

Attuning a mobile simulation game for school children using a design-based research approach

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Abstract

We report on a design-based research study that was conducted over nine months. It chronicles the development and implementation of *HeartRun*, a cardiopulmonary resuscitation (CPR) training approach for school children. Comparable to an unexpected emergency, *HeartRun* consists of authentic activities involving different roles, game tasks, locations and physical objects to support process-oriented learning for first responders. It aims to enhance the psychological preparedness of the rescuer and thus promotes a more prompt and appropriate response. In this paper, we describe a cycle of three design-based research (DBR) studies in which *HeartRun* was explored with school children. In order to better understand how to design mobile game environments that support dimensions of seamless learning, we analysed children and their knowledge-building practices while learning with *HeartRun*. The mobile game has evolved significantly from its initial conception through an iterative process of (re) designing and testing the synchronization between physical and digital worlds, learner collaboration and ubiquitous knowledge access, i.e. dimensions of mobile seamless learning activities. Based on our experiences, we conclude by discussing challenges and shortcomings of mobile game-based learning environments.

Keywords:

Mobile learning; serious games; health education; design-based research (DBR)

1 Introduction

The potential of mobile devices to engage learners and to support learning has been widely acknowledged by educational practitioners and scientists and by now, a broad range of practical studies across varied domains and application scenarios has proven the usefulness of these technologies for the process of teaching and learning (Garrido, Miraz, Ruiz, & Gómez-Nieto, 2011; Klopfer, Sheldon, Perry, & Chen, 2011; Sánchez & Olivares, 2011). Mobile devices are used within various learning contexts and their functions are employed in multitudinous ways. Location-based learning scenarios, for example, make use of location-sensing capabilities to guide learners through cities or museums, asking them to pick up or capture information at predetermined locations, make inquiries, enter information and answer a series of factual questions presented to them through the mobile device (So, Seow, & Looi, 2009). Augmented reality (AR) visuals as used in “TimeWarp” (Blum, Wetzel, McCall, Oppermann & Broll, 2012) or “Viking Ghost Hunt” (Carrigy, Naliuka, Paterson & Haahr, 2010) combine learning activities in the physical and digital environment. The switch between the two engage students’ involvement with digital information by drawing the attention of learners to specific landmarks or objects for example (Dunleavy, Dede, & Mitchell, 2009), this way enabling players to simultaneously focus on virtual and physical aspects of particular artefacts.

A format frequently used to take advantage of the manifold opportunities of mobile technology is mobile games for learning. For both commercial and scientific use they have been developed for various target groups and learning contexts.

Research that has evaluated their educational potential found evidence for their supporting of socio-affective and cognitive learning outcomes (Mitchell, 2007; Schmitz, Klemke, & Specht, 2012), or their potential to enable situated learning offers that make a meaningful and valuable contribution to the process of learning by providing aspects such as temporal flexibility, natural communication or situated learning scenarios (Klopfer, 2008).

However, using mobile devices for educational purposes faces challenges. It frequently implies a continuous shifting of attention between the different objects, tasks and activities (Rogers, Connelly & Hazlewood, 2010), which, for a start, interrupts the ongoing learning experience. Besides getting oriented on a screen, the learner now has to find orientation in the 'real' physical environment. Learning with mobile devices differs from the learning that takes place when using desktop computing in classrooms. It is characterized by short usage sequences (e.g., entering and comparing data, looking up and reviewing information, sending texts or photos to remote people) to support foregrounded physical activities (observing, probing, measuring) in a particular environment (Rogers et al., 2010, p. 111). These seams between tasks and activities are challenges for the design of mobile learning experiences. Though the switching between the different objects, tasks and activities is sometimes credited with a potential for *sensemaking activities* because the device supports people in finding structure in an uncertain situation through using a combination of information, communication and computation (Rogers et al., 2010), it can be very distracting for the individual learner and might even have a share in learners' cognitive overload (Wong & Looi, 2011). Based on the cognitive theory of multimedia learning, Mayer (2003) argues that presenting rich, diverse and complex multimedia elements in a confusing way easily exceed learner's available cognitive capacity. For example, multimedia presentations that use audio, narration and animations simultaneously to explain a given subject can already impose high intrinsic load on the learner and limit essential cognitive processing. The additional switch between digital and physical world, which is inherent to learning with mobile technologies, means further extraneous and in many cases redundant material that further increases cognitive load. Thus, the learner uses already limited cognitive resources to process additional information. As a result, engagement in substantial cognitive processing, a prerequisite for meaningful learning, is not possible (Mayer & Moreno, 2005). Kiili (2005), too, stresses that inappropriate ways of presenting learning material easily overload learners' working memory capacity. He notes that especially educational games run this risk because traditionally, games have consisted of rich multimedia elements. To maximize the process of learning with mobile games, instructional design needs to consider and optimize the switch of focus between the physical world and mobile digital services.

In order to avoid cognitive overload due to educational design decisions, Mayer and Moreno (2005) have proposed design principles for multimedia learning, which also guide design decisions for learning with "mobile network-centred devices" that harness the Internet to promote collaborative learning experiences (Wang & Shen, 2012). Mayer and Moreno (2005) emphasise the need for conciseness and coherence of the material presented and also refer to the redundancy principle. To maximize the process of learning with mobile games, the coherence principle implies a thorough consideration and if necessary elimination of information that is

not related to content and context as it may distract the learner and thus decreases the learning (Clark & Mayer, 2011).

Especially in the field of health education this switching needs substantial consideration. Health education often takes the combination of teaching theoretical knowledge, motor skills (i.e. using a particular skill) and procedural knowledge as a basis. Traditional cardiopulmonary resuscitation (CPR) training measures, for example, strongly focus on the level of resuscitation skills, frequency of updates or contents of sessions, such as the training of CPR skills on a puppet, the right compression depth, frequency and rhythm. In order to be effective, this explicit knowledge needs to be turned into action (De Jong, & Ferguson-Hessler, 1996), by simulating a real emergency situation, for example.

In general, the rate of bystander CPR at cardiac arrests is comparatively low, less than 20% (Vaillancourt, Wells & Stiell, 2008). One of the many explanations for this is the low number of trained laypeople. In order to increase their number and thus survival rates, it is necessary to enlarge the target group for CPR training activities. Addressing school children is regarded as one toehold in this. School children are willing and prepared to provide CPR if they are trained, and they are capable of learning CPR (Lester, Donnelly, Weston & Morgan, 1996). This is supported by studies which indicate that children aged 13-14 perform compressions on an unconscious patient as well as adults do (Jones et al. 2007). Organizations such as the American Heart Association expect that in the long run, mandatory training of schoolchildren at regular intervals will increase the number of trained adults (Cave, Aufderheide & Beeson, 2011) and will raise awareness, interest and sense of importance of taking action in out-of-hospital cardiac arrest. In their review, Plant and Taylor (2013) point out diverse methods of first aid training that have been successful with children. They state that especially the use of “virtual worlds and multiplayer online simulation could be an attractive training and/or retention tool to use in this age group” [p. 3].

In this paper, we report research that builds upon existing evidence of the educational potential of mobile learning games. It is based on the mobile simulation game *HeartRun*, which is targeted at giving school children an understanding of cardiopulmonary resuscitation (CPR) and getting them to take action. The overarching goal is to drive research towards the design and deployment of mobile simulation games for children with a strong focus on *seamless learning activities*. According to the framework provided by Wong & Looi (2011), mobile assisted seamless learning activities comprise learning activities based on mobile and ubiquitous technology, which encompass formal and informal learning, personalized and social learning, physical and digital worlds. The seamless and rapid switching between multiple learning tasks or the combination of multiple devices are salient dimensions of mobile assisted learning environments. However, they are relatively unexplored from a pedagogical point of view (Wong & Looi, 2011). This study explores these issues.

We examined individual features of a mobile game approach through which lay responders enhance their CPR skills, while expanding their procedural knowledge of how to act in case of emergency. Our focus is directed at children and their learning practices while learning with games. Thus, the focus that guided the

studies can be formulated as follows:

How can mobile game-based learning environments that support children while engaged in an ongoing task in a physical environment be designed?

What are the characteristics of an effective mobile simulation game approach, through which lay first responders enhance their CPR skills and their readiness to help, while expanding their procedural knowledge of how to act in case of emergency?

To answer these questions, this paper is divided into four main sections. Section one provides a summary of related work including a brief overview of mobile games for health, with a particular focus on games that teach basic life support (BLS) and resuscitation, including CPR. Section two introduces the game-concept of *HeartRun*. It describes the educational framework for the interplay of learner activities, physical environment and physical objects with the mobile device (smartphone). In the third section, we explain the methodology of three sequential studies that we carried out in order to answer research questions. We conclude with section four, discussing and highlighting design implications for mobile simulation games that support health-related learning outcomes by enabling and facilitating seamless learning activities, which we derived from this intervention research.

2 Related work

For the past decade, the areas of health education and physical education have started to investigate how digital games can assist their goals, i.e. raising awareness, facilitating empathy and increasing knowledge gain (Papastergiou, 2009). This newly created field of serious health games tries to leverage the acknowledged advantages and focuses on knowledge building, fostering positive health-related behaviours, strengthening motivation of patients to take a specific medication or to change their daily behaviour in order to live healthier lives (Gerling, Fuchslocher, Schmidt, Krämer, & Masuch, 2011). Various innovative approaches have surfaced, such as the health game “Balance,” which focuses on diabetes (Gerling et al., 2011), “Fatworld”, which is used in the field of prevention and health promotion (Lampert, Schwinge, & Tolks, 2009), “motivotion60+” that focuses on coordination and strength exercises for fall prevention (Goebel et al., 2010) or “Re-Mission”, a video game that was developed to strengthen the motivation of cancer patients to take medications (Papastergiou, 2009).

In the past decade, several innovative games have emerged that focus on first-aid training, BLS, resuscitation training or CPR and address children, young adults and adolescents. One recent example is the crisis simulator “*LIFESAVER*” (<https://life-saver.org.uk/>) by the Resuscitation council (UK) that fuses interactivity with live-action film. However, the actual affective and cognitive outcomes of such approaches have not been investigated in depth and need further evaluation (Papastergiou, 2009). Still digital game-based learning approaches are motivating tools for children, young adults and adolescents, which have the potential to positively impact on knowledge and are capable of changing attitude and behaviour

(see Appendix A for a summary of research articles concerning digital game based learning approaches for first-aid training, BLS and CPR).

Also, research offers little information on the effectiveness of game-based CPR instruction as against more traditional seminar based learning formats. One of the rare examples is the study conducted by Marchiori, Ferrer, Fernández-Manjón, Povar Marco, Suberviola González, & Giménez Valverde (2012). They assessed the usefulness of an educational video game and compared this way of instruction to the traditional teaching of basic life support manoeuvres through practical demonstrations by health care professionals. The results indicate that unsupervised use of the video-game instruction in a single 45-minute session significantly improved knowledge about the action protocol and the procedures involved.

Mobile game-based learning environments for CPR training are rarely researched, though several mobile technology-based approaches are in existence. Furthermore, as shown in Appendix A, recent innovative developments are more comprehensive such as the approach by Wattanasoontorn, Magdics, Boada, & Sbert, (2013). They describe a Kinect-based system for “LISSA”, (*L*ife *S*upport *S*imulation *A*pplication), which is able to provide feedback on the performance of specific parameters of the CPR procedure (chest compression rate and correct arm position). To the best knowledge of the authors, none of the current applications uses a mobile simulation game to train BLS and CPR.

3 *HeartRun*: a mobile simulation game to train resuscitation

Quick decision-making and taking actions are among the most vital activities in case of emergency. By applying emergency knowledge in an innovative way, *HeartRun* uses the simulation game concept to train these skills and to engage laymen in resuscitation. In order to train and increase procedural CPR knowledge, which is based on the sequence of actions required in case of a sudden cardiac arrest, the design of *HeartRun* combines digital and physical world activities, integrates physical objects (a manikin and an automated external defibrillator (AED)), digital game-based learning tasks (e.g. data collection) and multiple learning tasks, features characteristic for the design of seamless mobile-assisted learning environments (Wong & Looi, 2011). The diverse tasks involved in the game aim at producing a more authentic context for learners than the typical classroom lecture and are envisioned as an extension of classical group-based resuscitation courses.

The effectiveness of *HeartRun*, as opposed to traditional resuscitation trainings, is arguable by drawing on the concept of embodied cognition as grounding for situatedness and context in first aid trainings. Along the theory of Jean Piaget, who defines the development of sensormotoric abilities as basic requirement for cognitive development, embodied cognition argues that human cognition is deeply rooted in sensormotoric processing (Wilson, 2002). Besides relating cognition to situated activities, the concept of embodied cognition considers principles such as time pressure, (the need for real-time responsiveness to feedback from the environment) and action to be vital contributors for cognitive processing (Wilson, 2002). The mobile game simulation *HeartRun* supports these claims: Providing CPR and using the AED, for example, are motor activities that affect the environment in

task-relevant ways. But besides situation bound cognition, which is delivered by traditional training accordingly, the design of *HeartRun* continuously requires students to take fast decisions not allowing them to „build up a full-blown mental model of the environment“ (p. 628) from which they may derive a plan of action. This is argued to have „far-reaching consequences for cognitive architecture“ (Wilson, 2002, p. 628) as is the case for action learning. The interactive, action driven nature of *HeartRun* inherently supports this concept, which finds its equivalence in diverse approaches such as the *active learning approach* (Sokoloff & Thornton, 1997).

HeartRun is organized as a list of messages, which indicate the individual steps to take in case of emergency (Fig. 1). Each message triggers an activity by the players or requires input in the form of video/audio messages (Kalz, Schmitz, Biermann, Klemke, Ternier, & Specht, 2013). Students have to respond to the messages to save the victim. New messages appear as soon as the required task is completed. A CPR manikin and an AED are placed in the vicinity of the training location where participants are notified about the CPR case. The game simulation involves two roles, played by two students who make up a team:

Role A: CPR player. The messages require students to locate the victim (manikin) at the school facilities, and to provide CPR and assisted breathing. The message items of the *HeartRun* intervention that are displayed on the mobile device support them by specifying the number of compressions, the number of assisted breaths or the frequency of CPR compressions.

Role B: AED player. The messages require students to locate the closest automated external defibrillator (AED), scan the QR code next to it and go to the victim. As soon as the AED player arrives at the scene of action, the two roles synchronize, and both players now get the same messages, which require them to place the AED's electrode pads on the manikin's chest and administer the shocks while doing the heart massage.

[Fig. 1. Game screens *HeartRun*: welcome message, task, and instruction screen]

We based *HeartRun* on the platform *ARLearn* (Ternier, Tabuenca, & Specht, 2012), an open source authoring tool suite for educators and learners. *ARLearn* supports the design of interactive location-based mobile games and experiences and provides functionality for:

- (a) Role-based game environments, which enabled us to set up a realistic environment in which users are guided to an actual AED device.
- (b) Monitoring and recording user behaviour, which is reused for later reflection and feedback on the course of action.
- (c) Augmenting situations with location and object dependent information, processing information and notifications, as well as instructive, situation-dependent educational materials.

Augmentation in mobile games can range from eye displays that users wears as they move through the world to less obtrusive handheld technologies as we

employed for our study. In accordance with existing definitions, games that augment reality create a fictional layer on top of the real world context. They are played in the real world with the support of digital devices such as PDAs or smart phones (Squire & Jan, 2007). The location-based feature of ARLearn enabled us to create a realistic setting spreading out over school. The multi-user feature enabled the provision of different player roles thus supporting team play and collaborative actions between learners.

4 Research Design

In order to set up the game simulation, we conducted a series of studies over the nine-month period between March 2013 and February 2014. The studies were guided by the principles and attributes of design-based research (DBR) methodologies, which focus on how concepts work in real classrooms, operated by average teachers and students, supported by realistic technological and personal support. Brown (1992) phrased it as intervention research designed to inform practice. Often seen as “test beds of innovation” (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003), design studies involve introducing an intervention in a naturalistic setting and then observing how it functions to support learning in order to better understand the procedures and instructional tools that work in real-world classrooms. “By studying a design in practice with an eye toward progressive refinement, it is possible to develop more robust designs over time” (Collins, Joseph & Bielaczyc, 2004, p. 19). Reeves (2006) as cited in Plomp (2010) illustrated the individual steps of the underlying design process, which is depicted in Fig. 2.

[Fig. 2. The four steps of the design process as describes by Reeves (2006)]

Building on this strand of research we set up the research design. In stage one: *refinement of the problem*, needs were analysed and the target group was characterised. The game concept was set up based on a review of related work and subsequently a first draft of the simulation game was introduced and continuously discussed in the context of the project EMuRgency (www.emurgency.eu).

In order to better understand the design of mobile game-based learning environments and its effectiveness we conducted several studies. The first study in our design research cycle was carried out in stage two: *solutions*, and was targeted at medical experts. Its aim was to secure a sound and logical setting of the prototype design from a medical point of view. In the course of the three successive trials of stage three: *methods*, we studied the game being played by several groups of school children with and without prior CPR knowledge. Each trial session lasted for one day with children playing in succession and comprised piloting, testing, and evaluation leading to further design refinements. In the course of stage four: *design principles*, we set up a list of design issues that surfaced from the analysis of study results and might guide future research in the field.

5 Method

Prior to the game testing we briefly explained the aim of the game and gave basic instructions on how to use the device. We then randomly assigned participants to one of the two roles (AED player and CPR player). However, the roles pupils played were not relevant for data analysis but integral part of the simulation game. A further assessment of their impact is necessary and will be addressed by future research. While playing, intervention was kept to a minimum. The researcher's role during the case study was participant observer. Participants had to fill in a form after they had played the game.

5.1 Data collection

For the mixed data collection we used videos and field notes of researchers' observations and conversations with participants during the activities as well as focus groups after the activity to obtain information on (a) how learners think or feel about the game simulation and (b) how to improve planning and design of the simulation game. The qualitative feedback was validated by quantitative data and was collected through a standardized questionnaire based on the system usability scale (SUS). We chose the SUS because it is an accepted measure for attitudes toward system usability (Lewis, & Sauro, 2009), which makes results easily comparable. The overall SUS questionnaire is commonly used in educational research [Wang, Øfsdahl, & Mørch-Storstein, 2008]. We used the standard overall SUS score, instead of the eight-item usability scale, because the overall SUS allows estimating perceived learnability along with a cleaner estimate of perceived usability (Lewis, & Sauro, 2009). It provides a generic questionnaire of ten items for a simple indication of the system usability and learnability as a number on a scale from 0 to 100 points. Odd-numbered items are worded positively and even-numbered items are worded negatively. The items had to be rated on a 5-point Likert-scale.

To trace back answers we added specific questions to the SUS with regard to suitability and perceived usefulness. Furthermore, we added data from game progress tracking to complement the qualitative and quantitative results and document the actual game progress of individual players. Due to a coherent use of key numbers for both players and game IDs they can be traced back to individual participants.

The data we collected were analysed with regard to game usability, learnability, technology use and students' participation. Quantitative experimental data was analysed using the statistics programming environment R and the SUS guide and calculator package (Sauro, 2011). The actual increase in knowledge (the depth of pressure or frequency of pressure rates) was not assessed. The focus of this study was purely formatively with regard to game design issues. Table 1 summarizes the main data collecting methods, participants and outcomes of the individual stages.

Out of the 122 SUS questionnaires we received we omitted 25 due to insufficient data, which involved missing game ID (12), missing first page (7), missing second page of the questionnaire (4) or incompleteness (2).

[Table 1: Research instruments used for the different stages and outcomes]

5.2 Sample

The studies benefited from contributions and feedback from a total of 157 participants. Seven medical experts from four different medical clinics - Universities of Aachen (3), Genk (1), Liege (1), and Maastricht (2) and 149 students (study 1 $n = 60$, study 2 $n = 53$, study 3 $n = 36$).

6 Iterative Design Steps

6.1 Prototype testing

The prototype testing was conducted on 21st March 2013 at the general consortia meeting of the EMuRgency project in Leuven. In order to secure a sound and logical setting from a medical point of view, we tested the game prototype with medical experts ($N = 7$). None of them had played *HeartRun* before. The expert evaluation aimed at assessing (a) the *HeartRun* interface and game usability, with focus on adequacy of integrated game features in relation to the content ('chain of survival'), and (b) the technical functionality. To assess the prototype, we used the SUS. In order to further enhance this first feedback, we added two additional open response questions to the SUS: "For which target group would you use the game?" and "What would you suggest to improve the game?"

For the gaming session, we equipped participants with a smart phone each and randomly assigned the players to one of the two roles (AED player and CPR player). Before the testing, we installed the game on the devices and inserted SIM cards in order to set up an online connection.

6.2 Findings from the prototype testing

The overall SUS for the prototype testing revealed a mean SUS score of 73.6 (StDev = 8.0; median = 72.5) and a range between 66.16 and 80.97 for 7 valid responses. The internal reliability as measured by Cronbach's alpha is calculated at 0.334. Table 2 indicates the average values per questionnaire item for the second study.

[Table 2. Results SUS prototype testing, average values per questionnaire item]

According to standardized interpretation, a SUS score above 68 is considered above average and on an adjective rating scale could be described as good to excellent (Bangor, Kortum & Miller, 2009). In accordance with the proposition by Lewis and Sauro (2009), we analysed the overall SUS score using the two questionnaire items four and ten to assess the learnability scale and the remaining items to assess the usability scale. For perceived learnability, i.e. the ease of getting used to the application, the questionnaire yielded a mean score of 75.0. For perceived usability, the mean score was 68.8.

The expert interviews and observations showed that the game concept worked.

Especially the fact that players have to quickly decide what to do in a stressful situation was rated positively. The simulation game was accepted and participants liked using it, reflecting the qualitative SUS results. In the interviews participants specified that they think the game does not replace traditional resuscitation training but ideally complements it. Participants judged the simulation game suitable for school children aged 10-16 years and young laymen (up to 20 years) as well as persons who are new to a certain environment. Feedback from the expert interviews showed that the following aspects needed to be reworked:

- Directing players in the physical world needed improvement, for instance, looking at the device to read instructions while running around to find the AED lead to them overlook the sign that indicated the device. Users suggested adding further assistance with the device and integrating directions on where to go on the phone or an audio function, for example.
- Coordinating players at the manikin needed improvement. Though participants at the manikin were dealing with the same content and were in the same location, there was little interaction between the players, who were reading in silence.
- Teaching pupils resuscitation content needed improvement. It was recommended that the message items, which mirror the chain of survival, include further medical information.

6.3 First study

After integrating the feedback from the prototype study into the design of *HeartRun*, the first field-study was conducted. It took place in Aachen, on 12 July 2013 at the Pius Gymnasium and was designed to assess the concept and use of *HeartRun* in a CPR training context for school children.

[Fig. 3. Player using the *HeartRun* application at the manikin and player scanning the QR code at the defibrillator]

First, school children attended a traditional session with practical demonstrations on how to perform CPR. The training was provided by health care professionals and lasted 35 minutes. It comprised of a manikin and a control device that gave feedback about the depth and speed of compressions. In addition, a tutor provided feedback to the learners. Afterwards, a total of 60 students of 9th graders (between 14 and 16 years of age) were invited to participate in the simulation game. For the intervention, students were given a mobile device with *ARLearn* installed. We explained to them the aim of the game and gave basic instructions on how to use the device. Then the players were asked to start the game. Immediately the first message appeared and pupils started to play.

For the first study we applied a mainly qualitative approach. We combined participatory observations and conversations with participants while they were engaging in the training activities. Furthermore, activities at the manikin were video recorded to further support first-hand observations. The study involved four researchers and four medical students, whose combined expertise directed the

design and analysis of the mobile simulation game. They took notes of their observations and conversations with participants during and immediately after the activity. The design characteristics identified as vital for the educational intervention were systematically worked into the design.

6.4 Findings from the first study

Analysis of observations collected by the team showed that the actual fact of playing the game with a mobile device motivated children. Generally, they accepted the model of receiving text messages to structure the process of action, but participants did not consistently adhere to this structure. Due to connectivity problems some messages did not load correctly and/or immediately. Characteristically for many institutions, network accessibility was hampered. There was a school WLAN but students were not able to access it with their smartphones, only via private sim-cards. While adults in the prototype testing tolerated any delay, pupils simply skipped the message and carried on with the next message, thus skipping relevant content for the game play. For example, sometimes the alert message audio did not load immediately, but because pupils quickly engaged with the system, they carried on with the next message. As a result they did not know where the victim was located. The most striking aspect of learning design issues regarding the coordination of physical environment, physical objects and digital information surfaced when we analysed the game play activities at the 'scene of the emergency'. Four central themes emerged:

(a) The amount of interactions that needed to be processed and the way information was presented caused high extraneous cognitive load.

The multiple- and single-choice questions that were integrated in the game to diversify the game play and to trigger reflection on the process were not recognized as such. For example the alternative answer "*Looking for a blanket to keep the victim warm*" resulted in them actually looking for a blanket. They took the answer as part of the rescue process. What was unproblematic for adults proved to be impossible for children: i.e. carrying out game tasks while dealing with the manikin. Also, data that documented the game progress of individual players showed that the inquiry tasks, such as taking a photo of a potentially dangerous situation at the scene of the emergency, were easily skipped. Hence, *HeartRun* was not used in the way intended primarily because of the high workload required to complete the task-based interactions.

(b) The switch of attention between different devices and between the digital and physical world increased cognitive workload.

The access to information in the physical world was not synchronized with the digital world. For example, the tasks and information pupils received on their mobile, for example, how to use the AED in case of emergency, was redundant. Following the instructions on the mobile phone, children turned on the AED while listening to what they were required to do next. Turning on the AED, however, started its own audio instructions for use. Additionally, this double input muted conversations between children.

(c) The integration and realization of collaborative knowledge building depended on technical as well as individual decisions of game play.

Coordinating activities at the manikin was a difficult game task and frustrating at times (Fig. 3). Perhaps the most obvious problem was the organization and synchronization of the team players. When arriving at the manikin, pupils needed to scan a QR code tag to pull information and to let the system know that they had arrived at the specific location (scene of emergency). They then received text information on how to proceed. However, the individual message items of both players were not synchronized. Players read the messages at different times and at different speeds. This sometimes led to long waiting times at the manikin for one partner. Players who were standing next to each other deliberately trying to coordinate their actions were not able to do so because one partner was still dealing with previous message items.

(d) The boundaries of technical infrastructures directly interfered with basic design decisions.

Because the children quickly got into the game play, reading the texts was not the most urgent activity to them, despite the fact that the message items contained vital information for the game. The long downloading times (items contained audio and video sequences) led to the fact that pupils did not read the texts comprehensively and easily skipped messages items.

Thus, there were two important aspects of game usability that needed reworking: the notion of *cognitive overload* and the notion of *social interaction*. The initial goal of the design was to support the learning process by integrating game tasks that encouraged students to reflect, and motivating them to collaborate when helping the victim, e.g. when using the AED. However, this proved to hamper learning. In order to achieve better results, we made improvements to the usability of already existing functions. We modified the mobile game application by:

- Adding a full audio dimension to all items,
- Lengthening the interval between the appearance of individual items,
- Considering both partners' activities for the synchronization between players at the manikin,
- Deleting the game tasks at the manikin,
- Reorganizing the synchronization of players and making it less complex.

Regarding the synchronization of team players, we reduced complexity by attuning the series of messages that show to the CPR player to the activities of the AED player. In the new game version the number of messages that show to the CPR player depend on the time, the AED player needs to get the AED and bring it to the scene of emergency. There, the AED player has to scan a QR tag. This tag informs the system and triggers the message item: *The AED has arrived*. The message appears for both the AED player and the CPR player regardless of the helping activity the CPR player is involved with at that time. From then on both players have four minutes to coordinate their action until the final message item appears.

6.5 Second study

The results of the feedback analysis from the first trial were integrated into the design of *HeartRun* and available for the second study, which was conducted in the course of the Reanimatie Estafette at Charlemagne College in Landgraaf on 27 September 2013. The second study involved a total of 53 pupils between 10 and 15 years of age ($AV = 13$ years, $StDev = 1.11$).

None of the pupils had played *HeartRun* before. For the gaming session, we relied on the pupils' own devices in combination with a number of smart phones we brought along. Before playing, we briefly explained the aim of the game and gave basic instructions on how to use it. Then the game was installed on the pupils' devices, or pupils were equipped with a HTC Desire mobile phone.

The main focus of study 2 was the coordination of physical environment, physical objects and digital information at the manikin in response to the analysis of study 1 activities. In order to further specify usability aspects from SUS feedback, we added questions with regard to game-play experience, the self-assessed learning outcomes, attitude towards the use of educational games and asked players for suggestions to improve the game. Activities of pupils while playing were video recorded and transcribed. The transcripts were coded and analysed with qualitative content analysis. This feedback combined with the quantitative analysis enabled us to gain further information on how learners think or feel about the application and were the basis for the subsequent qualitative data collection of study 3.

6.6 Findings from the second study

The analysis of qualitative data indicated that the integration of time-critical physical tasks (running to the victim and interacting with the manikin by providing CPR) was among the strongest motivational factors. This is corroborated by quantitative data analysis as presented in table 3.

[Table 3: Results study 2, agreement of interest in game activities as a percentage of the sample]

Looking for a clearer understanding of what design elements participants valued about the application (fulfilling all the tasks, acting quickly, reading the text messages completely, looking at the videos, saving the victim's life, learning how to provide CPR and learning how to use the AED) and if this depended on whether they did or did not have resuscitation training, an inferential statistical analysis was performed. According to Pearson's chi-square test for independence algorithm, we compared all items pairwise. From table 3 it shows that there was no significant association between the fact that they did or did not have resuscitation training and their interest in game activities, except for item 7 (Learning how to use the AED). Participants who did not have a traditional training before reported significantly more appreciation of the AED interaction in the game $\chi^2(1, 53) = 4.16$, $p = .041$.

When asked to assess what they learnt, children most frequently reported *how to use the AED* (59.62%), *secure the scene of emergency* (46.15%) and *report an emergency* (36.54%). All results with regard to self-assessed learning outcomes are presented in table 4. Pearson's chi-square test was performed to assess the overall relationship between prior resuscitation training and learners' self-assessed learning outcomes. Results indicated no significant association between this criteria and the fact that they did or did not have prior resuscitation training, with the exception of item 1 (*Securing the scene of emergency*), which was significant

$$\chi^2(1, 53) = 4.39, p = .036.$$

[Table 4: Results study 2, self-assessed learning outcomes as a percentage of the sample]

The overall SUS for study 2 revealed a mean SUS score of 52.8 (StDev = 17.20; median 55.0) and a range between 48.09 and 57.57 for 53 valid responses. The internal reliability as measured by Cronbach's alpha is calculated at .747. (For the average values per questionnaire item for the second study see table 7). The decomposed SUS questionnaire revealed a mean score of 55.2 for perceived learnability (StDev = 28.40), and a mean SUS score of 52.2 for perceived usability, (StDev = 18.10). A SUS score of about 55 could be considered a marginal level and on an adjective rating scale could be described as OK (Bangor, et al., 2009). After the activity, children reported that Internet connectivity was often bad and thus the videos did not show, which mainly hampered information access and caused a high degree of distraction and frustration. Still, 35 out of 53 children stated they would like to use such systems in classes more often.

Using independent samples t-tests, table 5 illustrates t-test results of the two participant groups (prior CPR training and no CPR training) for each SUS scale and states the differences between them. From the analysis, no significant differences between the two groups of students showed.

[Table 5. T-test results of the two participant groups from study 2 for each SUS scale.]

6.7 *Third study*

Our third study integrates pupils with learning disabilities to evaluate design and implementation issues of a mobile game for learning that is meant to engage them in using such an educational tool for learning. The SEN learners comprise children with specific speech and/or language difficulties (SSLD) who are unable to express themselves in the normal effortless way, and where the difficulty cannot be attributed to physical or sensory impairments, (Bishop, 1997; Adams, Byers, Brown, & Edwards, 1997, as cited in Davis & Florian, 2004). They often have difficulties in learning to read, write and spell, in processing information and in sequencing and organizing activities.

The sample size of study 3 encompassed 36 learners with special educational needs between the ages of 12 and 18 years (AV = 15.41 years, StDev = 1.50). For study 3 we used quantitative techniques (questionnaire) and additional qualitative data (video recordings and focus groups). Based on the topics identified from the analysis of data from study 2, a semi-structured protocol was developed to guide the author's attention during the video observations and focus groups. The qualitative studies characterized the target group's interaction with the game

simulation in relation to the learning targets. Specifically, the team was interested in how learners perceived and interacted with the physical objects and the integrated learning tasks.

6.8 Findings from the third study

Analysis of diverse interactions showed that for pupils of study 3 the inclusion of physical tasks was motivating and enabled participants to enhance their skills. This is substantiated by quantitative data. When asked in the questionnaire what was particularly important to them when playing the game, most children marked tasks related to physical activity, such as *acting quickly* (80.56%) and *saving the victim's life* (77.78%). Also, 55.56% of the participants stated that *fulfilling all the tasks* was important to them. Game elements such as *looking at the videos* were rated less important for their involvement in the game (25.00%). According to Pearson's chi-square test for independence algorithm there was no statistically significant association between pupils' interest in game activities and the fact that they did or did not have prior resuscitation training for any of the seven items.

Figure 4 compares pupils' interest in game activities between study 2 and study 3 for individual items. Data analysis revealed a statistically relevant difference for the first two items. Pupils from study 3 (SEN learners) stated significantly greater interest in *fulfilling all the tasks* ($\chi^2(1, 89) = 5.76, p = .016$) and *acting quickly* ($\chi^2(1, 89) = 3.91, p = .048$) than pupils from study 2 (regular learners).

[Fig. 4. Comparison results from study 2 and 3, percentage of agreement per condition of interest in game activities]

When asked to self-assess their learning outcomes, participants from study 3 most frequently stated *providing CPR* (59.46%), *how to use the AED* (59.46%) and *checking the victim for a response* (36.54%). Pearson's chi-square test was performed to assess the relationship between prior resuscitation training and learners' self-assessed learning outcomes. Results indicated no significant association between this criteria and the fact that they did or did not have prior resuscitation training.

Table 6 compares pupils' self-assessed learning outcomes between study 2 and study 3 for individual items. It showed that pupils from study 3 (SEN learners) assessed their learning outcomes significantly better than pupils from study 2 (regular learners) for *providing CPR* ($\chi^2(1, 89) = 7.28, p = .007$). Learning how to provide CPR is an activity based on context information and provided on the smartphone at the scene of emergency in order to enrich the physical environment.

[Table 6: Comparison of results study 2 and 3, self-assessed learning outcomes as a percentage of the sample]

The *HeartRun* questionnaire from study 3 revealed a mean score for the overall SUS of 76.3 (StDev = 18.60), and a range between 66.9 and 85.51 for 36 valid responses. The internal reliability as measured by Cronbach's alpha is calculated at .879. According to standardized interpretation, a SUS score above 71.4 could be described as good to excellent (Bangor et al., 2009). For perceived learnability, the questionnaire revealed a mean score of 56.3 (StDev = 32.20). With regard to perceived usability, the feedback revealed a mean score of 81.3 (StDev = 17.80). Table 7 compares the average values per questionnaire item from study 2 and 3.

[Table 7. Comparison overall SUS scores *HeartRun* study 2 and 3]

From the qualitative feedback it showed that participants from both study 2 and study 3 valued the list of message items because it helped them to structure the process and guided them through the course of action. However, for the SEN learners, the organisation of the message items was rather problematic. They had problems connecting individual messages and tasks to the overall process: *"The relationship of the messages was not clear. It was difficult to keep the overview. Maybe better use something else, like a list to check off."*

A recurring theme that emerged from the focus groups and student usage studies was the alignment of the sequence of messages to learner activities, physical environment and physical objects. The transcripts revealed the switch between device, task and physical environment to be demanding, making it difficult to integrate the task-based interactions (audio and photo entry task) that could have enabled participants to enhance their skills.

When asked for the kind of support they would have wished for in order to make the game work better for them, participants from both studies frequently replied in favour of a usage scenario of 1:2 (as in pair work, sharing a device). They argued that this way: *"... they could compare notes. One deals with the device, the other one acts. This way both players could help each other."*

S 1: *The fact that two people can make it together, running and so.*

Researcher: *Two people with one cell phone?*

S 1: *Yes*

S 2: *To discuss what to do next.*

S 1: *Yes, I think so too.*

7 Summary of Results and Discussion

This section discusses and highlights the implications we derived from the analysis of research data. Our findings identify critical characteristics of *HeartRun* as well as strategies required to incorporate these features in the design of mobile game-based learning environments. The claims we make are based on learning contexts, which we influenced and which have individual systemic constraints. Therefore, generalizing our findings needs careful consideration. Barab & Squire (2014) already emphasized that „contexts are never without agency; there are always

teachers, administrators, students, and community members creating context and, therefore, local adaptability must be allowed for in the theory“ (p. 11). Still, our research allows to deduce design implications for mobile games for learning with a particular focus on design principles for *seamless learning activities*, such as learning activities based on mobile and ubiquitous technology that encompass physical and digital worlds, switching between multiple learning tasks, and ubiquitous knowledge access. To reflect these issues, we organized the discussion according to the three main design characteristics that emerged from the studies and related them to the framework provided by Wong & Looi (2011).

7.1 Accessing knowledge

Our studies illustrated how mobile learning games can support students while engaged in an ongoing task in a physical environment. The most supportive function was typically evident in situations of uncertainty, for example, *the usage of an AED*. In such instances, students resorted to information provided on the mobile device and the switch between physical environment, device and game activity was unobtrusive. Hence, one of the main benefits of using the mobile devices was to allow context information to constantly accompany and guide pupils, supporting their understanding and learning of the intended process or structure (i.e. helping in case of emergency).

A striking aspect of learning design issues surfaced when we analysed the activities at the ‘scene of emergency’. In a first game version, the digital device did not immediately provide participants with the necessary *context information*, which is needed in situations new to them. Context information supports learning on various levels by using environmental indicators of peripheral information or direct guidance, for example, (Specht, 2009) and has potential to increase the motivational appeal of educational game contents (Schmitz, Klemke, & Specht, 2013). The *seamless adaptation* of technology to the learner and the learning context in terms of language, level of difficulty or assistance is a core feature of seamless learning (Milrad, Wong, Sharples, Hwang, Looi, & Ogata, 2013). In their review on pervasive games for learning, Schmitz et al. (2013) describe how mobile games for learning use context information to enrich their contents with contextual metadata such as *activity context*, for example, by asking learners to work on various tasks at significant places thus providing an interesting and moving way for accessing knowledge. This, however, implies the careful consideration and coordination of the possible seams between physical environment, physical objects and digital information. Mobile seamless learning designs that are directed at enabling interactions with reality and sensemaking activities need to consider this. *HeartRun* integrates aspects of this by pupils scanning a QR code tag and this way pulling context information. Their need to reflect on this information by talking to each other and their need to coordinate their action in order to help the victim was first hampered by badly synchronized information items. The download of media items on the device was one possible pathway and resulted in the delivery of relevant content at appropriate locations and times despite the lack of network coverage. Rogers et al. (2010) emphasise that in order to understand “whether a sensemaking conversation is triggered during an ongoing task and what is covered during it, depends on a number of factors, such as how unusual an observation is, how often it has been seen before, etc.” (p. 122). If it is not possible for learners to make sense of new information they may eventually ignore the information as

incomprehensible “noise” (Wong & Looi, 2011). This also applies to redundant information, i.e. information from objects in the physical world and digital sources of information focusing on the same task. Mobile game designs for learning need to consider the prime sources of information and synchronise or complement them.

With regard to the aspect of learning it showed that besides enabling a direct access to knowledge via context information, for example, mobile games for learning might also enhance the actual learning environment. Our studies showed that the use of digital devices may foster social interaction and that students were trying to find suitable forms of cooperation while using them. Research in the past decades has emphasised that learning is inherently a social activity (Vygotsky, 1978). The potential of mobile learning scenarios to effectively promote social interaction, thus facilitating collaborative knowledge building is frequently emphasised by research in the field (Milrad et al. 2013; Patten, Arnedillo Sánchez, & Tangney, 2006; Sharples, Arnedillo-Sánchez, Milrad, & Vavoula, 2009; So et al., 2009, Toh, So, Seow, Chen, & Looi 2013). All the more, this is relevant in our context (helping in case of emergency). Seamless learning activities that involve communication and collaborative sensemaking can have a share in preparing students for taking initiative and informed decisions (Milrad et al. 2013), for example, and is likely to support time-critical action and cooperation between first responders with different backgrounds (Paul, Reddy, & deFlitch, 2008). However, a further assessment of the quality of social interactions is necessary.

7.2 Integrating learning tasks

Mobile games for learning have potential to involve children in different tasks of learning such as content generation, collaboration, problem solving or navigation in space and may thus supporting a wide variety of cognitive and social skills (Spikol & Milrad, 2008). Also, Wong & Looi (2011) in their review on mobile-assisted seamless learning argue in favour of integrating a variety of inquiry tasks into the mobile-assisted seamless learning flows in order to nurture 21st century skills and competencies. From a learning perspective, the integration of learning tasks is desirable, for this supports learning by facilitating reflection and thus securing knowledge. However, from the design studies it surfaced that the switch between device, task and physical environment was demanding and the task-based interactions (multiple- and single-choice questions, audio and photo entry tasks) that were integrated in order to diversify game-play and to trigger reflection on the process, which could have enabled participants to enhance their skills, were not recognized as such and easily skipped. Thus, we argue that the integration of learning tasks as a main characteristic of games for learning needs the careful consideration of previous action, context and target group. However, this dimension of mobile game-based learning environments, the seamless switch between different learning tasks, is relatively unexplored (Wong & Looi, 2011) More empirical research is needed in order to provide constructive environments that promote the active sensemaking nature of learning when coping with new situations and problems (Weick, 1995).

7.3 Switching between physical and digital activities

Switching between physical and digital worlds is inherent to learning with mobile technology. It usually comprises a wide range of diverse media such as text, audio, and graphics on the mobile device and includes physical objects in the real world.

This rich offer of diverse material can easily exceed learners' cognitive capacity. The study conducted by Liu, Lin, Tsai & Paas (2012) corroborates this. It showed that similar learning information provided on the mobile device and in the physical world (text, picture and physical object), resulted in a redundancy effect that affected learning negatively. Results from our study imply comparable effects with regard to using the AED, for example. In order to enable learners to control cognitive load and to organize and integrate the material to be learned, a coherent phasing of the interrelating objects, tasks and activities is required that avoids presenting identical streams of information.

Besides, the switch between physical and digital worlds frequently involves physical activity. Results from the present study showed that the inclusion of physical activity tasks was engaging and enabled participants to enhance their skills, which is consistent with findings from previous research on engagement and learning. Blum et al. (2012), for example report research wherein the initial task immediately put players into action and created a physical and emotional peak, which involved players in the simulation game. However, coordinating tasks such as receiving directions on the device while running through the physical environment needs careful consideration. In this context, audio emerged as a core design aspect. Setting up the task with audio instructions that direct players through the environment avoids an unnecessary switch of visual focus (looking at the device to read subsequent instructions while players are already running to get to the scene of emergency), which is also a safety issue. This especially is true for children between 11 and 14 years, who quickly became immersed in the game and acted as if they were in a real emergency situation.

8 Conclusions

This research reported a mobile game application where children play an active role in the simulation of a dynamic process. We provided a summary of related work including an overview of mobile games for health, with a particular focus on games that teach BLS and CPR and outlined the underlying game concept for our design-based research approach. Subsequently we described the iterative design process and deduced design implications for the development of mobile game applications for school children. In the process described above, the DBR approach was demonstrated to be valid, useful and informative in an educational context, which is verified by connatural recent research (Palalas & Anderson, 2013; Annetta, Frazier, Folta, Holmes, Lamb, & Cheng, 2013). Likewise, this human-centric design practice offers new dimensions and opportunities to promote novel ways of learning for schools (Spikol & Milrad, 2008) and the alignment of learning interventions to the individual needs of learners (McCombs, 2000, Collins et al., 2004). Even though scientists have increasingly started to consider how technology can support the diverse needs and capacities of learners, there still is a surprising lack of systematic evaluations that investigate the benefits of the 'new' communication technologies for SEN learners with more complex and severe communication and language needs (Davis & Florian, 2004; Williams & Nicholas, 2006).

The design implications we derived from our research indicate that mobile game-based learning environments can productively support seamless learning activities

for children. Though the approach to seamless learning design is often difficult to achieve, it is worthwhile and in the context of our research unveiled valuable results that can help us to bridge the gap between learning in physical and digital worlds.

So far, we have not investigated the differences in school children's knowledge gains or their attitudes towards *HeartRun* versus a more traditional seminar-based learning format. This will be part of future studies. We are currently conducting a large-scale study to evaluate the influence of *HeartRun* on behavioural intention. This research extends the Theory of Planned Behaviour by introducing variables of empathy, competence and role-playing to TPB in order to predict helping behaviour. First research approaches in the field indicate that the theory of planned behaviour (TPB), introduced by Ajzen (1991), should be capable of explaining bystander's motivations with regard to CPR training and performance. To explain the constructs of the model and the related hypothesis will be part of a subsequent article, which will report the experimental settings and results.

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