IF ONLY...
Designing Novel Games for Collaborative Learning with Smartphones and Sensors

Cliff Randell
University of Bristol, Woodland Road, Bristol, U.K.

Ben Clayton
Calvium Ltd., Pervasive Media Studio, Anchor Square, Bristol, U.K.

Tarim
Media Playgrounds, Pervasive Media Studio, Anchor Square, Bristol, U.K.

Tom Bennett
Interactive Places, Pervasive Media Studio, Anchor Square, Bristol, U.K.

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Abstract: In this project we describe research into playful learning experiences featuring smartphones and external sensors. We built and tested a number of games which can be played using environments populated with sensors and/or actuators interfaced wirelessly with smartphones. An overall story interlinking the games was developed based on the need for action to tackle climate change. Trials with teenage schoolchildren revealed approaches which both appeal to players and have the potential to educate.

1 INTRODUCTION

Learning as you play has been recognised as a valid technique, particularly for children, for many years. It is well researched and documented (Piaget, 2002; Papert, 1993). The brain loves to learn patterns as they enable us to be efficient and thereby survive. Once a pattern has been seen in something, and has been understood, we can move on to the next challenge. When presented with something new, we automatically try to see already recognised patterns in it so that we can create a new chunk, and move on. This ability to chunk and reuse knowledge provides a mechanism for transferring experience learnt from playing games to real life.

Games are abstracted versions of the world, and are therefore ‘safe’. There may be risk/jeopardy within a game but it has no impact on the ‘real’ world and trial and error can be used to learn the patterns of play. In formal learning being good at games is not considered as important as being good at reading, writing and mathematics, and yet the brain is performing exactly the same routine. A good game is one that has the right balance of challenge and achievement. Too difficult and players give up. Too easy and players get bored. Get it right, and the brain goes into ‘flow’ mode releasing endorphins and making the learning experience pleasurable (Csikszentmihalyi, 1975).

With the advent of modern mobile computer technology forms of play are changing rapidly to include interaction with virtual scenarios using smartphones. These can provide alternate worlds or act as mediators with the real world. Consequently expectations of ‘play’ are changing. In this project we use two different approaches to explore the appeal of a number of futuristic playful learning games using smartphones.

The use of handheld computers for educational purposes outside of the classroom has already taken many forms. For example, in the Ambient Wood project an outdoors learning experience for schoolchildren was created in a Sussex woodland

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aimed at encouraging students to carry out contextualized scientific enquiry and to reflect on their interactions (Rogers et al., 2005); and in the Savannah project players experience and learn collaboratively about a virtual savannah that appears to be overlaid on a grassy field (Benford et al., 2004). The introduction of competitive gaming has also been shown to have educational benefits (Di Blas et al., 2010). In our project we are interested in creating interlinked, interactive scenarios which provide schoolchildren with challenges which are both enjoyable and educational. We use smartphones and external sensors to provide a cohesive environment in which a storyline can be developed. The smartphones are an integral part of each of the scenarios.

The underlying objective is to create cross-platform, smartphone learning game applications which will work with a number of sensors. This approach enabled us to demonstrate and streamline the production process and skills required in creating a novel product and experience, crossing film, game and online experiences with physical interaction with real objects. The project shows how sensor technology can be integrated with existing smartphone technology to create new, exciting and dynamic learning experiences.

This paper describes two approaches using climate change to provide the underlying scenario. The players are presented with a series of challenges which if completed successfully will give them the arguments necessary to change the development strategy of a power generation company, headed by ‘Brandon Riches’. The players are guided by a girl from the future, ‘Gaia’. The first approach is described in section 2 where fact finding challenges are completed by using iPhones. In the second approach, described in section 3, the challenges are more physical with additional gameplay. Section 4 gives a technical overview and we conclude in section 5.

2 FACT FINDING GAMES

The first iteration of the project was intended to raise awareness of climate change issues by providing simple games in which iPhones gather relevant facts using data triggers. Before any application building was started a workshop was held with a group of 12 to 14 year olds in order to test the game concepts. We wanted to be sure that the concepts of the story and the games were appealing to the target audience.

Using feedback from the workshop we designed a set of climate change related games linked together using the storyline which involved Gaia reporting from a climate devastated future using a time-shifted video link. The overall object was to collect facts to change the investment strategy of Brandon Riches, our power magnate. The games were introduced by Gaia. Each game followed the same procedure: enter game region; receive video call; find source of game instructions (video tells you how); listen to/watch instructions; complete game; receive score and store information gained; and finally move onto the next region. The games were intended to be played indoors or outdoors using a mixture of WiFi and GPRS to provide connectivity to a central server.

Six themes were chosen and different sensing technologies were associated with each one.

- **Transport** - To complete the game the player had to cycle a fixed distance on an exercise bike. The game was started by ringing the bicycle bell.
- **Clothes** - The players identified sustainably produced items from a range of clothes on display using a sonar-like system. The iPhone emitted a pulsed audio tone which was received by hidden microphones in the relevant clothes. A shop bell was used to initiate the game.
- **Deforestation** - By showing the iPhone display to a tree fitted with a webcam/light sensor, information is revealed on the iPhone when the display is recognised.
- **Travel** - In response to correctly answered multiple choice questions on the iPhone, UV painted signs are illuminated by UV lights.
- **Energy** - Strategically placed QR codes are associated with different energy sources. The iPhone reads the codes, causing a call to be made to the iPhone in which the information is given as a verbal message.
- **Food** - In a similar design to the Energy game, bar codes on food products are read by the iPhone.

The games were followed by a video sequence in which Brandon Riches explained the affect of the gathered information on his thinking.

A group of sixteen 14 year olds from a local school were invited to carry out a trial of the game. They participated in pairs, each pair using a single iPhone or iPod touch. This was intended to encourage collaboration. It was clear that the games with multiple components were the most popular, and any repetition of task spoiled the enjoyment of doing something new; the patterns were easily learnt. The Transport and the Energy games were enjoyed more than any others. The fact that these were both the most enjoyable and very different from one another caused us to reconsider some of the other sensors we intended using. Often in games, players like the opportunity to skill-up through repetition, but this age group appeared to relish the new challenges that each game brought. This may have been a desire to grasp and complete each new concept as quickly as possible.

In the feedback session the children reported that the aspects they liked best were the active/physical games; the searching for QR codes and items of clothing; ease of use; continual feedback; games that worked and watching each other playing the games. Technical problems which had a negative impact on their experience included using headphones (especially splitters for dual use); having to change handsets (as we had a mix of iPhones and iPod touches); and games/sensors apparently not working. They also found the games too easy. Useful points were also made on feedback sheets: “may be better for a younger audience”, “this age prefer guns and adventure”, “a platform game that requires skill to progress would be better”, “avoid anything educational as it’s too preachy and we’ve heard it all before”!

Enjoyment was possibly impaired by issues of interconnecting devices using WiFi, GPRS etc, as some of them were almost certainly dropping connections as they left/entered the building. Also the fact that videos seemed to stop when headphones were removed was an issue. Some of the players didn’t realise that the real bell had to be rung in the ‘shop’, and at times it would have been better to have audio instructions as well as text, with the ‘continue’ button only appearing on the screen when the audio finishes, so that it would not be possible to skip forward without hearing important instructions. Coupled with this would be more ‘back’ buttons, and the option to quit if the game is taking too long.

On the basis of the feedback we decided on a radical re-think of the project. If we wished to retain the prime emphasis of the story promoting the need to tackle climate change then we would need to switch to a younger audience. Alternatively we could make major changes, for instance switching game and story in importance so that the games become the focus, not the story and theatrical elements. Either way we needed to improve the reliability of the experience.

3 ‘FUN’ GAMES

3.1 Redesign

We therefore decided to make some major changes with the emphasis on games which provided a greater challenge to the player with secondary educational benefits, and also to introduce an element of fun. The story became the means to connect the games. We decided to stay with the mid-teens age group bearing in mind the difficulty of producing something that would be enjoyed by a wider age group. So we worked on games which were ‘fun’, incorporating the iPhone with external sensors, and then tried to weave the games into the climate change story. To improve reliability we chose to use WiFi for as many games as possible, to abandon the use of headphones, and to restrict the overall game area to a number of indoor rooms with space made available for a small audience to view each game as it was being played. We could then concentrate on improving the games.

The games that were developed were intended to be collaborative with ideally two players, and also be entertaining to watch. Each game would provide solutions to parts of an overall puzzle with top scorers winning prizes. The games could be played more than once if desirable. The structure previously developed of a video introduction to each game, and an initiating event were retained. Game instructions were also shown on-screen to assist the players and a menu used to select each game (see Figure 1).

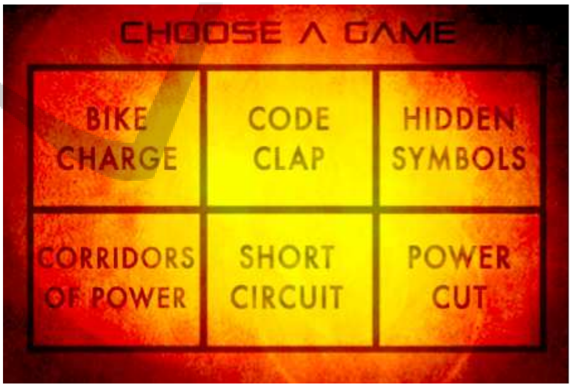

Figure 1: iPhone Menu.

After a brainstorming session, the following games were developed and tested with colleagues:

- **Bike Charge.** An extension of the bicycle game described in Section 2 with improved feedback on the iPhone. As before ringing the bicycle bell initiated the game. One player then had to cycle to three (virtual) checkpoints over set distances, with each becoming harder. Reaching each checkpoint earnt the player points and started virtual wind turbines shown on the iPhone. The second player used the iPhone to report progress, and encourage the first. A ‘pause’ button enabled the players to swap roles.
- **Code Clap.** A grid of nine squares was laid out on the floor, with key numbers in them to align the grid with a numbered diagram on the iPhone screen. A single handclap initiated the game. One

player held the iPhone and observed the squares lighting up in sequence on the display and the other player had to move to the associated square on the floor and perform a handclap. The game sped up until the code had been completed.

- **Hidden Symbols.** This game was played in a dark room, and was initiated by opening the door. Three correctly answered multiple choice questions on the iPhone reveal three hidden painted symbols on the walls by turning on UV lights. These symbols then have to be recognised from a list of symbols on the iPhone.
- **Corridors of Power.** A novel interface was designed using two proximity sensors. Movement of the players hands - left, right or both - were sensed to enable the player to navigate through a 3D maze. The maze depicted corridors in a power station where 'power rings' could be collected. The other player viewed a 2D blueprint version of the maze displayed on the iPhone and was able to give directions to the next ring. A game being played is shown in Figure 2. Crossing a start line initiated the game, and players had to collect six rings and then exit the maze.
- **Short Circuit.** In this game, the iPhone was used to control three motors which move indicator flags on a display panel. The motors run at different speeds and with some latency. The player was required to line up the flags. This is a speed/skill test with the accelerometers in the iphone being used to activate the motors when the iphone was tilted.
- **Power Cut.** Again using actuators, this game intended to use mirrors mounted on servomotors controlled by the iPhone. These would to direct a laser beam around a room onto a light sensor.

Completion of each game gave the players part of the solution to an overall puzzle. Initial feedback from colleagues was positive with the comparison being made with a fairground experience combining different attractions into a cohesive experience. The use of the iPhone as a gateway to, and not as the focus of, the experience was also recognised as a welcome feature.

3.2 Testing

For our final testing, we invited the previous group of school pupils to return. The six games were presented in an interface shown after an introductory video from Gaia. The players could choose which one to do from this menu as shown in Figure 1. The games all followed a similar pattern, with instructions on where to go and what to do when there to get instructions, both on video and onscreen as text.

Figure 2: Playing in the Corridors of Power.

The final game Power Cut was not completed as there was not the time to overcome the accuracy problems, although it would have been relatively simple to include as it used the same software as Short Circuit. This was largely due to the fact that Short Circuit presented many mechanical issues to the extent that it was still not working reliably enough when the pupils arrived. Disappointingly, then, we only tried out four of the games on the pupils. They all worked as intended, although some did throw up other issues.

The games were well received by the 16 participants (10 boys, 6 girls, age 14-15) and both verbal and written feedback was collected. The favourite games were Corridors of Power (8 votes); Code Clap (4 votes) and Hidden Symbols (3 votes). The boys particularly liked the Corridors of Power, and the girls particularly disliked Bike Charge.

A series of questions were asked as part of a short questionnaire given to the participants after the test session. For each question the player had to provide a rating on a graphic scale, i.e. make a mark on a 10cm line reflecting their agreement from 0 (not at all) to 10 (very much). From these marked scales we learnt that:

- all the players found the instructions easy to follow;
- nearly all enjoyed the experience very much;
- three found it too easy, but still enjoyed it very much;
- they all enjoyed the Corridors of Power;
- the girls liked the Code Clap and Hidden Symbols, but only a couple liked Bike Charge. Three really didn't like the Bike game at all;
- the boys tended to be more neutral, with the Bike Game getting more scores towards the top of the scale. One boy didn't like Code Clap, and one boy really didn't like the Hidden Symbols game.

We also enquired which age range they thought would be appropriate for this experience. Three said 10-12, and five more had the lowest age as 10, but apart from the three, all had mid-teens as their range (with some going higher).

In discussion they commented that overall it was much better than the previous time, though one player did enjoy playing the games outside during the previous tests. They thought that the games were "futuristic", "more modern than most games", "unique", "more active than most games" and simply "fun". Further exploration revealed that they thought that it was better because the games were interlinked and made sense within the story. They all agreed it was challenging and fun both to watch and to do.

4 TECHNICAL OVERVIEW

4.1 Architecture

The If Only game used a central Notification Server to keep track of which iPhones are interested in which events. A Variable Database was also provided on the server to store the current state of the system. An Event Client ran on each of the iPhones updating the User Interface when events were triggered remotely by sensors; and also sending events to the Notification Server to operate actuators. Communication was enabled by using HTTP over WiFi or GPRS to/from the server. These modules are described in more detail below:

Variable Database. For each possible event in the game, a named variable was created and stored in this database. The current value of the variable and the time the variable was last modified were stored. Updates to the value of the relevant variable were made using an HTTP request containing the variable name and value to the server.

Event Client and Notification Server. The Event Client runs on the iPhone and is used to allow the user interface to be updated when the value of particular variables change in the database. For instance, when the Bike Charge game is started, the iPhone sends a message (using HTTP) to the Notification Server asking to be notified when the 'bikeBell' variable is changed. When this change happens, the iPhone plays a sound and switches the user interface to the 'start pedalling' game screen. This was achieved by using long polling where the server will deliberately not return a response until an event of some kind has happened. This technique means that the iPhone is able to respond to changes usually in less than 200ms over WiFi.

Actuation System. The actuation system was used to cause an action in the real world as a result of performing an action on the device screen, such as answering a question or pressing a button. The iPhone software itself would make an HTTP request to the Actuation Server with the name of the device to actuate, and the desired value.

4.2 Sensors and Actuators

A diverse collection of sensors and actuators were employed using bespoke PIC and Arduino microcontroller boards to interface with wireless internet capable devices (Microchip, 2010; Arduino, 2010). The data was sent to the server either via an Arduino and GPRS internet connection, or via a Macbook using WiFi. The devices included:

- **Transport/Bike Charge.** A magnet mounted on the bicycle wheel operated a reed switch on the frame to sense the rotation of the wheel and hence determine the distance travelled. The bicycle bell was fitted with a microswitch. Both switches were connected to an Arduino with a GPRS shield.
- **Sonar.** The iPhone generated a high-pitched beeping sound which was picked up by the hidden wireless microphones. The signal was amplified, filtered and sampled to determine the proximity of the iPhone to the microphone. The shop bell was fitted with a vibration sensor. The sensors were connected to an Arduino.
- **Deforestation.** A simple light detector at the end of a long tube was used, again connected to an Arduino.
- **Travel/Hidden Symbols.** A commercial mains remote control was adapted and received control signals from an Arduino. The Remote control switched three UV fluorescent lamps on and off. The door to the room was fitted with a microswitch.
- **Energy and Food.** The built in iPhone camera was used to read the QR and bar codes.
- **Code Clap.** Four 25kHz ultrasonic sensors were arranged in a square on the ceiling of the playing area. By measuring the arrival times of the handclaps at the sensors, an estimate of the position of the claps was obtained using a PIC and MacBook.
- **Corridors of Power.** The two handed proximity detector was built using commercial Theremin modules (IEEE, 2008; Doepfer, 2010) and a PIC adaptor. These were connected to a MacBook which rendered the maze and provided sound effects. The MacBook connected to the server using WiFi, sending the current position and orientation of the player.
- **Short Circuit and Power Cut.** DC motors and servos were controlled by an Arduino.

Apart from the UV lights, all the sensors and actuators were battery powered. Observations on the technical performance of the architecture, sensors and actuators are included in the next section.

5 CONCLUSIONS AND FUTURE WORK

The If Only ... project has tested two very different approaches to playful learning using smartphones and sensors. In the first the emphasis was placed on learning about climate change through gathering facts and considering their implications. Sensors were used as triggering devices to reveal pertinent information. The second approach was to concentrate on producing 'fun' games with a greater emphasis on challenge with the learning process being incidental. In this case sensors and actuators were used as integral parts of interactive games. This approach clearly had many benefits and was enjoyed more by the test group, with enthusiasm shown to return to the games. Taking the focus of the games away from the smartphone and using it as a gateway to a larger experience worked well. Important facets of active learning were demonstrated with the collaborative aspect generating discussion and deepening learning, and the physical aspect aiding memory by engaging the players. The latter being especially important to kinesthetic learners.

Overall the project was successful and much was learnt about producing games using the iPhone with external sensors. The subject choice was too well known, as observed by the schoolchildren, to warrant any testing of knowledge retention. We would wish to choose a different topic for a future version in order to be able to carry out appropriate tests. Using sensors as data triggers was not considered sufficiently novel by the players who relished entirely new forms of interaction. A future version would also attempt to increase the learning element while retaining the 'fun' aspects of the games. There would also be a greater element of jeopardy introduced such as a (virtual) security guard constantly pursuing the players. Apart from the Hidden Symbols, the games were set up in empty rooms and would have benefited from more attention to the environment to increase the sense of immersion. The latency associated with GPRS meant that it had to be used with care, and games requiring fast interaction needed to use WiFi. The software architecture performed well for the limited experience which was offered, however it would not scale well to very large numbers of players and games.

The approach of focusing on the games and sensors rather than the story has provided a framework which has the potential to underpin a range of future possibilities providing a good mix of familiarity and surprise in a learning environment.

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