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Wearable Learning Technologies for Math on SmartWatches: a feasibility study

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Abstract: A theory of cognition called embodied cognition believes that the development of thinking skills is distributed among mind, senses and the environment. Research into this field has resulted into the development of applications in different areas including Mathematics. This paper reports one part of a larger series of studies on the design and implementation of embodied cognition of Mathematics educational systems. We describe the migration and evaluation of a game called "Estimate It", a wearables-based game for teaching measurement estimation and geometry. Experts were invited to evaluate the game, for which a generally positive rating was acquired. The game's collaborative nature, its hands-on way of teaching estimation, and the incorporation of technology were seen as promising points. Infrastructure readiness, classroom control and adjustment to the new technology were areas of concern.

Keywords: Embodied Cognition, Wearable Learning, Ubiquitous Learning, Mobile Devices

1. Introduction

Cognition has traditionally been viewed from a narrow perspective where the body has mostly a sensory and motor function, subordinate to central cognitive processing. In recent years, though, cognition has taken on a broader perspective in which it is believed to be distributed among mind, senses, motor capabilities, and social interactions (Wilson and Foglia, 2011). This theory of cognition, called embodied cognition, assumes that sensory perceptions, motor functions, and sociocultural contexts shape the structure and development of thinking skills including mathematical abilities and higher-ordered abstract reasoning, as well as sense-making in general (Hornecker & Buur, 2006; Redish & Kuo, 2015).

In this paper, we report part of a larger study about the design and implementation of embodied cognition of mathematics educational systems. We describe Estimate it!, a wearables-based game for teaching size estimation. We then summarize the results of an expert review of the application. We attempt to answer the following questions:

1. In what ways is this method of teaching estimation superior (or inferior) to traditional ones?
2. What student characteristics (intellectual, social, cultural) might make the application suitable (or not suitable) for teaching estimation?

2. Prior Work

The work described in this paper is the continuation of work described in Arroyo (Cyberlearning watch) (Arroyo, 2016). The Cyberlearning Watch is a device that students wear on their wrist to receive clues that help them search for geometric pieces that may be hidden. As they complete the tasks, they receive correctness feedback via the watch's display, buzzers, or lights, making the student's experience immersive and interesting.

We migrated the Arduino-based framework to an Android-based and Tizen-based system. To demonstrate the system's functionality, we specifically migrated the game Estimate It! (Rountree, 2015) and asked a group of grade school mathematics teachers to evaluate it. In Estimate It!, students receive clues such as "Find a rectangle 2' wide by 14' long and have to traverse a physical space searching for objects, being provided with specific measurement tools such as a 12" dowel without markings which encourages rounding, and either partitioning or subsequent placing of the stick to measure larger objects (Rountree, 2015) . The participants are given 20 minutes to find as many objects as possible using the clues given, and can work in teams, with watches semi-synchronized to each other.

3. Migration

Migration entailed (1) Migrating 'Estimate It!" to a locally-connecting AndroidOS mobile application and (2) migrating "Estimate It!" to a locally-connecting TizenOS watch application. Both applications were deployed to Heroku for testing and evaluation

3.1 Migration to Android OS

"Estimate It!" had to be loaded to an Android webview where a Javascript interface was created to be responsible for communicating with native Android functions (NFC). The Rails server code was refactored to handle this new communication.

The client devices loaded the website to a special <webview> tag and a URI object parses a specified URL into an Android Intent. Figure 1 shows how the 'Estimate It!' game, the WebView and the Android native kernel relate with one another.

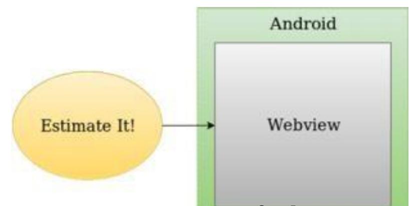

Figure 1. Deploying "Estimate It!" to the Android Webview

It was necessary to create a bridge between the webview and native Android because they are private from each other by default. Javascript was used to ensure that the communication with the web-based Rails code would not be compromised (Android Developers Hub, 2016). The same javascript bridge was used to give "Estimate it!" the facility to scan NFC tags.

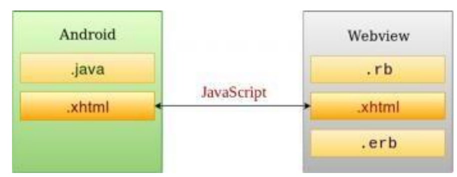

Figure 2. Using JavaScript as a bridge between Android native and WebView.

For the server to understand the changes in how the client sends data, a global keyword was introduced that stores messages as objects the server could unpack. This keyword also allows for two-way binding (sending data back to native android). The Android Developers Hub calls this migration style a "Hybrid App" (Android Developers Hub, 2016).

3.2 Migrating to Wearable (Tizen OS)

For the wearables part, "Estimate It!" was migrated to a Samsung Gear S2 watch running on Tizen OS. Migrating a rails app like *Estimate IT!* required help from an open-source webkit github.com/WebKit/ (figure 3 right) primarily because HTTP requests cannot be parsed by the native lightweight Tizen browser for watch (figure 3 left). With this, a non-NFC version of *Estimate IT!* can now be played in the Samsung Gear S2 and similar versioned tizen watches.

Figure 3. Samsung Gear S2 response when testing if native browser has XMLHttpRequest support using standard testing code provided in Tizen developers' website (left)."Estimate It!" running on Samsung Gear S2 using Open-Source Webkit browser (right)

The application was coded in a way that forces open webkit to be used everytime the app gets launched. Corresponding code was added to make sure the default browser gets activated back when the app exits.

4. Expert Evaluation

The goal of the expert evaluation was to obtain feedback from grade school mathematics teachers regarding the feasibility of use and implementation of *Estimate It!* in the classroom. More specifically, we are trying to answer the research questions posed at the end of section 1.

4.1 Participants

A total of fourteen (14) Mathematics teachers from Ateneo de Manila University participated in the evaluation, eight females and six males. Eleven (11) of them have handled grade school, one handled secondary school while the other two are college instructors. They were of varying ages ranging 23-64 year olds. Teaching experience was also diverse, with the youngest having taught for 1 year, and the longest teaching experience at 27 years.

4.2 Methods

The evaluation took place in a classroom equipped with wireless network connection. The server, a laptop running on Linux that ran the web server software, was set up in a designated area. The geometric pieces were everyday objects (e.g. a book - rectangular prism, ball - sphere) depicting the objects to be sought for, described by the clues given by the application. These objects, tagged both with NFC tags and sequences of color codes (Figure 4), were scattered around the room. Two Samsung Galaxy S5 smartphones and a Samsung Gear S2 SmartWatch were used during the evaluation. These were pre-installed with the game and were made to connect to the wireless network.

The experiment team consisted of a facilitator and a test monitor. Upon welcoming the participants, the facilitator described what the game is, how it works, and how it may be implemented in their classes. The evaluation goals and method were explained. The teachers were asked to fill out a demographics questionnaire and after the testing, a debriefing questionnaire.

Figure 4. Geometric objects used in the evaluation of 'Estimate It' (left). Color codes and NFC tags attached to geometric objects (right).

As the game commences, the participants awaited clues in their devices and moved around the room to find the objects described. The facilitator and test monitor followed them throughout the game explaining how it is proceeding and answering questions, should there have been any.

4.3 The Debriefing Questionnaire

The debriefing questionnaire used a 5-point scale, with possible responses going from "Strongly Disagree" (1) to "Strongly Agree" (5). Questions were derived from the criteria described by Whitton (2009) for effective educational design of game-based learning applications. Items relevant to the purpose of the experiment were re-constructed into questions. There were 18 questions in total classified into (a) Active Learning Support, (b) Engenders Engagement, (c) Appropriateness, and (d) Classroom Use. Groups a and b each had 5 questions; groups c and d each had 4.

Follow-up questions asking about what aspects the evaluators liked the most/least about the game, as well as their insights on its advantages/disadvantages over current teaching methods were also included.

4.4 Findings

In general, the experts gave highly positive evaluations of the game. The aggregated frequencies of each question are summarized in Figure 5. The dispersion of responses is average to little variance except for Question 5 (Q5: Game levels are appropriate and challenging.) in "Engenders Engagement" in which one of the evaluators strongly disagreed with the statement that the game levels are appropriate and challenging.

The results also show an important neutrality in Question 3 (Q3: I think I would use this game in my classes.) for "Classroom Use", which is on their inclination to use the game in their classes. After digging into their comments, we found this may be due to the perceived difficulty in organizing the game for a big class, as well as the extra time needed to set it up. Someone specifically raised a concern about grade school boys needing lengthier orientations on the activity and the interface.

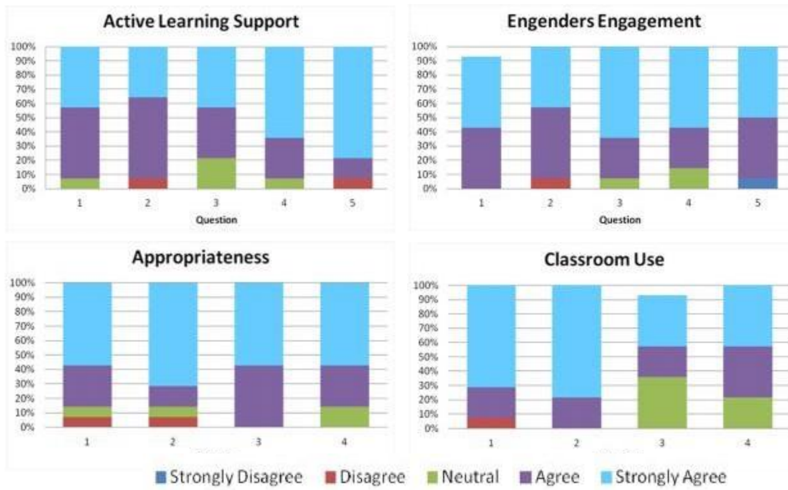

Figure 5. A graph presenting the aggregate percentages of responses from the evaluators

The evaluators found the game goals clear and achievable (Q1-Engenders Engagement: Goals of the game are clear and achievable.). All agreed that a game-based approach is applicable for teaching estimation (Q3-Appropriateness: A game-based approach is applicable for teaching mathematics, specifically estimation.). Pointing out that the generation at present is very much into interactive technologies, the teachers concur that the kids will find the game fun (Q2-Classroom Use: I think my students will find this game fun.).

4.4.1 Most/Least Likeable Aspects of the Game

The evaluators liked the idea of allowing students to collaborate and the opportunity provided for interaction with classmates and the environment. The method provides a more concrete and pictorial way of presenting the concept of estimation. The use of common, ordinary everyday items came out as a strong point because of their accessibility. Furthermore, the interaction with the surroundings appeared to be a promising aid in allowing the students to physically associate measurements in everyday things.

Conversely, its high dependence on technology was a concern. The need for a stable Internet connection and the presumption that students are familiar with SmartPhones and SmartWatches led to the speculation that it might be feasible for private schools, but not with public schools in the Philippines. Setting up was also a concern, which was seen as a potential for technology getting in the way rather than being of aid. Another point of concern is how it would scale for a class of 40 students, the typical size of their classes. Improvements to the user interface were also suggested. They noted the instructions are too wordy for a small screen in the watch. Lastly, there was a recommendation to review certain unclear terminologies (e.g. a sphere which is x inches wide) in the instructions. Mathematical terms (such as circumference to refer to a sphere's "width") may be more appropriately used to avoid confusion.

4.4.2 Advantages/Disadvantages Over Current Teaching Methods

According to the evaluators, the use of technology will be attractive to students. Hence, they assume that the Estimate IT! game would be a motivator in the classroom. The interactive nature of *the gane* makes it fun and exciting than the usual classroom lecture. The collaboration it stimulates by allowing students to work in teams to achieve a goal was seen as a plus. It was mentioned that it would help the audience, being that they are kids, see and appreciate Math. The dynamicity of the game was highlighted, since it gets the kids to “get their hands dirty” as opposed to just sitting down throughout discussions.

The logistics and technological requirements, however, were gray areas. Connectivity, being a key factor in the intervention, may hinder implementation since schools may not be ready for it infrastructure-wise. On top of that, the need to provide smartphones and/or smartwatches may be an issue affecting feasibility. The setting up may be time consuming and tedious to teachers. Also, some were concerned that, since the users are children, their behavior could/might not be easily controlled, compared to traditional instruction. Lastly, there was concern that the gadgets may possibly avert the attention of the student from learning the concept to just playing with the device.

Figure 6: Math teacher being assisted by the facilitator in scanning Geometric objects around the classroom using a Samsung Galaxy S5 phone during the evaluation

4.5 Difficulties Encountered

Initially, we planned to conduct the tests using the version of the game uploaded to the Heroku server. However, the school network only had Port 80 open and did not allow to establish a communication through other ports. We had to reschedule one of the test sessions because of this, and had since resorted to testing via Localhost. Also, the game response was affected whenever the Wi-Fi connection in the venue was unstable. During one of the tests, we had problems with the connection and had to invite the participant/evaluator teacher to step outside so we would be able to get a good network signal.

5. Conclusion and Future Work

This paper presented the migration and evaluation of "Estimate It!" as part of a larger study about the design and implementation of embodied cognition of mathematics educational systems. Originally designed to run on Arduino Uno Microcontroller Cyberlearning Watches (Arroyo et al., in press), *Estimate It!* has now been successfully migrated to both AndroidOS and TizenOS. Specifically, the game can now be played on phones running on Android 2.3 (Gingerbread) or higher and on watches running on Tizen 2.3.1. The phone version is now capable of playing the game via NFC. Server code has also been refactored, deployed and tested to run in a public domain

Evaluation objectives were two-fold. It aimed to investigate how the method compares with traditional ones and what cultural, social and intellectual characteristics would make the application suited or not suited for teaching estimation. Math teachers were invited to appraise the game's value in terms of the objectives. Most of the experts gave positive evaluations of the game as per their responses in the questionnaire.

In general, the evaluator teachers liked the collaborative nature of the technology presented and enjoyed how the game allows students to interact both with their classmates and their environment. There was appreciation for how the overall teaching method provided a more concrete and hands-on way of presenting estimation concepts as well as how the method allowed the teacher to monitor and move around the classroom together with the students, allowing for active participation and communication between students and teachers, and among students themselves. The ability to include common household objects in the game had its appeal as it made the game seem accessible and easily customizable. The evaluators estimated that the game's competitive nature would make the method "more fun and exciting" than the usual classroom lecture. It is a common guess among the evaluator teachers that the injection of technology would be seen by students as attractive and motivating to them. These strong points made *Estimate It!* seem like a promising aid to teach and cover estimation concepts as part of the curriculum.

At the same time, there were areas of concern among the evaluators, that we may consider "cultural" concerns. There was a common worry that implementation of the game in schools may be hindered because schools may not be ready for the technology infrastructure-wise. In particular, a stable Internet connection was one that was repeatedly mentioned. Acquiring devices (SmartWatches or SmartPhones) for students to use might already be difficult. Others worried that setting up the game might be too tedious for some teachers, and one particularly disliked how playing the game rids the students of the process of writing down their math. One evaluator urged the researchers to reflect on how the game can accommodate a class of 40 students as most classes in their school are approximately of this size. Evaluators also dwelled on the propensity of students to misbehave while playing and on the possibility of going off-task because of other interesting applications in the device.

In light of the feedback, we can summarize that the evaluators seemed open to the idea of adopting a game-based reinforcement in their math classes. As one respondent has put it, "When executed well, the advantages of *Estimate It!* will outweigh the disadvantages".

Moving forward, an iteration of the game that accommodates the findings in this paper may be created and afterwards tested with students to assess how they would respond to this new way of teaching estimation. Given that previous evaluations had respondents that came from the United States, perhaps an evaluation of how this new method may affect the performance and understanding of estimation of Filipino students can be conducted. Results can then be compared to discover similarities and differences.

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