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Designing Mobile Augmented Reality Exergames

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Abstract

Exergames aim to make exercise more enjoyable, especially for children and young adults who are accustomed to digital technologies. Calory Battle augmented reality (AR) is a mobile exergame that utilizes context awareness and AR to enable interaction with virtual content. Designing mobile exergames and AR interaction has received little scholarly attention. This article has several contributions to the design discussion: (1) implementation of a mobile AR exergame, (2) discourse on the game design process, (3) evaluation with 29 South Korean elementary school children and university students who suggested a good reception of the game and generated ideas for improvements of usability and AR interaction, (4) analysis of the game with respect to established game motivators and the Immersion, Scientificalness, Competitiveness, Adaptability, and Learning (ISCAL) exergame design model, (5) design principles and lessons learned, and (6) discussion of the flow experience in exergames. These results can be used by designers to create motivating and interactive mobile AR games.

Keywords

exercise, mobile game, design, augmented reality, context aware

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Introduction

Engagement in physical activity during childhood has been associated with physical activity levels in adulthood (Ortega, Ruiz, Castillo, & Sjöström, 2007). The factors that impact on children's capacity to acquire skills and enjoy the psychophysiological benefits of participation in sports and exercise are of crucial importance, given the worldwide concerns over decreasing physical activity rates and the concomitant increases in obesity in the populations of postindustrial societies (e.g., Department of Health, 1999; McLean et al., 2009; Oh et al., 2008). According to the World Health Organization, worldwide obesity has nearly doubled since 1980 and more than 40 million children under the age of five were overweight in 2012 (World Health Organization, 2014). Furthermore, overweight children are more likely to grow up to be overweight adults (Biro & Wien, 2010; Serdula et al., 1993; Whitaker, Wright, Pepe, Seidel, & Dietz, 1997). Figure 1 projects future trends for the overweight percentage of the population for several postindustrial countries (Organization for Economic Cooperation and Development, 2010). Obesity is a major factor for many diseases such as diabetes, heart disease, stroke, hypertension, and metabolic syndrome (Haslam & James, 2005). Child and adolescent obesity can be even more serious, leading to lifelong health problems related to the cardiovascular functions, metabolism, pulmonary functions, and musculoskeletal system as well as psychological problems (Daniels, 2009).

Lack of motivation can be seen as an important factor that contributes to the lack of physical exercise, and for obese children, this is an even greater challenge (McWhorter, Wallmann, & Alpert, 2003). Thus, new solutions should be discovered to increase motivation—especially intrinsic motivation—toward participation in physical activities. Well-designed games are known to increase intrinsic motivation (Malone & Lepper, 1987) and facilitate the immersion of the player in the game world (Calleja, 2011; Sweetser & Wyeth, 2005; Yee, 2006). When players are deeply immersed, they may enter a flow state where they become highly motivated to perform the activity, even to such an extent that they lose track of time (Csikszentmihalyi, 1998). The flow state should be the goal of any physical or educational activity, and gamification is a promising method to achieve it.

Today's children and young adults have grown up among hi-tech gadgets and toys. For example, 69% of South Korean elementary, middle, and high school students owned a smartphone in 2013 (South Korean Ministry of Education, 2013). These individuals excel at using modern interfaces such as touch screens, motion sensors, and gesture-based user interfaces, and they are not afraid to try out novel technological innovations. A major weakness of this technocentrism is that it promotes a sedentary lifestyle. Children at 8–10 years of age have been found to spend nearly 8 hr per day in front of screen, and for teenagers, screen time is more than 11 hr per day (Strasburger & Hogan, 2013). A big question is how to motivate children to get off the couch or computer where they play these highly immersive video games and engage in physical exercise instead. An answer to this question lies in merging the

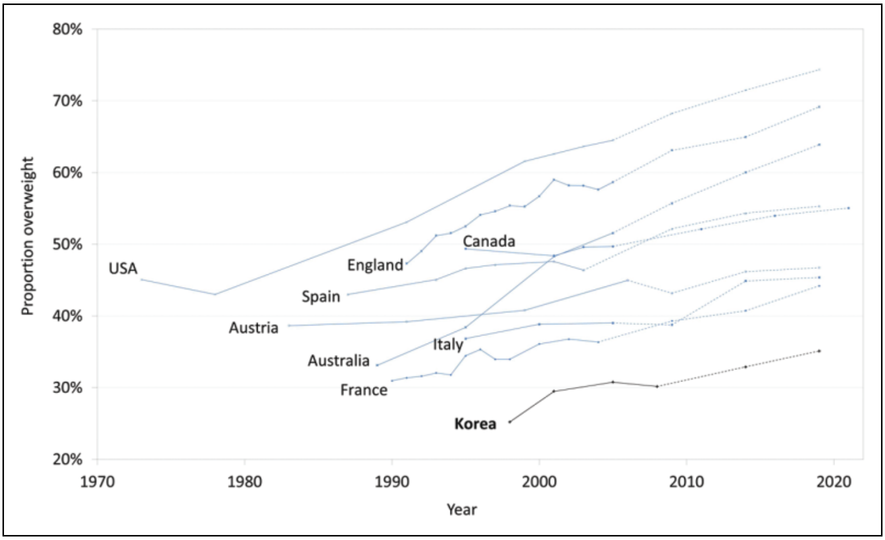

Figure 1. Past and projected overweight rates (©OECD, 2010).

two things that children are good at—handheld technologies and gaming—with appealing content on exercise and pedagogy. Such technology-enhanced *exergames* could be deployed at schools, but they specifically encourage out-of-school usage in parks, forests, and backyards.

The exergame is a game genre that combines physical exercise with digital gaming. It has been seen as a potential solution to the childhood obesity problem (Lamboglia et al., 2013), delivering cognitive and physical challenges in an entertaining package. Staiano and Calvert (2011) reviewed the literature to identify the benefits of exergames. According to their findings, exergames yield physical benefits in caloric expenditure, heart rate, coordination, and motor skills. They also have psychological benefits related to social interaction, self-esteem, self-efficacy, mood, and motivation. Finally, exergames can also benefit cognitive and academic aspects such as attention, visual-spatial skills, and academic performance. Peng, Lin, and Crouse (2011) further suggest that exergames can increase energy expenditure, heart rate, and oxygen consumption both for adults and children.

Augmented reality (AR) is a user interface technology in which a camera-recorded view of the real world is augmented with computer-generated content such as annotations, graphics, animations, and three-dimensional (3-D) models. In past years, many systems leveraging AR have been developed in fields such as commerce (Zhu, Owen, Li, & Lee, 2006), urban planning (Kato, Tachibana, Tanabe, Nakajima, & Fukuda, 2003), education (Kaufmann & Schmalstieg, 2003), tourism (Linaza et al., 2012), and entertainment (Cheok et al., 2004). Early AR systems used inconvenient head-mounted displays, portable computers, and power sources. Today, smartphones are powerful enough to run AR technology smoothly, thus the number of mobile AR applications that do not require additional hardware is growing. Many of these applications only visualize virtual content without providing the user with means to interact with it.

In this article, we present the design and development process of Calory Battle AR, a mobile AR exergame. Calory Battle AR aims to motivate children to be more physically active and learn about physiology as well as healthier living. In the game, the players search and defuse virtual *calory bombs* in the real world. The player must interact with the virtual bomb by using a special *Multitool*. Both calory bombs and the Multitool are implemented using AR. We present the Calory Battle AR concept and technical platform together with design decisions that were made about the game. The game was evaluated with elementary school children and university students. The results of the gameplay evaluation and lessons learned are described, followed by a discussion of the flow experience in exergames. The results of this article will be useful to colleagues who wish to design motivating mobile AR exergames.

Background

In this section, we present concepts and previous research related to exergames and AR. Furthermore, we analyze the existing literature on motivational game design and exergames in particular.

Exergames and AR

Exergames form a game genre that combines exercise and gaming. In this study, we consider only mobile-based exergames that are played outdoors, thus games on indoor platforms such as Nintendo Wii and Microsoft Xbox with the Kinect motion detector are omitted. Because of the popularity of smartphones and their location-sensing capability, many commercial games that promote movement in real-world contexts have been developed for smartphone platforms such as Android and iOS. Many of these games belong to the genre of geocaching or scavenger hunting, where the players search for and collect virtual items or fight over territories with real-world locations. Examples of commercial location-based games that involve consequential exercise include Turf Wars (MeanFreePath LLC, 2014), Zombies, Run! (Six to Start, 2014), and Foursquare (Foursquare Labs, 2014).

In addition to exergames developed by commercial companies, researchers have developed and evaluated exergame concepts. Lin, Mamykina, Lindtner, Delajoux, and Strub (2006) described a game that links a player's daily foot step count to the growth and activity of an animated virtual fish in a fish tank. Their evaluation suggests that the game served as a catalyst for promoting exercise, but the players' enthusiasm toward the game decreased after a couple of weeks. Barkhuus (2006) proposed an activity tracker named Shakra that aims to motivate users to move more through social networking. Shakra automatically records a user's movement based on Global

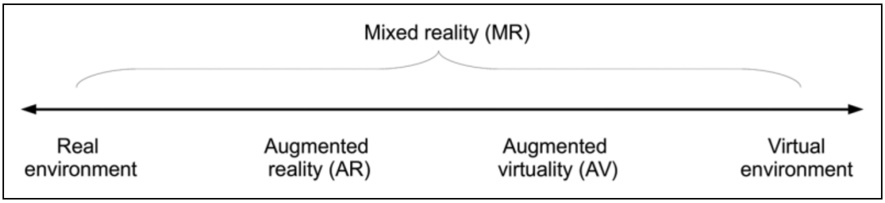

Figure 2. The virtuality continuum (Milgram & Kishino, 1994).

Positioning System (GPS) and mobile network signals, and then shares the recorded data with friends. An evaluation suggested that the participants received the technology well and were motivated by it. If such automatic movement recording and sharing features would be coupled with an appealing game concept, then the users' motivation could grow even higher. Finally, (indoor) exergames have also been applied to medical rehabilitation (Burke et al., 2009; Smith & Schoene, 2012), but in such cases, the physical exertion components of the game must be carefully designed by medical professionals.

AR is a user interface technology that utilizes machine vision and 3-D graphics to embed virtual content in a real-world view. This augmentation is typically achieved by recording a scene with camera, and then detecting targets such as fiducial markers (e.g., bar codes) or objects from that scene with machine vision algorithms. Upon detecting a target, virtual content, such as 3-D models, graphics, and annotations, can be drawn on it, resulting in a scene where virtual content appears to hover over the target. Milgram and Kishino (1994) define AR as a subset of mixed reality (MR). In their definition, MR comprises AR and augmented virtuality (AV). The difference between AR and AV is that in AR, virtual elements are brought into reality, whereas in AV, real elements are brought into virtual reality. Figure 2 illustrates this as the "virtuality continuum."

Televised sports events are good examples of the presence of AR in everyday life. For example, tracks in swimming competitions can be augmented with swimmers' information and results at the end of a race. During the first decade of this millennium, AR was increasingly applied to gaming and other entertainment. Some of these games required the player to wear obtrusive head-mounted displays (Cheok et al., 2004; Herbst, Braun, McCall, & Broll, 2008), while others were based on a mobile phone camera (Squire & Jan, 2007). A common factor to all these games is that they utilized the mobility of the user in the real world. A recent, extensively promoted example of AR technology is the Google Glass, which aims to augment the view of the user's everyday life through unobtrusive, wearable glasses that perform all necessary information processing via a cloud service.

So far, outdoor-based exergames have utilized little AR. GeoBoids is an exergame that uses AR on a mobile device (Lindeman et al., 2012). The game's idea is that the player searches and catches virtual GeoBoid creatures with the aid of a map and mobile device. As the GeoBoids move, the player must run in order to catch them.

The player can also interact with the creatures by whistling. This game logic is close to that of Calory Battle AR, but in the latter, the player interacts with a virtual bomb using another virtual object. Furthermore, the game mechanics in these two games are different. Another example, Freegaming (Görgü et al., 2010), is an outdoor exergaming concept that promotes play within mobile contexts and social environments. In this research, the authors proposed the Freegaming system architecture to support location-based exergames. A game prototype was described in which the players must take pictures of certain objects at given locations. To our understanding, AR is only used for visualization in this system.

AR has been harnessed in some location-based games that do not primarily target exergaming, but in which exercise may happen because of gameplay. One example of these location-based AR games is Niantic Labs' Ingress, a massively multiplayer AR game where the users form teams to fight over mysterious Exotic Matter that has been scattered around the world (Niantic Labs, 2014). The players of Ingress traverse the real world to acquire portals at public places and link them, creating triangular areas. The players are likely to consume calories as they search and link these portals. Temple Treasure Hunt (ThoughtShastra Solutions, 2014) is another example of location-based AR games with consequential exercise. In this game, the player assumes the role of a treasure hunter traversing an automatically created trail in an outdoor environment. AR content is represented by treasure guardians who present the player with clues to decipher. As a third example, Cheok et al. (2004) presented the Human Pacman game that takes advantage of positioning technologies and AR, allowing the players to traverse an outdoor space, avoiding ghosts and collecting virtual cookies. The players of Human Pacman carry a head-mounted display and a computer in a backpack that may be inconvenient to carry for long periods. The evaluation results were positive, but because of the short evaluation period, it is not clear whether the Human Pacman game would outlive the novelty effect because of the lack of comfort.

Designing Exergames

Game designers typically base their concepts on well-established motivators to make the games attractive. In particular, intrinsic motivators, as opposed to external motivators such as money or fame, are associated with the psychological concept of flow (Csikszentmihalyi, 1998). According to Malone and Lepper (1987), intrinsic motivators for games include challenge, competition, control, cooperation, curiosity, fantasy, and recognition. Although several other useful studies on game motivators exist (e.g., Calleja, 2011; Fu, Su, & Yu, 2009; Garris, Ahlers, & Driskell, 2002; Sweetser & Wyeth, 2005; Yee, 2006), in this article, we use Malone and Lepper's motivators. This is because the primary focus of this article is not motivation, and the work of Malone and Lepper is well recognized among game researchers.

A major question that exergame designers must consider is how to make exergames both engaging and effective. As a reference model for exergame design, we use Zhang et al.'s (2012) Immersion, Scientificalness, Competitiveness, Adaptability, and Learning (ISCAL) model that encompasses Immersion, Scientificalness, Competitiveness, Adaptability, and Learning. These five components are explained in the following, along with supporting literature from game theory and exergame design researchers. According to the ISCAL model, an exergame should support the *immersion* of the player in such way that the player feels that they are participating in a realistic sports experience. This is supported by several studies that identify immersion as one of the motivators in games (Calleja, 2011; Fu et al., 2009; Sweetser & Wyeth, 2005; Yee, 2006). Scientificalness requires that exercises in an exergame must conform to scientific guidelines, an idea that has also been proposed by other exergame researchers such as Gao and Mandryk (2011) and Sinclair, Hingston, Street, and Lawley (2009). According to the *competitiveness* requirement, an exergame should contain nonplayer competitors to increase the feeling of a sports competition. This connects directly to Malone and Lepper's competition motivator (Malone & Lepper, 1987) and other studies that have recognized the importance of social aspects in games (Fu et al., 2009; Sweetser & Wyeth, 2005; Yee, 2006). An exergame should also be *adaptable* to ensure that players at different fitness levels can enjoy the game. Other exergame studies have suggested the need for the customization of game content to match not only the players' fitness levels (Park et al., 2012; Sinclair, Hingston, Street, & Lawley, 2009) but also their physical environments (Knöll, Dutz, Hardy, & Göbel, 2014). Finally, Zhang et al. suggest in their ISCAL model that an exergame should include *learning* content. Many commercial games also have features that promote learning, although it is not their primary goal. For example, the Assassin's Creed (Ubisoft, 2014) and the Age of Empires (Microsoft Studios, 2014) game series include historical facts in their story lines. While educational gaming is outside the scope of this article, the interested reader may refer to a body of educational game research (Alessi & Trollip, 2001; Fu et al., 2009; Garris et al., 2002; Malone & Lepper, 1987) to better understand how games can motivate educational activities. The ISCAL model does not include all of Malone and Lepper's motivators, excluding those such as fantasy, cooperation, control, and challenge. Additionally, definitions of immersion and adaptability in the ISCAL model are not generic but instead specific for the type of exergame that Zhang et al. proposed. In next section, we explain the design of Calory Battle AR, where we employed some of the Malone and Lepper's game motivators while also considering the exercise component and expandability of the platform.

Designing Calory Battle AR

The Calory Battle AR Concept

Calory Battle AR is an Android-based AR mobile game that aims to promote physical activity among children, but can also be enjoyed by adults. It is different from console-based exergames (e.g., some Nintendo Wii games) in that it is based on real-world contexts, thus including additional motivation through context

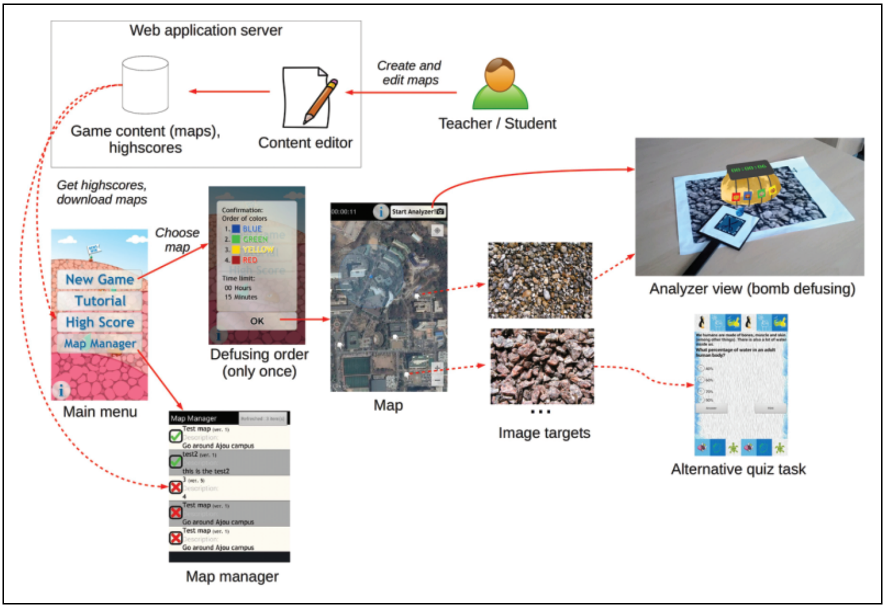

Figure 3. Calory Battle AR game flow.

exploration. The game can be easily deployed at different locations because it does not require any special equipment other than an Android smartphone and printed image targets representing AR content. Context awareness is currently implemented with the mobile device's GPS sensor, but the utilization of other onboard sensors, such as the accelerometer for movement detection, is also viable.

The Calory Battle AR story features the Dews (player allies) and the Caloroids (antagonists). The Dews extract energy from the players' sweat and with that energy cast spells on the players who make their bodies healthier and minds sharper. The Caloroids hate sweat and thus want to stop players from sweating and hence become unhealthy. The player's role is to help the Dews by finding and defusing *calory bombs* that have been placed around a geographical area by the Caloroids. The basic game flow is presented in Figure 3. There is a global time limit for finding the bombs, so the player must run from one bomb to another. After finding a bomb, the bomb's local countdown timer is started at a random time from 10 s to 60 s, during which the player must defuse the bomb. A bomb is defused by carefully removing virtual fuses in the correct order. The fuses have the appearance of unhealthy food such as pizzas and hamburgers. The player earns points by defusing the bombs and for any remaining time at the end of the game (i.e., when all bombs have exploded or been defused). After finishing the game, the player can upload his or her score to a hall-of-fame website where the score can be compared to other players' scores.

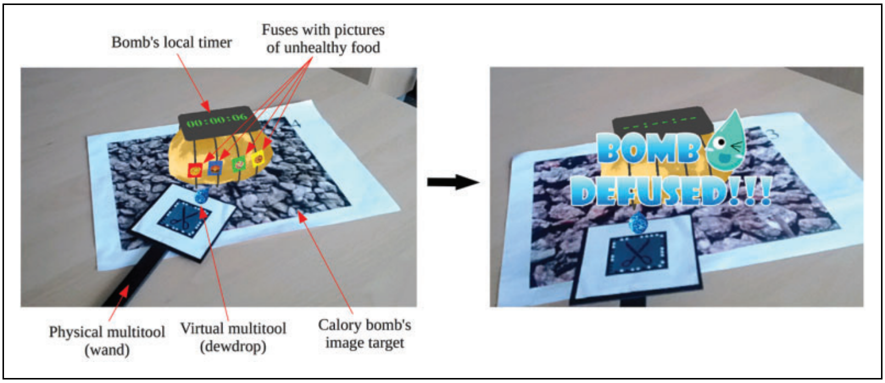

Figure 4. Defusing a calory bomb.

The game can be set up at any outdoor location. Game maps can be prepared with a web-based editor. Created maps can be downloaded using the map manager feature of the game. Before playing the game, printed image targets representing virtual calory bombs are deployed around a geographical area (Figure 3). These image targets can be almost any images that have high contrast and a high level of detail. Each image target is assigned a geo-coordinate in the game's database. As a result, the targets can be connected to a virtual game map based on Google Maps. The player controls the analyzer (i.e., the smartphone) and the Multitool (Figure 4). After starting the game, the player sees the game map with the approximate bomb locations as well as the player's own location (Figure 3). The player then uses the map to find one of the targets, after which they can start the analyzer to see a virtual bomb and defuse it by touching the fuses with the Multitool (Figure 4). The Multitool looks like a wand, but it has a virtual dimension: When the player views it through the analyzer (i.e., the smartphone's camera), they can see a dewdrop hovering on the marker glued to the Multitool. The Multitool can be used for different types of interactions with augmented (virtual) content, but in this first version of the game, it is used to remove bomb fuses in the correct order. The correct fuse removal order is given to the player only once at the beginning of the game, hence memorization is necessary.

Calory battle AR can be played alone or as a team. Multiple teams can play the game at the same time, but they are not connected in the gameplay. At the end of the game, the teams can compare their points on a hall-of-fame website. Figure 5 shows a team of children sharing the work: one is holding the analyzer while the other is defusing a bomb with the Multitool.

Even though the main purpose of Calory Battle AR is to make children sweat and have fun, the game also contains some pedagogical aspects that manifest themselves in the game concept and content. Ultimately, the game aims to persuade the players to change their perceptions and motivations regarding physical exercise. The story line of the game further emphasizes the importance of being physically active and

Figure 5. Players working as a team.

implicitly teaches the player that calorie intake and expenditure should be balanced. The game also teaches the player how to navigate using a map.

In the Calory Battle AR concept, defusing virtual bombs is just one type of activity. From a technical point of view, it is possible to define any type of Android activity to launch when an image target is detected by the analyzer or when the player interacts with an AR object. Hence, it is easy to extend the game to include more pedagogical content such as information screens and quizzes. The extensibility of Calory Battle AR's architecture was first discussed in Westlin and Laine (2014).

Design Process

The game design process began with a brainstorming session with seven South Korean elementary school children (Figure 6). First, the children were taught about exergames and shown examples of existing exergames and possible technologies, including AR. The children were then asked to invent ideas for future exergames. While the idea of Calory Battle AR did not come directly from the children, many of the game features (e.g., GPS, treasure hunts, and outdoor missions) were present in the generated ideas.

After brainstorming, we established a set of principles to be followed in the game design and development:

- Out of the living room: encourage outdoor gameplay to get fresh air and to explore and utilize the real-world environment.

Figure 6. Brainstorming game ideas with elementary school children.

- Family friendly: aim the game at children but make it fun for grownups as well.
- Augmented experience: use AR to enable interaction with virtual content, thus bridging the virtual and real worlds.
- Fun together: add a social dimension by enabling team play and competition.
- Fantasy elements: use storytelling to create a fantasy world that facilitates immersion.
- Technology ownership: use a smartphone as the primary interaction device to avoid the need for special hardware and allow players to use their own devices.
- Mainstream platform: target a platform that is widely available (e.g., Android) and that has built-in context-sensing capabilities.
- Dynamic content: make game locations and content flexible.
- Subtle learning: embed pedagogical content, but avoid making it the main objective.
- Agile development: use iterative development with a working prototype at the end of each cycle.
- For and with children: invite children as end users to codesign and test prototypes.

A team of undergraduate university students from computer science and digital media was formed to polish the game idea and start the development process. The team comprised one Finnish computer science student and two Korean digital media students who were supervised by the professors of their respective disciplines. The design and development process was iterative, with weekly review and steering meetings. The

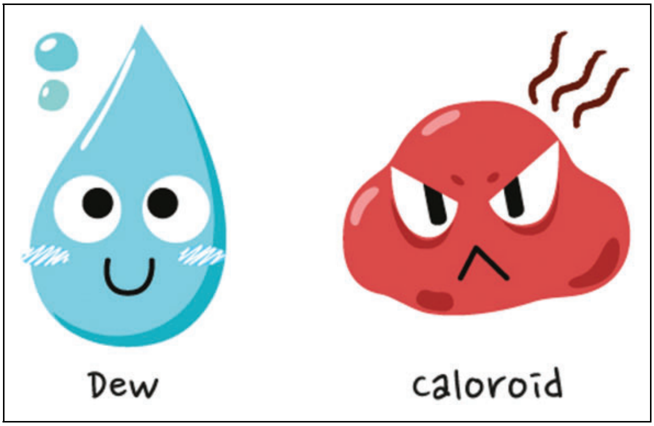

Figure 7. The design of game characters.

students had no previous experience in AR or game development on the Android platform, thus they spent a considerable amount of time studying these topics.

In the user interface design, we emphasized simplicity and avoided complexity. The game controls are minimalistic, the buttons are large, and a simple localized language is used. In the sound design, we prepared appropriate background music for each screen type: main menu, map screen, and defusing screen. For example, the defusing screen has a background tune that reflects tension and excitement.

One of the success factors behind the *Angry Birds* games (Rovio Entertainment Ltd, 2014) and their spin-offs is the simple, appealing story about birds and pigs that captures the player's interest. In the story of Calory Battle AR, we aimed for an easy-to-approach concept with likable and meaningful characters with which the players could identify. The game character designs (Figure 7) are based on the story: The Dew was modeled after a clean drop of sweat with a happy facial expression. The Caloroid's appearance resembles a lump of grease with an evil face. These appearances connect directly with the story of the battle between the sweat-loving Dews and fat-craving Caloroids.

The first bomb design was a bundle of cylinders (dynamite) with wires and timer, as often seen in cartoons and movies. This was later changed to resemble the appearance of Caloroid— a lump of greasy texture with a slightly alien look. The evolution of the bomb design is presented in Figure 8. The first challenge in the bomb design was to balance the bomb's complexity (number of vertices) and smooth performance (acceptable model loading and rendering time). After a few iterations, the model was complex enough to look like a bomb and yet simple enough to be processed adequately.

The second challenge in bomb design was to make user interaction with the bomb smooth. We wanted to create a separate bomb defusing instrument to promote social gameplay, as it would allow two players to cooperate when defusing a bomb. Originally, we planned to use virtual scissors to cut the bomb wires, but the operation was

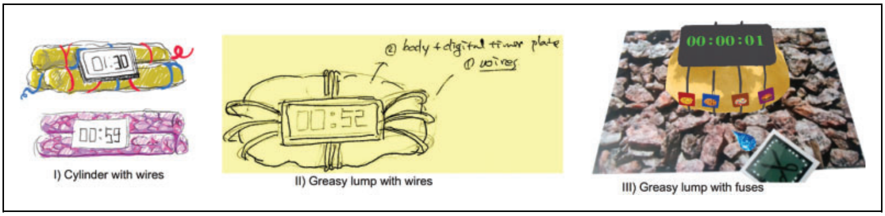

Figure 8. Evolution of calory bomb design.

too delicate and required extreme precision from the player. Furthermore, the wires were close to the bomb's body and easily resulted in accidental "punctures" of the bomb. Thus, the wires were replaced with fuses that allowed us to include additional elements on the bomb, that is, pictures of unhealthy food. Instead of scissors, the concept of the Multitool emerged, as this would allow us to use the same object to perform different types of operations in the future. The first design of the Multitool was a Swiss army knife with different blades, but it was too difficult to implement as a 3-D object because of the high level of detail and moving parts. The appearance of dew was chosen as basis for the Multitool, which is now covered with a watery texture. Finally, the Multitool model was positioned in front of and above the physical Multitool wand to avoid pushing the wand through the virtual bomb object. This setup worked fairly well; however, some training may still be needed because this type of AR interaction is not yet familiar to most users.

Technical Design

Figure 9 illustrates the overall architecture of the Calory Battle AR client, which is divided into the AR engine written in C++ and the Game engine written in Java. Communication between these two parts is done over the Java Native Interface that allows Java code to call native functions written in C++. We used the Google Maps Application Programming Interface (API) to implement the map functionality. The AR feature is implemented using Qualcomm's Vuforia Software Development Kit (SDK), which supports both Android and iOS platforms. Vuforia also has an extension available for the Unity 3-D game engine, but it was not used in this project because its sophistication was not required. The Vuforia SDK automatically tracks up to 100 image targets through a camera and also supports virtual buttons, video playback, custom shaders, and optional target recognition in the cloud. One of the disadvantages of Vuforia SDK is that 3-D object rendering (i.e., the bomb and Multitool) must be done by the developer. Hence, we created a custom AR engine to handle the rendering, collision detection, simple animations, and event triggering. Our AR engine was written in C++ so that it communicates with Java code using events. For example, when a new image target is detected or a collision happens, appropriate events are triggered. The event manager in Game Engine delegates received events

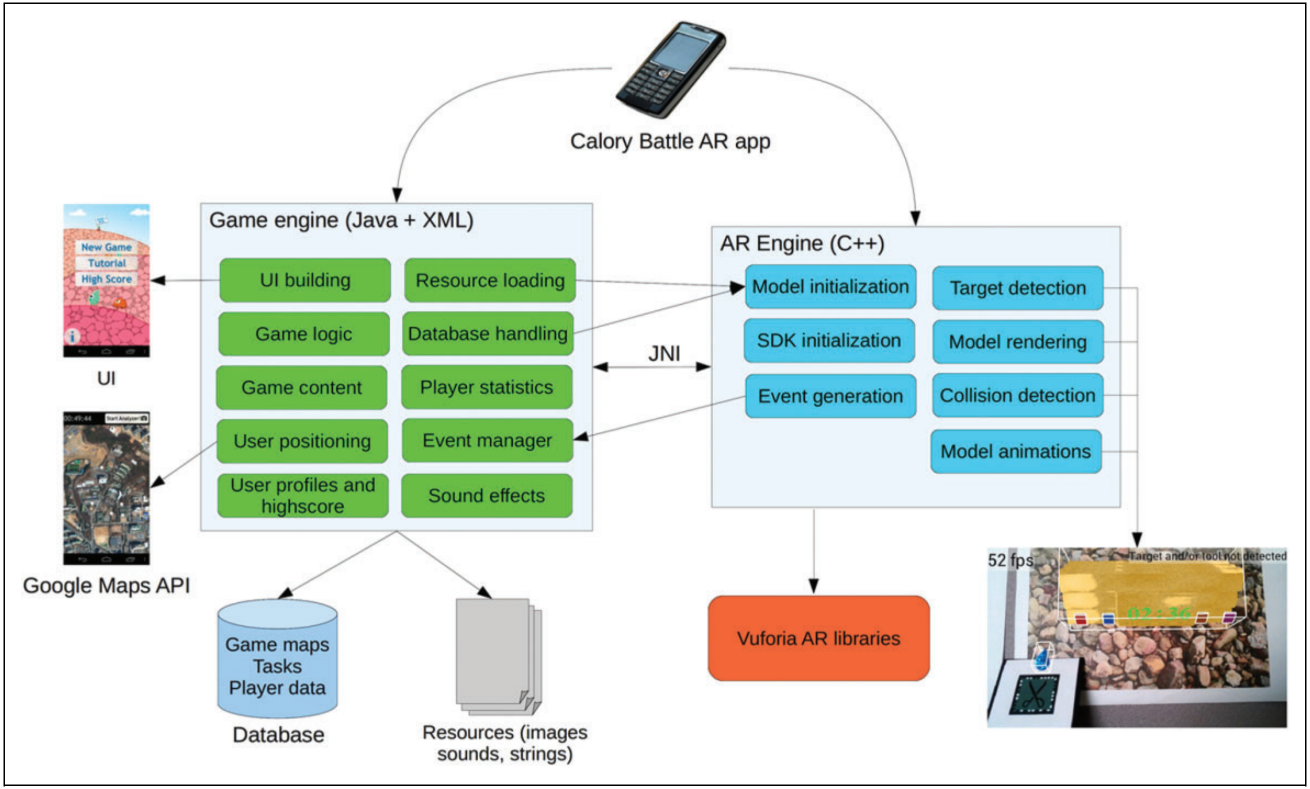

Figure 9. Calory Battle AR client architecture.

to all registered listener components that then perform the necessary actions. This technique allows us to change the user interface, game logic, and content in the Game Engine without changing the underlying AR engine.

Game content in a game session is stored in a GameMap object (Figure 10). This object holds a set of tasks that represent the different types of activities that a player might perform. Currently, there are two task types—bomb defusing tasks and multiple choice quizzes—but only the former is used in gameplay. Each task has a location on the map (latitude–longitude), possible timer, state (active, cleared, or failed), and an image target ID. When an image target is viewed through the camera, the game can then start the correct task with the detected image target ID. An image target can be connected to multiple GameObjects that represent drawn virtual objects. These GameObjects can contain multiple Drawables (not to be confused with Android's Drawable objects) that represent 3-D models to be drawn on the screen. Drawables contain several parameters that define, for example, scaling, rotation, collisions, and visibility. Hence, we can include any 3-D model in the game by connecting them to image targets, and we can change properties of a model without touching the original model or AR engine.

Game maps can be created and modified with a web-based content editor that manages maps stored on the server. Figure 11 shows the user interface of the content editor, which is implemented using Google Maps API, JavaScript, and Java. New tasks can be created by clicking any point of the map, after which a task type is chosen (i.e., bomb defusing or quiz). Existing tasks can be moved by dragging and their content edited through a popup window. After a map is created with the editor, players can download it using Calory Battle AR's map manager feature. The content editing system automatically keeps track of map versions so that players can be notified when new versions of installed maps are available.

As is the case with most mobile games, also Calory Battle AR can cause severe battery drainage because of its interactive elements. The bomb defusing screen comprises a live video feed, target detection by analyzing the video, and rendering of 3-D models. These AR features require significant processing power that affects a device's battery life. During gameplay, most of the players' time will be spent on the map screen as they search for the bombs. The active GPS sensor and Internet connectivity drain the battery when in the map screen, but the effect is less serious than in the defusing screen. Finally, to preserve the battery, the screen goes off after a period of inactivity (e.g., when the player is running to the next bomb) during which the game remains active in the background. If the player swaps to another application, the game goes into an energy-saving pause mode, except for the global timer, which remains active. This is to prevent the players from cheating.

Evaluation

To evaluate the concept and design of Calory Battle AR, we introduced it to a group of Korean elementary school children and another group of Korean university students. The university students were included in the evaluation to see how a game

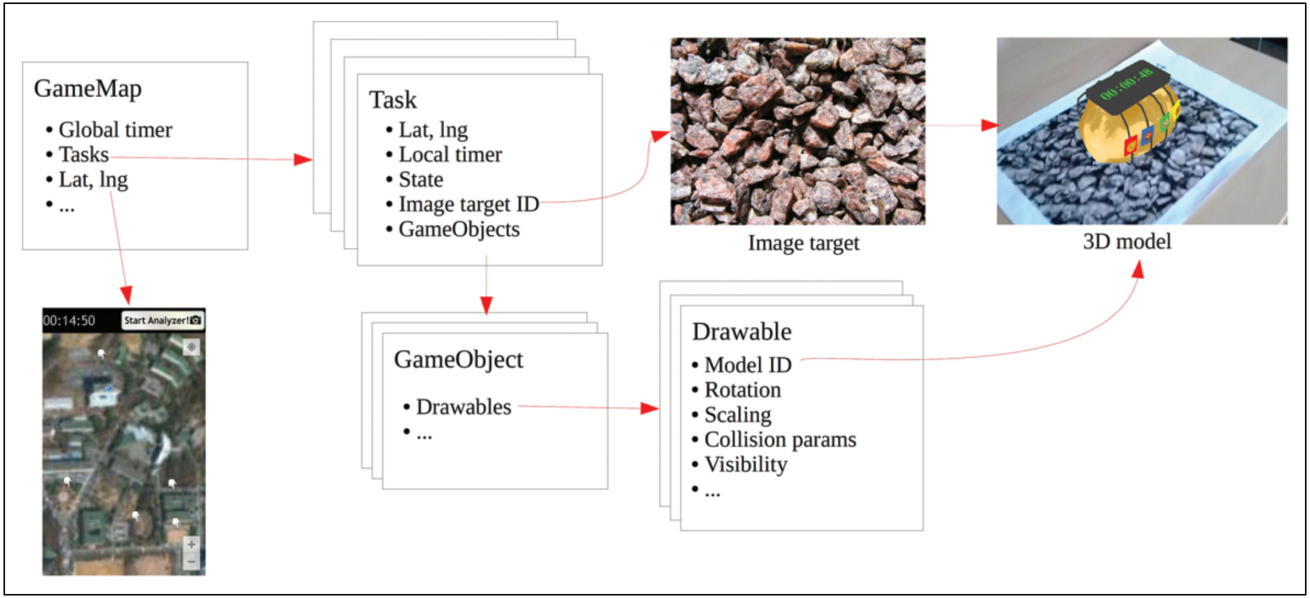

Figure 10. Data structure of game content in a game session.

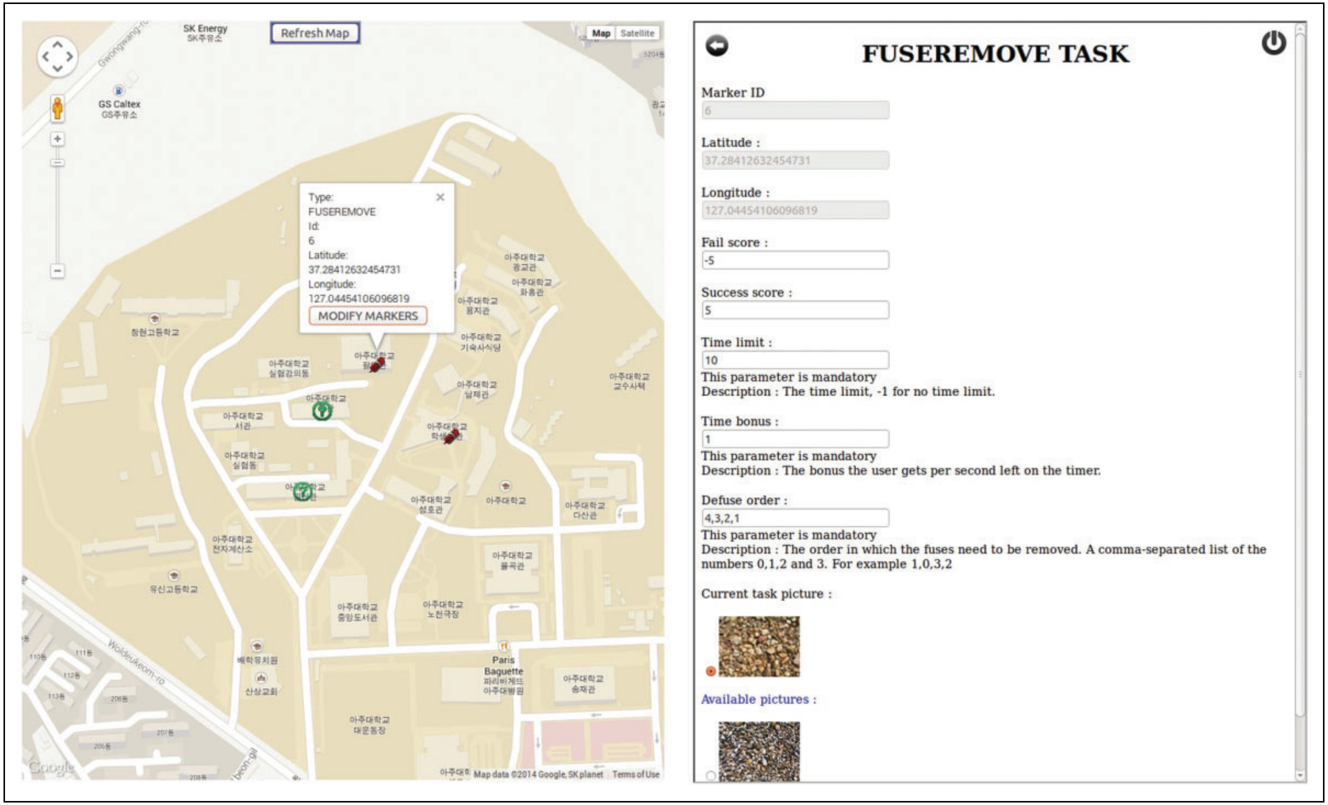

Figure 11. Web-based game content editor.

designed with and for children appeals to young adults who have also grown up with digital technologies. When reporting the evaluation results, we refer to the university students as young adults.

Research Design and Procedure

Calory Battle AR was evaluated during two sessions in Korea in October 2012 and March 2013 with 11 elementary school sixth graders (7 males, 4 females; average age: 13 years) and 18 university students (16 males, 2 females; average age: 24 years), respectively. The school children who participated in the evaluation were not the same as those who participated in the brainstorming session. Regarding age, it is noteworthy that in South Korea, newborns start at age 1. To illustrate this, consider a Korean person who says her age is 15. In Western reckoning, this may be 13 or 14, depending on whether that person has had a birthday already in the current year. The reader is advised to take this into account when considering the participants' average ages.

Test participants filled in a questionnaire (in Korean) that included open-ended and multiple choice questions on a 5-step Likert-type scale (5 = *strongly agree*, 1 = *strongly disagree*, and 3 = *no opinion*). The pretest part of the questionnaire collected demographics and background information such as feelings toward sports and games. The posttest part of the questionnaire measured participants' perceptions on motivation, usability, game activities, game's appropriateness, overall game experience, and relevance to other games and sports. For the school children, researchers acquired a permission letter from their school before evaluation.

The evaluation began by researchers explaining the game concept and story, after which participants filled in the pretest questionnaire and practiced defusing bombs. Participants were then divided into teams of two and the teams were given 20 min to locate and defuse five calory bombs around a university campus—a task that could not be completed easily without running. Researchers provided test devices (Samsung Galaxy S2 and S3), but some players insisted on playing with their own phones. After defusing all bombs or running out of time, participants returned to the starting point to fill in the posttest questionnaire.

Results

We asked the participants about game activities that they liked (Figure 12). All activities were appreciated by the majority of the school children. Searching bombs and playing with friends were particularly liked in both groups, as these statements received 93% and 90% of overall positive answers, respectively. Young adults' answers to statements about running, using the phone, and competition appears to be lower than those of the school children, but this can be partly explained by the high number of "no opinions," which were 33%, 33%, and 22%, respectively. These results suggest that the game's features are well suited for children and young adults, albeit some work remains to make the running activity more appealing. A few school

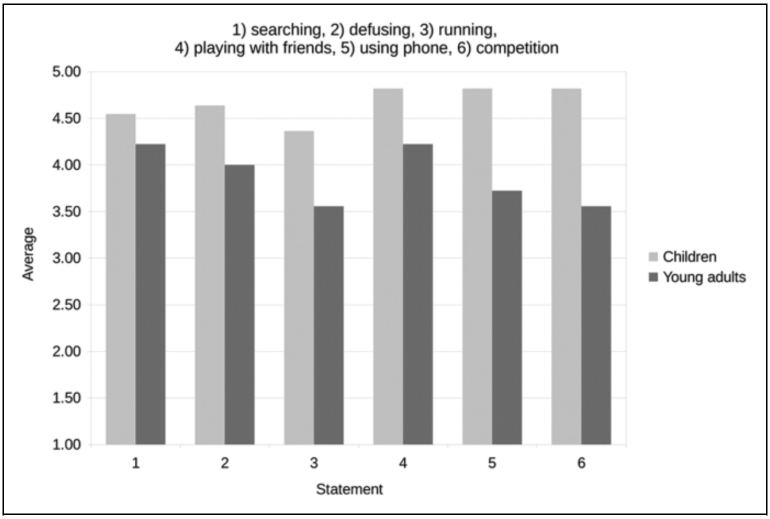

Figure 12. Evaluation of game activities.

children complained about running in the open questions, but interestingly, some of them enjoyed finding the bombs nevertheless, as these comments reveal:

School children were eager to compare scores with each other, while young adults showed less interest in doing so. This could be because the school children were familiar with each other, whereas this was not the case with all the young adults.

Player	What did you dislike about the game?	What did you like about the game?
Male, 13	"That I had to run"	"Running to find bombs"
Female, 13	"It is hard to run"	"It is fun to find [bombs] with a friend"

To increase competition as a motivator for older players, additional incentives might be required, such as detailed user profiles and connections to social networking services. We also observed that the school children were more serious about finishing the game successfully than the young adults. This was evident in the exhaustion levels of the children compared to those of the young adults. One young adult noted that he started walking but later realized that it would not be sufficient, thus it is important to emphasize the time limit to players:

> At first I walked, but later I recognized that there was not enough time. (Male, 24)

The usability of the game was evaluated by eight statements (Figure 13). Statements 1–4 are negative statements, and hence they have low averages. While the

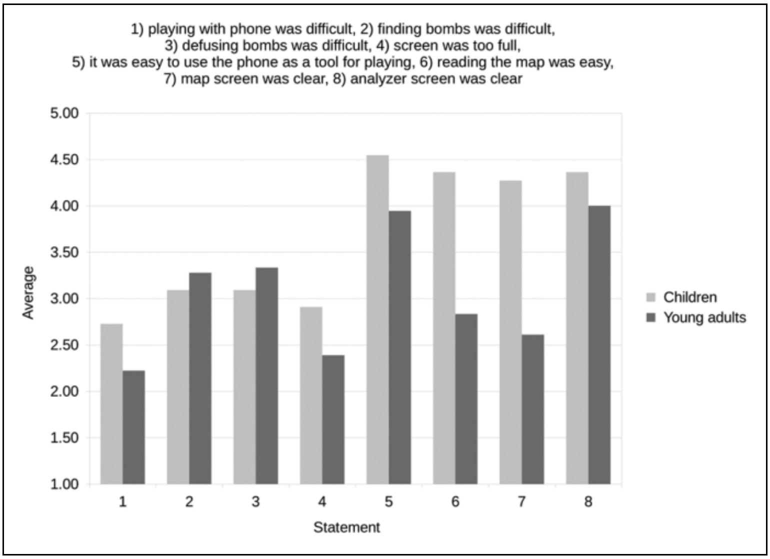

Figure 13. Evaluation of usability.

phone was considered easy to play with, finding and defusing bombs was difficult for 41% and 52% of all participants, respectively. The latter could be caused by the lack of training in AR interaction, and the former relates to the map screen, which was found to be unclear for many players. For the young adult group, the Google Maps satellite image tile resolution was lower for reasons unknown to us. This is a feature of Google Maps that cannot be changed by Calory Battle AR. Poor map tile quality clearly affected the answers of the young adults for Statements 6 and 7, which measure the usability of the map screen. Possible solutions to this problem are to use a road map instead of a satellite map or to use an alternative map provider with higher tile resolution. The map resolution issue was reported by these young adults:

> Map resolution is not good, so it is a little bit hard. (Male, 29)
>
> Make map resolution bigger/mark current location. (Male, 21)

The last remark is interesting, because the current location is marked with a blue dot on the map. To address this, the current location indicator size should be increased.

The difficulty of defusing bombs (i.e., the AR interaction) was also commented on by several players and some suggestions were given as how it could be improved:

> Make the distance between colors [fuses] longer, or make the control more sensitive. (Male, 21)

> When the bomb is on the ground, it is hard to push the fuse exactly. It would be better if the fuse was a little higher. (Male, 21)

> I don't know why the shape [of the Multitool] is a water drop. It would be better to change the shape to be more sharp. (Male, 23)

One school child found the quality of bomb model unsatisfactory and had the following suggestion:

> Design bombs more realistically. (Female, 13)

As we described previously, the balance between realistic and reasonably computable models is one of the challenges of AR content design. To create and process a realistic 3-D model is not a simple task for the developers and yet that is what some players expect. Thus, in the future, we should improve the model and optimize loading and rendering code.

The overall game experience was measured by six statements (Figure 14). School children's answers follow the trend of previous results, confirming that the game created excitement and enjoyment among the players. Young adults gave a particularly low rating to Statement 2 regarding length of game time allowed (44% of answers were negative). This confirms that they were less eager than school children to run. Among school children, there were also some, such as this girl, who were not happy about the amount of time given:

> Please add time extension and reduce the number of bombs. (Female, 13)

The low averages of the young adults are significantly affected by the high number of omitted opinions, ranging between 22% and 56% in Statements 1–6. Furthermore, Statement 6 regarding attitude changes toward sports received only 28% positive answers. We suspect that this might be because many young adults did not run in the game, thus they might have not related it to sports. In contrast, school children gave only positive answers to Statement 6.

Calory Battle AR was considered more exciting than ordinary computer games by 67% of young adults and 91% of school children. Compared to sports, Calory Battle AR was found to be more interesting by 44% of young adults and 73% of school children. In the latter, 34% of all students did not have an opinion, perhaps because the play time was too short to form one. The social nature of the team play was appreciated by 67% of young adults and 100% of school children. Because the game does not strictly enforce team play, a question remains as to whether the players would prefer to play alone or with a friend.

We asked in an open question if the participants found anything surprising while playing the game. Several players in both groups noted that the AR feature (i.e., bomb defusing) was surprising. Others were surprised by their own stamina (or lack of it) and the distance between bombs. It is likely that the game bears a novelty effect regarding AR that may wear off in the future, as this player suggests:

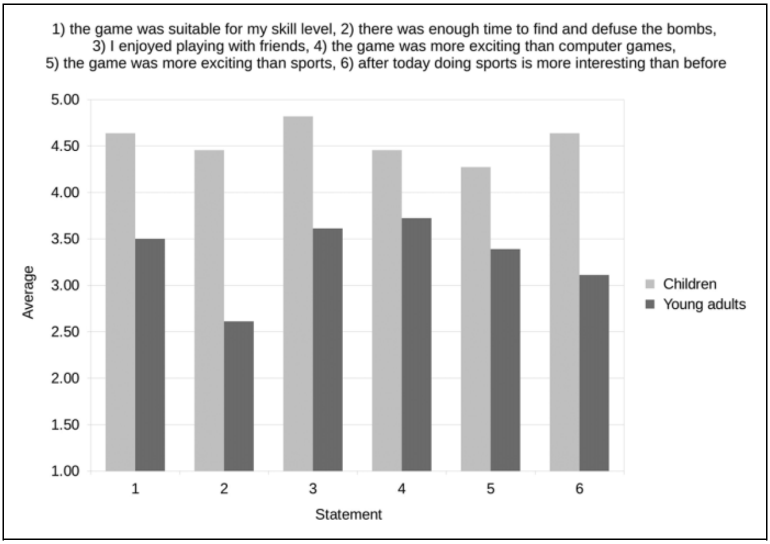

Figure 14. Evaluation of the overall game experience.

> I experienced [AR] one time so it was not surprising, but when I saw it the first time I was surprised that this kind of technique was applied. (Male, 26)

Finally, there were two difficulties regarding game mechanics and content that were reported by some of the players. First, memorizing the fuse color sequence seemed to be harder for young adults than for school children. Several young adults commented about it, for example:

> While running the color sequence gets confused. (Male, 27)

> It would be better see the RGBY sequence later again. I often forgot it. (Male, 24)

It is difficult to determine the reason for this without further investigation, but one valid assumption is that the immersion levels of the young adults may not have been as high as those of the school children. This assumption is also supported by the observation that many young adults started the game walking instead of running.

Second, the lack of narrative in the user interface was noticed by some participants. Before playing, researchers explained the game concept and story to the participants. The story characters are visible in the game's splash screen, main menu, on the map screen, and when bomb is defused or exploded. Apart from character images, there is no other narrative content in the user interface. Adding narrative to the game could lead to better immersion. This hypothesis is supported by popular video games that often have intriguing story lines. The absence of narrative in Calory Battle AR's user interface is a fault that should be corrected, as suggested by these young adults:

It would be better if the game reminds me of its background story while I'm playing. (Male, 24)

What is a Dew? (Female, 24)

Discussion

Success Factors in Calory Battle AR

We described earlier Malone and Lepper's (1987) taxonomy of game motivators as well as Zhang et al.'s (2012) ISCAL model for exergame design. Together, these components can be used as factors to analyze the success of Calory Battle AR's design. Appendix A describes which of these factors are present in Calory Battle AR and which still need improvement. Additional evidence from the user evaluation was provided where applicable. The adaptability factor has been widened to cover adaptability in relation to context, not just the player.

Lessons Learned

The design and development process of Calory Battle AR has taught us valuable lessons about creating mobile AR exergames in an outdoor environment for children and young adults. Some of the requirements and pitfalls are similar to other digital game projects, but differences in platform capabilities, user interaction, game genre, and context introduce some challenges that may not be present in ordinary game development projects. Appendix B lists lessons learned by topic and explanation.

Finding the Flow in Exergames

Popular videogames are often able to engage players so deeply that they become completely immersed in the game world, thus losing the track of real world phenomena such as time. This state of flow, as described by Csikszentmihalyi (1998), should be the primary design goal of exergame creators. In the section 2.3, we explained that in order to reach the flow, an exergame must provide adequate intrinsic motivators. Established intrinsic game motivators, such as curiosity and challenge, are likely to be of help to achieve the flow experience in exergames, but the evaluation of Calory Battle AR suggests that we must overcome a major obstacle that does not affect traditional videogames—the unwillingness to do physical exercise. Paradoxically, increasing physical exercise is the primary goal of exergames.

We have previously used the term *disturbance factor* to indicate a property of a learning system that has negative effects on the learning experience (Laine, 2012). This term can also be applied to Calory Battle AR (and to exergames in general) to describe running as a property that damages the flow experience, as shown in the evaluation results. Examples of other discovered disturbance factors are the need to memorize a color sequence, poor map tile quality, and lack of storytelling. We can facilitate the flow experience by diminishing these disturbance factors and increasing intrinsic motivators. Thus, the likelihood for a flow experience can be roughly estimated through the relationship between intrinsic motivators and disturbance factors. We call this the Flow Experience Factor (FEF):

$$FEF = \{\text{intrinsic motivators}\} - \{\text{disturbance factors}\}.$$

A positive FEF indicates high likelihood for a flow experience. Conversely, a negative FEF is likely to result in unpleasant game experiences. This formula also suggests that if a game has a strong set of intrinsic motivators, some disturbance factors can be forgiven by the players. It is clear that the formula in its current form is only usable for supporting a conceptual discourse. In order to refine it into a mathematical formula that could be used as a design and evaluation tool, we must define the values for each intrinsic motivator and disturbance factor. A major challenge is that these values depend on the player type and personal preferences. That is, different players are motivated by different aspects of a game (see, e.g., Bartle, 1996). Thus, we propose this to be a future research problem to be solved.

In order to diminish disturbance factors, we must understand at which stage they affect the flow experience. The flow experience can be divided into two stages: (1) entering the flow and (2) staying in the flow. In the case of playing games, the former stage requires the player to acquire the *lusory attitude* in which the player voluntarily attempts to overcome unnecessary obstacles that are created and controlled by the rules of the game (Suits, 2005). In Calory Battle AR, an unnecessary obstacle is formed by the distance between the player and the image targets. A dishonest player without the lusory attitude might cheat by downloading and printing all image targets, and then playing the game without taking a single step. After acquiring the lusory attitude, the player must be provided with intrinsic motivators that further facilitate immersion in the game experience, thus finally bringing them into the flow. Disturbance factors emerging at this stage are particularly critical because they will prevent the player from entering the flow altogether. For example, unwillingness to run is a disturbance factor that was experienced by some of the young adults who played Calory Battle AR, thus preventing them from entering the flow. A few children also complained about running, but they ran nevertheless, presumably because they were intrinsically motivated by competition and team play.

Once successfully entered, staying in the flow requires constant balancing between the game's challenge level and the player's skill level which is likely to increase over time (Csikszentmihalyi, 1998). An example of this imbalance is when an exergame requires the players to physically exhaust themselves to the point of giving up. In addition to the challenge-skill imbalance, there are other disturbance factors that can lead into premature exit from the flow, such as poor user interface design or confusing game rules. Exergame designers must therefore consider not only the challenge–skill imbalance but also other potential disturbance factors.

We did not provide a silver bullet to solve the paradox of required and unwanted exercise in exergames. However, we proposed some ideas that pave the road toward a better understanding of motivational issues in exergaming. The next steps in this research include building taxonomies of intrinsic motivators and disturbance factors in exergames, and analyzing their values and relationships to player types. These will enable us to complete the formula given above which, in turn, unlocks new opportunities for creating design and evaluation tools for exergames.

Limitations

The evaluation has several limitations that should be accounted for in the future. First, while the evaluation gave us interesting indications of how the game was perceived by children and young adults, the amount of data was too small to gain statistically strong evidence from quantitative data. Second, the majority of participants were males, thus the differences between genders cannot be reliably analyzed. Third, the data set consisted of South Korean players only, which means that applicability of the results to other cultures is questionable. Finally, the effects of long-term exposure were not tested. These limitations will be mitigated in subsequent evaluations by using a larger and more heterogeneous data set over a longer time span. In addition to the user evaluation, the game and particularly its AR interaction should be analyzed to establish AR usability principles (e.g., Ko, Chang, & Ji, 2013). Furthermore, in order to measure the depth of players' immersion in the flow, a framework such as Calleja's player involvement model could be used in future evaluations (Calleja, 2011).

Conclusions

Motivating people to move by combining exercise with digital gaming is not a new phenomenon, but so far, exergame design issues have not been widely investigated. We presented the design and development process of Calory Battle AR—a mobile exergame that leverages AR to provide a new type of gameplay experience. Initial evaluations, conducted on elementary school children and university students in Korea, yielded generally positive responses, but several problems were also revealed. The evaluation results are essential for advancing the game concept further and improving usability. These results together with proposed design principles can be useful to other designers who wish to design motivating mobile AR exergames. In addition, our retrospective analysis of the design process resulted in lessons learned that can be beneficial to the exergame design community.

We showed that Calory Battle AR supports most of the factors found in fundamental game motivators as well as the ISCAL exergame design model. However, some work remains to be done, such as making the game support the scientific principles of exertion, integrating learning content into the game, and emphasizing the story line. Other future development tasks include adding custom game maps, developing new task types to diversify the gameplay, and adopting a powerful 3D engine (e.g., Unity 3D). Finally, we intend to perform a deeper player evaluation in terms of length and participant heterogeneity.

Appendix A. Success Factors in Calory Battle AR.

Factor	Analysis	Additional Evidence
Challenge	The game has multiple challenges: finding bombs, defusing them, and running to beat the timer	Figure 11: Statements 1 and 2; Finding bomb on my own and running is fun (Male, 13)
Competition	Players compete against each other and against the clock. Points can be compared at the end of the game	Figure 11: Statement 6; [I liked] running and defusing in limited time (Male, 30)
Control	A player has control over the strategic order in which the bombs are searched, and this affects the game outcome. Pace can also be player regulated as long as time does not run out	Figure 11: Statement 1; At first I walked but later I recognized that there is not enough time (Male, 24)
Cooperation	Players can play in teams, joining efforts to locate and defuse the bombs	Figure 11: Statement 4; it is fun to find [bombs] with a friend (Female, 13), Playing with friend is fun and fresh (Male, 23)
Curiosity	AR as a novel technology can create curiosity, but this effect may not be long-lasting. In the first version of the game, there were no AR tasks other than defusing bombs. It is possible to add other task types that make players curious about what kind of task is waiting behind each image target. Deeper integration of the story into the game can also increase curiosity about what will happen next in the story	AR is amazing (Male, 27)
Fantasy	The story of the Dews and Caloroids introduces fantasy into the gameplay, but this should be emphasized even more in the gameplay	Sorry Dew that I cannot save you (Male, 21)
Recognition	Players are ranked according to their performance in the gameplay, thus they can gain recognition among peers. Helping the Dews may also serve as a recognition motivator	We observed that school children were eager to compare scores after the game session
Immersion	Immersion is the result of other successful motivators. Positive feedback from players suggested that some of them were immersed in the gameplay, but a deeper qualitative study is needed to verify this	[i liked] thrill and tension (Male, 13)

(continued)

Appendix A. (continued)

Factor	Analysis	Additional Evidence
Scientificalness	Currently, the only physical activity that the game has is running. Scientificalness could be enhanced by capturing the distance travelled by the player and calculating calorie consumption based on it. If higher accuracy is desired, an activity detection algorithm could be applied on accelerometer signal to detect whether the player is running, walking, or stationary. This information could be applied in game mechanics. If more elaborate exercises are to be added, scientific guidelines on exertion must be followed	We observed that some school children were clearly exhausted and sweating after the game, so the game has some efficacy in terms of exercise
Adaptability	The game platform is adaptable to any outdoor context. Game maps for these contexts can be created using the content editor. Currently, the gameplay does not require any player-based adaptation	—
Learning	The aim of the game is to persuade players of the benefits of exercise. However, there is no explicit pedagogical content about this in the current version of the game. The game supports alternative tasks such as quizzes that make the inclusion of pedagogical content viable in the future	—

Note: AR = augmented reality.

Appendix B. Lessons Learned.

Topic	Lesson Learned
AR engine	Building a custom AR engine on top of an AR toolkit gives the developer the freedom to determine what is drawn on the screen and how. This requires significant development effort, thus the designer should carefully consider adopting a third party rendering/game engine such as Unity 3D if the game uses many interaction techniques, visualizations, and animations

(continued)

Appendix B. (continued)

Topic	Lesson Learned
Models and textures	Even though modern smartphones are becoming increasingly powerful, we learned through trial and error to avoid creating models and textures that are too detailed and therefore have high computational complexity. The time required for loading models and textures and drawing them on the screen is directly proportional to their complexity. The designer must balance between creating realistic models and keeping the loading/ processing time reasonably low
Story	The presence of story is essential for creating a deeper purpose for the game. Including only game characters is not enough. Following the example of *Angry Birds*, a game should have at least an introductory narrative that escorts the player into the game world
Environment	In outdoor games, environmental conditions play a significant role. A smartphone can be easily damaged by rain or when dropped on the ground. In an AR game, low light levels can make image target detection inaccurate. This happened to at least one team with one bomb. Humidity and extreme temperatures can also cause technical problems or at least make players feel uncomfortable. Many smartphones have light sensors and ability to retrieve weather information, so one solution to different environmental conditions is to make the game environment aware. For example, if the light level is too low for AR, then there could be an alternative way of defusing the bomb (or another activity). Aspects of designing exergames that take into account the player's environment are discussed further in Knöll, Dutz, Hardy, and Göbel (2014)
AR interaction	Even though AR has existed for some time, it is a novel technology for many smartphone users. If the game requires interaction with AR content, the designer should pay special attention to 3-D object interfaces for accurate collision detection. For example, in Calory Battle AR, the fuses could be enlarged and the Multitool's point sharpened. Including a training mode in the game could also help the players become familiar with AR interaction
Expandability and portability	Player-generated content can extend the lifetime of a game. In location-aware games, portability across geographical contexts is essential for gaining a wide audience. A major shortcoming of the first version of Calory Battle AR is that it does not yet support custom game maps that could be created, shared, and downloaded by players. By providing content management features, the designer can shift ownership and responsibility of content creation to the players. A centralized repository is needed to host content generated by the players

(continued)

Appendix B. (continued)

Topic	Lesson Learned
Map	Most location-aware games use an interactive map. During evaluation, we noticed that map quality and accuracy are essential for navigation. The designer must consider which map provider and what type of map to use. The designer must also consider how the player's current location is indicated on the map and whether the player is able to see other player locations. Sometimes, it might be reasonable to exclude GPS and use a static map (e.g., in an indoor game) instead. Whatever the approach, the quality and features of the map should be adequate for navigation
User profiles	One evaluation participant suggested that it would be good to have a login name so that one would not have to give a name every time the game is played. Allowing players to create profiles has many advantages such as unique IDs as well as the ability to create and share content, maintain friend lists, and connect to social networking services. The designer must decide if the game features require user profiles and whether to use the credentials of an existing service (e.g., Facebook, KakaoTalk, or OpenID)
Game mechanics	Although a variety of successful game mechanics have been developed for popular video games by the entertainment industry, it is clear that the same mechanics may not be directly applicable to exergames. For example, some Calory Battle AR players suggested that memorizing the correct bomb defusing sequence was difficult because of running. As pointed out by Baranowski et al.'s (2013) roundtable discussion, exergames and other games for health require an adaptation of game mechanics to the target game's tone and content. Thus, more research is needed to create a taxonomy of game mechanics for exergames with guidelines of how to apply them

Note: AR = augmented reality; GPS = Global Positioning System; 3D = three-dimensional.

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