order to reach a decision. |
| Schrier, 2006 | Reliving the Revolution (RtR) | Data literacy skills are highly necessary in RtR, where participants collect evidence (discovered around Lexington Common or retrieved using the GPS-enabled handheld device), analyze information (discuss and interpret the evidence with a partner, categorize it on the notes sheet), decide on next steps |

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| | | (choose how to navigate the game environment), select other participants to ask for information, make hypotheses, collaborate with others to formulate bigger hypotheses, and draw informed conclusions. In other words, they don't just collect data; they also interpret it and relate it to other data. Thus, in this unique game environment, participants are required to manage and navigate vast amounts of data in order to construct one's own narratives and hypotheses regarding the event. |
| Klopher & Squire, 2007 | Environmental Detectives | The game resorts to data literacy skills - a core component of the scenario is understanding the interaction of primary (raw data collected by the researcher) and secondary (summative and background information from texts) data. Basically, the players get to understand how to perform "deskwork" on the nature of the chemical, its health effects, toxic levels, legal limits, similar cases, historical records and local geology, while simultaneously integrating "fieldwork", in which they collect data on local concentrations. |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | The game does not offer too many opportunities for the development of data literacy skills. The only reference to this field consists in the antigen count possessed by each player and virtual character. This represents an indicator of the number of virus particles in their body. Players are not informed about its precise value, but its effects are reflected in the reduction of the player's health level. The antigen counts are influenced in a distinct manner by the Seasonal and Bird Flu. The antigen count in someone's body can only be measured by taking a mucus sample and analyzing it. |
| Kamarainen et al., 2013 | EcoMOBILE | The game contributes to the development of data literacy skills by instructing the students to use both handheld devices and environmental probes in order to measure four water quality variables: dissolved oxygen concentration, turbidity, pH and temperature. The mobile device possesses a data collection mode that displays the probe reading and warns the student if the measurement is outside the normal range for the pond. Therefore, the students get accustomed to |

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| | | the habitual span of the above mentioned parameters of water quality. |
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Alien Contact!, Rhodes K-nights, Mad City Mystery and RtR all provide data from different sources such as video, audio and text files which provide narrative, navigation and collaboration cues. This data is provided for the players in order to gain more background information, clues and richer context for play (Squire & Jan, 2007). In order to process this type of data from different sources and to interpret the data and laying links between the data, requires data literacy skills (Schrier, 2006).

Likewise, the environmental detectives provide learners with two kinds of data: primary data, which is collected by the players themselves, and secondary data, summative and background information data, provided through the game. In order to make this data useful, players have to combine the two forms of data, making the game scenario a great platform for learning opportunities regarding data literacy skills.

In the game EcoMOBILE a lot less data is given, but users are given the opportunity to collect the data themselves. They are assigned to measure for water quality variables such as turbidity, pH and temperature. After collecting, the game provides the opportunity to learn and interpret the data by providing warnings if the measurement is outside the normal range for the pond. Therefore, students get familiar with habitual span of the mentioned parameters of water quality.

Applications of scientific knowledge to everyday life

In this section, we summarize opportunities the twelve analyzed games provide to their users to apply scientific knowledge to everyday life. Drawn upon the studies reviewed in this literature review, six of the twelve AR games provided such opportunities. Table 16 gives an overview of these opportunities.

Table 11. A summary of opportunities for applications of scientific knowledge to everyday life

| Research | Name of the game | Opportunities for applications of scientific knowledge to everyday life |
|----------------------|---------------------------------------|---|
| Gariepy et al., 2018 | (No specific name) a mobile videogame | <ul style="list-style-type: none"> • Simulation of decision-making in real-life scenarios • Modeling short- and long-term consequences of decisions. |
| Squire & Jan, 2007 | Mad City Mystery | <ul style="list-style-type: none"> • The educational goals of the game are to help students develop investigation and inquiry skills, specifically scientific argumentation skills through the virtual investigation. • Digital tools used in the game (spreadsheets, calculators, research labs, gravity guns) also mediate play, allowing players to process scientific information and interact with the environment (including affecting it) in new ways. |

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| Schrier, 2006 | Reliving the Revolution (RtR) | <ul style="list-style-type: none"> • The game allows a link between its scientific, historic content and everyday life in that it brings history closer to the human consciousness. • Participants became more aware of diverse viewpoints, the involvements of different historic figures, the interrelation of economics, geography and politics, and the spectrum of agendas for the various social classes involved (e.g. townspeople, soldiers etc.). |
| Klopher & Squire, 2007 | Environmental Detectives | <ul style="list-style-type: none"> • Example: the understanding of the impact of certain chemicals (Tri-Chloro-Ethelene - TCE) on both the environment and on the quality of human life overall. |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | <ul style="list-style-type: none"> • In the game it is emphasized the importance of vaccination for preventing the players to get infected with Bird Flu. Vaccines are no longer useful for those who are already sick. This is an example of how scientific knowledge proves to be extremely helpful in everyday life. • Spending a longer period of time with someone who has flu does not have a more damaging effect on a player's health. The virus infection is a discrete event that happens at a certain moment, so isolating yourself after becoming infected does not contribute in any way to the improvement of your health state. The only thing that is left to do in this case is taking medicines. • The participants in this game also get accustomed to terms specific to the disease transmission mechanism and in this way they become aware of the importance of wearing protective gear like gloves and mask when coming into contact with sick people. |
| Kamarainen et al., 2013 | EcoMOBILE | <ul style="list-style-type: none"> • By helping the students deciphering the meaning of concepts like pH, dissolved oxygen and turbidity and the way these |

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| | | <p>influence the life conditions of fish and other organisms. For example, they learn that very low or very high pH values are unsuitable for most aquatic organisms.</p> <ul style="list-style-type: none"> • Understanding the concrete implications of the previous scientific notions, students become more responsible when it comes to collecting appropriately the water measurements so as not to alter the results and consequently have a distorted view of the conditions needed by the animals and plants living in that habitat. • Furthermore, the augmented reality technology used to create this game offers children the possibility to discover a new world by showing them how molecules or bacteria look like. In this way, it becomes much easier for them to know what the processes of photosynthesis and cellular respiration really involve. |
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Mad City Mystery and the mobile intervention game from Gariepy et al. (2018) both focus on developing general scientific skills like decision-making, modeling short-and long term consequences or developing inquiry skills, which users can apply in everyday life.

On the other hand, games like Environmental detectives, Outbreak @ The Institute and EcoMOBILE provide users with specific scientific knowledge which they can apply to everyday life. Environmental detectives, for example, teaches their users about the impact of certain chemicals on both the environment and on the quality of human life. Likewise players of the game Outbreak @ The Institute learn more about the importance of vaccination for preventing the players to get infected with Bird Flu and teaches them that vaccines are no longer useful for those who are already sick. These are examples of specific scientific knowledge which can be helpful in everyday life. EcoMOBILE provides similar learning opportunities by giving the users feedback on their measured variables of their water sample. The given feedback indirectly teaches the users over the acceptable pH values for aquatic organisms. Simultaneously, the game illustrates the importance of correct measurements, which teaches the users the value of appropriate collected water samples.

Critical thinking skills

The Oxford dictionary defines critical thinking as ‘the process of analyzing information in order to make a logical decision about the extent to which you believe something to be true or false’. This section provides a summary of the opportunities for development of critical thinking skills in the analyzed AR games from the twelve papers this review draws upon. Table 12 provides an overview of these opportunities.

Table 12. A summary of opportunities for the development of critical thinking skills

| Research | Name of the game | Opportunities for the development of critical thinking skills |
|---|---------------------------------------|--|
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | <ul style="list-style-type: none"> • players have to think how they can save Elli |
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | <ul style="list-style-type: none"> • Players have to select the appropriate object and follow the guidelines |
| Garipey et al., 2018 | (No specific name) a mobile videogame | <ul style="list-style-type: none"> • Players have to make decisions |
| Squire & Jan, 2007 | Mad City Mystery | <ul style="list-style-type: none"> • Through the scenario and the additional data, players were encouraged to critically evaluate information and form hypotheses. |
| Schrier, 2006 | Reliving the Revolution (RtR) | <ul style="list-style-type: none"> • In order to solve the game’s objectives, participants need to be genuine critical thinkers in relation to the information they gather from various sources • They have to critically analyze the evidence found and identify any biases in it, to question any hypothesis, to relate information to other data, and to respect the limitations of their interpretations. • Thus, RtR enables participants to critically analyze realistic evidence and concrete data and solve an actual question from within a historical, social and geographical context. |

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| Klopher & Squire, 2007 | Environmental Detectives | <ul style="list-style-type: none"> • There are multiple viable solutions for addressing the problem and the players are supposed to make choices • gather reliable information and question it if the case • synthesize it • critically assess the data obtained within a limited amount of time <p>Therefore they are supposed to use their critical thinking skills while playing this game in order to reach the most adequate solution.</p> |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | <ul style="list-style-type: none"> • Gathering information from multiple sources such as the testimonies of the virtual characters encountered, the results of the diagnostic tests and the findings of their fellow colleagues. • After collecting all these pieces of information, it depends on the players' capacity of making the right inferences in order to identify the sick characters and quarantine them so as to avoid mass infection. • Then, they should discover the best treatment methods and give the patients the proper medicines to cure them. |
| Kamarainen et al., 2013 | EcoMOBILE | <ul style="list-style-type: none"> • Enabling the children to navigate from one trigger location to another and explore the ecosystem by themselves. • The fact that they are encouraged to look for pieces of information, then put them together, collect data, make associations between the collected measurements and the previously acquired knowledge stimulates their interest in science and scientific practices. |

From the twelve AR games that are reviewed in this literature review, eight provide opportunities for developing critical thinking skills. The AR games all create the opportunities for these learning opportunities in a similar way. The game scenario creates an environment in which players are invited to gather information through multiple sources such as virtual characters, objects or tests. Players must critically evaluate the data and make decisions based on the data that are most in line

with their goals or form hypothesis which they can test further. Hence, they are supposed to use their critical thinking skills while playing the games in order to reach their set objectives (Kamarainen et al., 2013; Klopfer & Squire, 2007; Rosenbaum, Klopfer & Perre, 2007). In short, learners are given the opportunity to develop their critical thinking skills by providing an open game scenario in which learners have the freedom to explore, analyze, and come up with their own strategies or hypothesis which helps them to accomplish their goals.

Information literacy skills

The Oxford dictionary defines literacy skills as ‘a person's competence measured by their ability to identify, access, evaluate, and organize information in order to complete a task or solve a problem’. This section provides a summary of the opportunities the AR games create for the development of information literacy skills of the users. In total we found eight out of the twelve AR games which create such opportunities. Table 18 gives an overview of these opportunities.

Table 13. A summary of opportunities for the development of information literacy skills

| Research | Name of the game | Opportunities for the development of information literacy skills |
|---|--------------------|--|
| O’Shea, Mitchell, Johnston & Dede, 2009 | Alien Contact! | Students are expected to: <ul style="list-style-type: none"> • Gather information • Write down information • Share information in order to solve a puzzle. |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | <ul style="list-style-type: none"> • Players collected and compared information from multiple and contrasting resources, • Excluded inferences by combining them • Chose the best solution while rejecting the tricky ones in order to solve mystery puzzles. |
| Squire & Jan, 2007 | Mad City Mystery | Students were encouraged to: <ul style="list-style-type: none"> • Share information • Synthesize what they read • Communicate orally with their group • Ask questions • Debate meanings. |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | <ul style="list-style-type: none"> • students are encouraged to use information from different sources in order to reach a decision. |

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|----------------------------------|-------------------------------|--|
| Schrier, 2006 | Reliving the Revolution (RtR) | <p>RtR encourages participants to:</p> <ul style="list-style-type: none"> • gain further knowledge in what information skills are concerned, because it requires participants to access, navigate and handle a rich virtual historical database mapped to an actual physical environment. <p>In order to construct their own unique course through the content, players have to:</p> <ul style="list-style-type: none"> • carefully analyze large amounts of information • discover the relations between it • manage their resources • integrate information from multiple sources. <p>The abundance of information available may be initially overwhelming, especially when new pieces of information are constantly discovered and the existing data need to be reorganised permanently, but an adequate management in this direction is essential to deciphering the story.</p> |
| Klopher & Squire, 2007 | Environmental Detectives | <p>The central idea of the game is that of gathering information that would prove to be useful in clarifying the causes of and formulating the solutions to the problem of toxic spill and soil contamination.</p> <p>More specifically, information literacy skills are aimed at in Environmental Detectives by:</p> <ul style="list-style-type: none"> • managing information • Integrating information • organizing information. |
| Rosenbaum, Klopfer & Perre, 2007 | Outbreak @ The Institute | <ul style="list-style-type: none"> • Helping students to familiarize with scientific notions related to various types of flu, names of medicines used only to alleviate symptoms and others meant to cure the diseases. • The professions needed for containing and stopping an outbreak are introduced to the students as well as the names of testing devices used to diagnose patients and |

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| | | several other items involved in the medical process. |
| Kamarainen et al., 2013 | EcoMOBILE | Information literacy skills are aimed to be improved by: <ul style="list-style-type: none"> • the fact that students are given a certain amount of information at the beginning of the field trip about the ecosystem and its inhabitants. • Their capacity of reading through the introductory information and familiarize with it quickly is tested by means of a series of questions whose purpose is to clarify the key notions regarding the types of organisms and their functional role for the environment. • Afterwards, they receive feedback to their answers as a way of reinforcing the recently made observations. |

Alien Contact!, Rhodes K-nights, RtR, Mad City Mystery, Environmental Detectives and the game examined by Sanchez, Delorme, Jouneau-Sion and Prat (2010) all challenge the players to collect and integrate data from multiple resources. This gives the users the opportunity to develop their information literacy skills by focusing on collecting and organizing the information.

After obtaining information from multiple resources, users get the opportunity to synthesize the information and discover the relation between the different kinds of information. In Rhodes K-nights, Mad City Mystery, RtR and Environmental Detectives synthesizing the information is a necessity in order to complete their quests.

Alien Contact! And Mad City Center stimulate users to share their information with other players, providing an opportunity for players to train their literacy skills, specifically their skill to organize information. Moreover, Mad City Center invites students to communicate about their information and debate about the meaning of it. In this way players get the opportunity to train their information literacy skills by identifying and evaluating the data in groups.

Technical affordances

The technical affordances of the AR games are the technologies that are used in the game design and are available to the players while playing the game. In this section we summarize the technical affordances of the AR games reviewed in this literature review. Table 19 provides a summary of the technical affordances of the AR games.

Table 14. A summary of the technical affordances of the game: sound, usability, rating system, reward element, feedback and visuals.

| Research | Name of the game | Description of the technical affordances of the game: sounds, usability, rating system, reward element, feedback and visuals |
|---|----------------------------------|--|
| Pombo, Marques, Afonso, Dias, & Madeira, 2019 | EduPARK | <ul style="list-style-type: none"> • It should be user-friendly, so users, even children in the 1st cycle of education, can use it without support. • The app developed is for offline use. • The only requirement for having a mobile device with a fully functional EduPARK app, in an offline mode, should be to download the app and its educational guides before going to the park to use it. • The app integrates several tools : (1) backpack, a place to store and visualize photographs taken during the game; (2) camera, a tool to recognize the AR markers and to take photographs; (3) compass, a tool that supports orientation in the park based on the display of the direction of magnetic north; and (4) park map that also supports orientation in the park, as it shows the players' location (a yellow dot) as well as the next game location (flagicon) or cache (treasure icon). |
| Koutromanos, Tzortzoglou & Sofos, 2018 | Save Elli! Save the Environment! | The game was built on an open-source, location-based game platform called ARIS |
| Furió, González-Gancedo, Juan, Seguí, & Rando, 2013 | iPhone AR game | <ul style="list-style-type: none"> • It combines AR with video games. An iPhone 3GS with the iOS 3 operating system. • The game includes AR and several interaction forms (physical manipulation, touch-screen interaction, and accelerometer). • Followed the systems development life cycle (SDLC). • In the game, has been also incorporated a shift from an external perspective to an embedded agent. |

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| | | <ul style="list-style-type: none"> used ARToolKitPlus 2.1.1. |
| Gariepy et al., 2018 | (No specific name) a mobile videogame | simulation of decision-making in real-life scenarios, and modeling short- and long-term consequences of decisions. |
| O'Shea, Mitchell, Johnston & Dede, 2009 | Alien Contact! | This narrative-driven, inquiry-based AR simulation is played on a Dell Axim X51 handheld computer and uses GPS technology to correlate the students' real world location to their virtual location in the simulation's digital world. As the students move around a physical location, such as their school playground or sports fields, a map on their handheld displays digital objects and virtual people who exist in an AR world superimposed on real space. When students come within approximately 30 feet of these digital artifacts, the AR and GPS software triggers video, audio, and text files, which provide narrative, navigation, and collaboration cues as well as academic challenges. |
| Markouzis & Fessakis, 2016 | Rhodes K-nights | The game was designed with ARISGAMES platform and played through smartphones. Each interaction with a virtual character presented player a small video, a dialogue text and then a multiple choice quiz. |
| Squire & Jan, 2007 | Mad City Mystery | No description provided in the article. |
| Sanchez, Delorme, Jouneau-Sion & Prat, 2010 | (No specific name) | The game was designed with MITAR (now known as Taleblazer). Students used pocket PCs with GPS functionalities that displayed interviews of local "inhabitants" when they reached the places where the projects were planned to be implemented. They got information from these interviews and from the field itself. |
| Schrier, 2006 | Reliving the Revolution (RtR) | The game employs basic technical tools (a Pocket PC handheld computer, GPS technology, a basic map of Lexington Common with GPS navigation), has good technical features (sound, interaction between players, visuals) and uses multiple media formats (written testimonials, real world objects, and images of documents). The participants were enthusiastic, |

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|---|---------------------------------|---|
| | | <p>motivated, appropriately challenged and took their tasks very seriously, therefore the feedback they provided was a very positive one.</p> |
| <p>Klopher & Squire, 2007</p> | <p>Environmental Detectives</p> | <p>The game employs basic technical tools (a Pocket PC, a GPS calibration mechanism, a basic map with GPS navigation, the proper protocols for interfacing between the Pocket PC and the GPS modules, a working scaleable architecture with the suite of tools that was emerging for the Pocket PC platform etc.), has good technical features (sound, interaction between players, visuals) and can be adapted to other contexts based on largely the same scenario, therefore its usability is high. Feedback from the students participating in one trial of the game showed that they enjoyed the combination of real and virtual worlds, as well as the interplay between primary and secondary information. Students were particularly intrigued by the virtual characters and were excited to see game play linked to character interactions (e.g. virtual races with characters to locate information, interrogations, or virtual “stalking”). There was consistent approval of the format and concept, and all of the students requested to play the game again.</p> |
| <p>Rosenbaum, Klopfer & Perre, 2007</p> | <p>Outbreak @ The Institute</p> | <p>The game does not require a sophisticated device. It can be played using a handheld computer also called a personal digital assistant that enables the player to be constantly aware of his status in the game, his position and take actions. Throughout the game, there are permanently displayed on the screen information about a player’s status like his current health indicated by a meter and an inventory of items collected during the game that have different functionalities. As players progress from one location to another, they encounter several virtual characters to whom they can address questions and their answers appear on the screen in the form of a text. Players fulfilling the role of field technicians receive feedback after using diagnostic testing kits by means of which they are informed about the health state of those tested. The world of the game is dynamic being significantly influenced by the actions of the characters.</p> |
| <p>Kamarainen et al., 2013</p> | <p>EcoMOBILE</p> | <p>The main goal of the game is to facilitate the integration of probeware into the field trip experience,</p> |

| | | |
|--|--|--|
| | | <p>as its authors declared. The game does not require advanced skills of using mobile devices. It provides simple and clear instructions to the participants in this project indicating the precise place where measurements have to be taken, the steps to be followed for collecting a sample and offering immediate feedback to the values displayed. It is worth mentioning the prompt feedback that is also offered to the multiple-choice questions concerning the classification of organisms around the pond. The reward element for answering correctly to the questions posed consists in a measurement badge that implies certain privileges. The visuals are pretty simple just the way they should be in order not to become disturbing for the eyesight throughout the game. In conclusion, all the information is presented in a compressed and logical manner without giving too many details that may result confusing for the users.</p> |
|--|--|--|

RtR and Environmental detectives use sounds to increase the engagement of the players and various games such as Alien Contact! have audio that provide the players with new information when they come within approximately 30 feet of a digital artifact. Likewise, audio information is triggered when players interact with virtual characters in Rhodes K-nights.

Besides audio, AR games often use visual as well. AR technologies can be used to make people see the unseen, like EcoMOBILE does. Moreover, RtR, Environmental detectives and Rhodes K-nights provide the users with visuals when they interact with virtual characters, or when they find digital artifacts. EduPARK shows how visuals can also guide and support the users. This game provide the players with a virtual map of the park which helps them orientate through the park.

Another important technical affordance of an AR game is the usability. EduPARK had a high usability because the game is user friendly, appropriate for offline use, without the need for additional requirements besides a mobile and the app. Likewise, Educational Detectives, RtR and the game examined by Sanchez, Delorme, Jouneau-Sion and Prat (2010) only require a pocket Pc with GPS functionalities. Educational Detectives distinguishes itself from the other games by making easily applicable to other contexts based on largely the same scenario, this makes the usability of the game high.

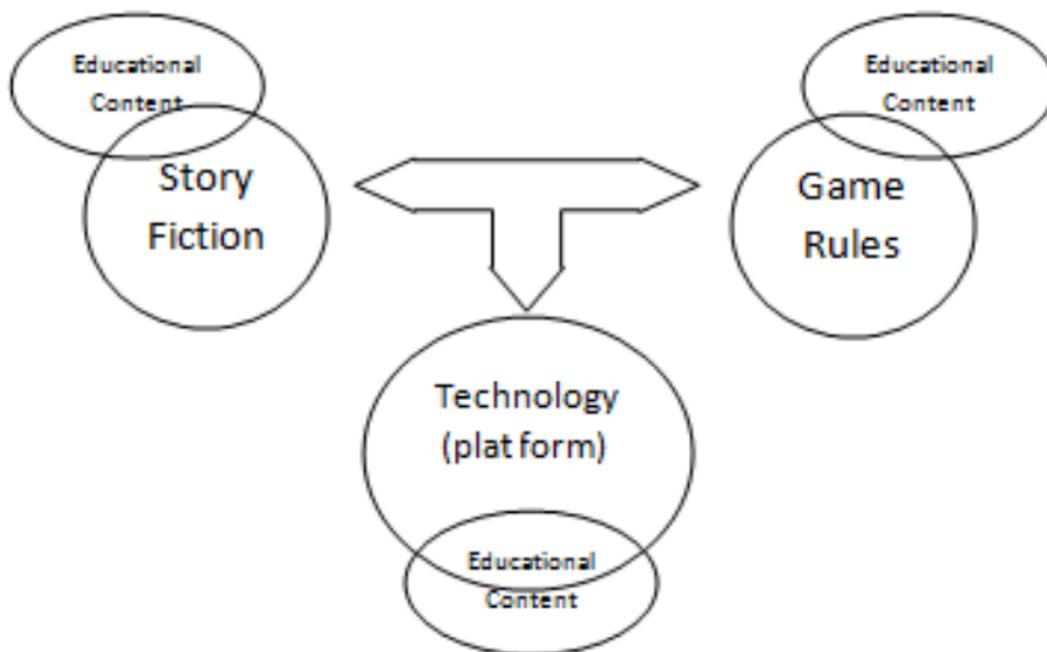
Technical affordance such as rating systems, reward elements and feedback have been barely discussed in the literature, indicating that the games have not implemented such technical affordances. Outbreak @ The Institute is the only game in which a player's status is permanently displayed in the form of their current health status and an inventory of items collected during the game. EcoMOBILE is the only game that includes a reward element, which players receive when they answer a question correctly. The rewards are measurement badges that imply certain privileges. EcoMOBILE also provides users with feedback when they answer multiple-choice questions, regarding information they were handed during the game, incorrect. Outbreak @ The Institute is the only other game that provides users with some form of feedback. In this game, players receive feedback when the players with the role 'field technicians' use diagnostic testing kits to test the health state of characters in the game. The feedback that is provided to them yields information about the health state of those who are tested.

SUGGESTED FRAMEWORK FOR THE DESIGN OF THE GAMES

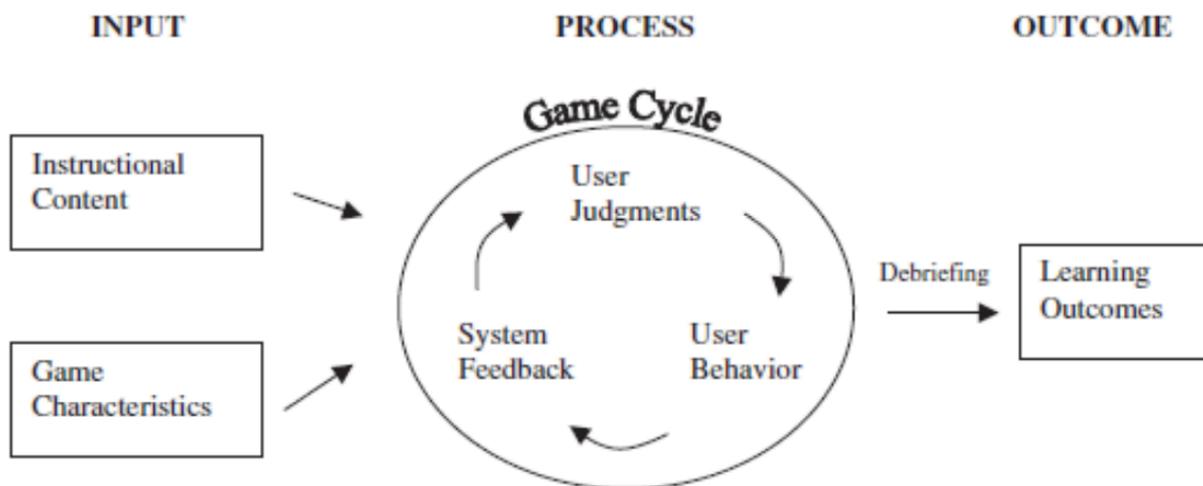
For the purpose of the design of the games for this project, we will use a combined framework which includes the following:

1. game-based learning model (Garris et al. 2002)
2. dimensions of game design (Rouse, 2001)
3. framework for the development of the games (Rouse, 2001)
4. specific game components that are crucial based on the outcomes of this literature review

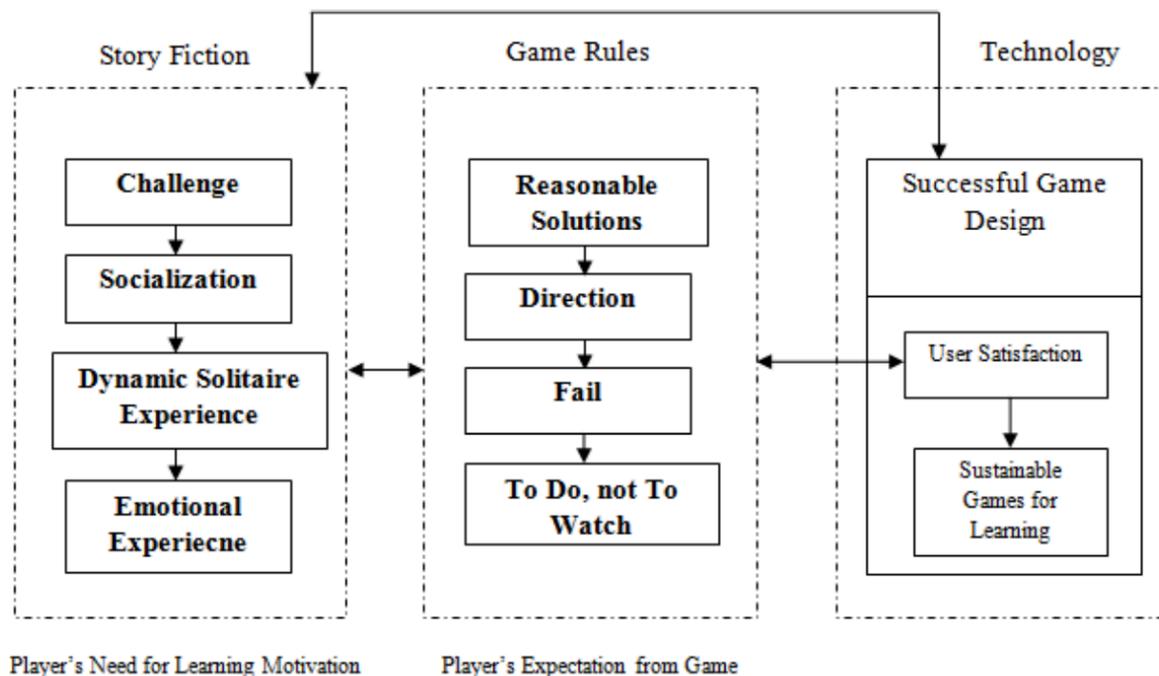
1. GAME-BASED LEARNING MODEL



2. DIMENSIONS OF GAME DESIGN



3. FRAMEWORK FOR THE DEVELOPMENT OF GAMES



4. GAME COMPONENTS

| |
|--|
| Game component |
| Game character(s) |
| Clear story/series of events/beginning-middle-end |
| Opportunities to learn about diversity |
| Opportunities for Collaboration |
| Opportunities to develop problem-solving skills |
| Opportunities to develop leadership skills |
| Opportunities to develop active citizenship skills |
| Opportunities to develop data-literacy skills |
| Opportunities to develop critical thinking skills |
| Opportunities to develop information literacy skills |
| Applications to everyday life |
| Sound |
| Feedback/rating system |
| Visuals |

References

- Garris, R., Ahlers, R. & Driskell, J.E. (2002). Games, Motivation, and Learning: A Research and Practice Model, *Simulation Gaming*, 33(4), pp. 441-467.
- Rouse, R., III (2001). *Game Design: Theory & Practice*. 2nd ed. Plano, TX: Wordware Publishing.