Gaming Projects for Cognitive Testing in an Undergraduate Mobile Healthcare Technology Course

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***Abstract*—This Research to Practice Full Paper describes the research and development experience of building two brain training mobile Android applications as part of an undergraduate mobile healthcare technology course. Along with faculty mentors, project teams researched that symptoms like loss of cognition, memory, and reasoning are indicators of the early onset of dementia, Parkinson's or Alzheimer's disease. Active brain training has been shown to alleviate some of these symptoms. Using this knowledge and the skills learned in the course, student teams designed Android mobile gaming applications with cloud back-end infrastructures to train the brain. Observations about the class composition, together with units of instruction to facilitate successful project implementation and critical thinking in an ethnically diverse STEM student pool of an R3 University are described.**

I. Introduction

With the ubiquitous nature and powerful computing power at the convenient disposal of individuals through modern day mobile devices and smartphones, mobile health (mHealth) applications are gaining prominence. According to a study, the number of companies in the mHealth space has increased rapidly in the last few years [1], [7]. The portability and ubiquity of these devices make them ideal for healthcare givers who are on their feet constantly. Further, these devices are suited for self management of health goals pertaining to specific health conditions [5]. For instance, monitoring the calories expended during the course of the day using the pedometer function of a smartphone is useful for diabetics [11] who need to maintain specific caloric intake goals in their nutrition.

There is a critical need to train computer scientists and engineers in the biomedical domain [8], [13], [3]. The demand for a larger skilled workforce makes it important to engage ethnically diverse and female student populations in the STEM field to successfully develop and deploy applications in this area. According to a 2017 report by the U.S. Department of Commerce, Economics and Statistics Administration, women with Science, Technology, Engineering and Math (STEM) degrees are less likely than their male counterparts to work in a STEM occupation; they are more likely to work in education or healthcare [21]. Combining STEM fields with healthcare may prove to be successful in increasing participation of female students. Educational institutions, including ours, are dedicating resources for course offerings and research in this area [5]. There have been several papers on integrating Andriod gaming application development in primary school education [23]. This paper highlights an undergraduate course at our institution titled *Mobile Healthcare technology* that educates students to research an application area in health, and create mobile applications for the same. The experience and implementation of two projects focusing on gaming applications to help with cognitive testing is described.

The rest of this paper is organized as follows: Section II looks at the background of mobile devices in healthcare, specifically to improve cognitive function through brain training; section III describes the course, tools, and project details for the brain training games implemented in this course; section IV discusses student evaluation results; section V concludes with a discussion of the classroom experience and possible future directions for similar courses.

II. Background

With the popularity and ease of mobile computing, along with the affordability and variety of connected devices, more and more people are taking advantage of the many benefits associated with mobile health applications. The medical field and the elderly can reap great benefits from mHealth applications. One area where mHealth applications can have significant impact is within the areas of cognitive training and brain testing. Recently this area has garnered much more attention to help the elderly, especially those susceptible, at risk, or at the early onset of Parkinson's disease, dementia or Alzheimer's disease [22]. It is important for academic institutions offering STEM programs to train students at the intersection of healthcare and technology to fill the critical need for professionals in this area. Garnering the interest of underrepresented female students for these programs may hold the key to fill the workforce gap in the future as well.

Our institution is very diverse in its student body with 65% enrolled females to 35% enrolled males. However, in our computer science degrees, the enrollment trend for fall 2017 was only 22.3% female to 77.7% males. Our division offers a mobile health (mHealth) application course, which teaches mobile software development specifically for the healthcare domain. The course is an undergraduate Internet of Things class for medical and health analytics using mobile devices. This makes it different from a traditional mobile software development course. Projects created in this course were developed with Academic Service Learning (ASL) in mind. On the

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day of the project presentations, members from the university's service learning and mHealth research sites including Ronald McDonald House and the Boehringer-Ingelheim corporation were in attendance to see the presentations of the mHealth applications developed. It was hoped that the projects could be used to serve members of these organizations or be further developed for research and analysis.

It is interesting to note that the project teams highlighted in this paper consisted of one male faculty mentor and one female faculty mentor, with a majority of female students across all class projects.

One of the areas the students in this course focused on was on memory and brain training along with the benefits that can be achieved using and playing mobile games. According to Zelinski et al, nearly 72 million people or 20% of the US population by 2030 will be over 64 years old, an increase from about 12% of the US population in 2003 [16]. This increase in the number of people who could potentially have cognitive decline associated with dementia, Parkinson's or Alzheimer's disease is what makes research and treatment imperative to the quality of life for this age group. Nouchi et al report that the elderly can improve cognitive functions in regards to speed and memory while playing brain training memory games [12].

Research indicates that playing games, especially those geared towards brain activity can reduce cognitive impairment [16]. Results in [24] suggest a high level of interest in brain training apps among the US public, especially those in younger demographics. However, the low concern about data security and lack of clinician endorsement suggest apps are not being utilized in clinical settings. In [25] the authors agree that brain-training interventions improve performance on the trained tasks, and make recommendations to scientists and policy makers that could lead to better evidence regarding the efficacy of brain-training interventions.

Many companies have already invested in brain games adapted to improve cognition memory including but not limited to Nintendo, Lumosity, and Master Quiz. These academic and commercial games can help with cognition and motor skills using a simple tap or click. Key findings from McCallum and Boletsis [9] indicate that patients with dementia who participated in a nine week training session and six month follow up retention test using Nintendo Wii Sports, demonstrated improvements in performance and memory for procedural components of the game. Those patients with mild cognitive impairment who participated in an 11 week study testing Lumosity were found to improve their performance across a variety of tests. Patients who had been tested for six weeks with Master Quiz who had mild signs of dementia were able to play without any aid as the games were designed with ease in mind [9]. These studies and ideas formed the basis for some of the mHealth applications developed in this course.

With increasing life expectancies, more and more of the elderly are developing Alzheimer's, Dementia or other age related diseases [17]. Vina and Lloret discuss in their paper why there has been an increase in more women than man developing Alzheimer's Disease [17]. They found that the proportion of women suffering from Alzheimer's is usually greater amongst women than men from any age group studied and note that perhaps this is true due to longer life expectancy of women along with higher rates of obesity and diabetes [17]. Craig and Murphy have also reported, based on studies they found, that more women than men suffer from Alzheimer's Disease and other brain degenerative diseases [18]. They note that by 2050 30% of people will be aged over 65 and about 10% of them will be suffering from a brain degenerative disease such as Alzheimer's or Dementia [18]. Given this research, our teams wanted to reach this population with its brain games to help improve cognition. Many elderly people, especially women tend to watch game shows and play games on paper like crosswords or suduko from the daily news. Our project teams created games targeted at the growing age group of technically savvy people, together with those in the future who would like to improve cognition abilities by playing games at the convenience of their fingertips on their phones, tablets or laptop devices.

Being one of the most diverse universities in the state, student teams were interested to see if any studies were conducted on the correlation of race and ethnicity with Alzheimer's Disease. Griffith reported on M.P. Mattson's study that understanding how race and ethnicity may be associated with cognitive degenerative diseases may lead to early detection, prevention and or treatment [19]. Weiner reports on the finding of Radebaugh and Ward-Robinson about the importance of knowing not only the race, ethnicity or culture of people (since 99.9% identical in genetic makeup), but also having knowledge about the environment, surroundings, experiences and lifestyle. This can help determine the possible causes of cognitive degenerative disease and the early detection and/or prevention and treatment [20].

III. Course Description

The course described in this paper, *Mobile Healthcare Technology*, was a special electives course focused on developing Android mobile applications related to the healthcare field. 14 Students taking the course comprised of computer science majors with a minimum prerequisite course requirement of introductory data structures in the Java programming language. 10 students had taken a course in database management systems and were well versed with designing standalone back-end databases. All students had taken a year or more of programming courses.

In addition, the course enrollment of females in this course was 58%, which was well above the institution average of 22.5% for the STEM program. This was a surprising indicator aligning with the fact that female STEM students are inclined towards careers in health related disciplines as stated in [16]. The integration of healthcare with technology attracted more female participants.

The course was run in-class once a week for two consecutive course periods. Initially the lessons focused on the state of mobile healthcare and enabling sensor and mobile technologies that are pushing the phenomenon. Since the main objective

of the course was on developing mHealth applications on the Android platform, introductory hands-on labs were conducted in class to familiarize students with the Android studio IDE (Integrated Development Environment) and program structure of Android applications.

One of the key components of the course was to work in groups simulating software development teams. All groups were required to set up projects on GitHub. This tool made it easy for group members to share thought processes while committing portions of the project they were responsible for to the rest of the group. Students were required to submit the final deliverables on GitHub, with all their source code and documentation.

A. Android Studio Labs

Even though students in the course were relatively proficient in programming, introductory Java and XML lectures geared towards the Android platform using the Android Studio IDE were delivered. Android Studio is Android's official IDE. It is purpose built for Android to accelerate development and help build the highest quality applications for every Android device. It offers tools custom-tailored for Android developers, including rich code editing, debugging, testing, and profiling tools [2]. The Android Emulator installs and enables prototyping the app for testing on various Android device configurations: phones, tablets, Android Wear, and Android TV devices. A variety of hardware features such as GPS location, network latency, motion sensors, and multi-touch input can also be simulated.

Various facets of mobile application development were taught pertaining to the life cycle of an application. Since students were required to develop graphical user interfaces, concepts related to event-driven programming were taught. The resources used for teaching ranged from open source projects freely available online, to tutorials available on the Android developer website. These were modified to make them more specific to healthcare applications.

Labs started with introductory exercises in setting up the Android studio IDE, designing user interfaces using XML, to writing sample applications linking buttons to text fields. Fig. 1 shows the Android Studio screenshot for a sample lab adding or concatenating two strings.

Subsequent labs increased in complexity tapping into sensors on the mobile phone and implementing the back-end infrastructures for collection and analytics focused on healthcare services. Here are descriptions of some later labs:

- Lab3: Students were asked to investigate how to record sensor data of their choosing on a mobile device. Accelerometer, voice, and touch sensor data were the sensors that were widely chosen by the students. Once they figured this out, they were asked to think of healthcare applications they could integrate this into. The idea of reading a collection of user initiated sensor interactions needed to be conveyed to the end-user of the application. Students used this lab to think about their own projects and the sort of sensor interactions they would need.

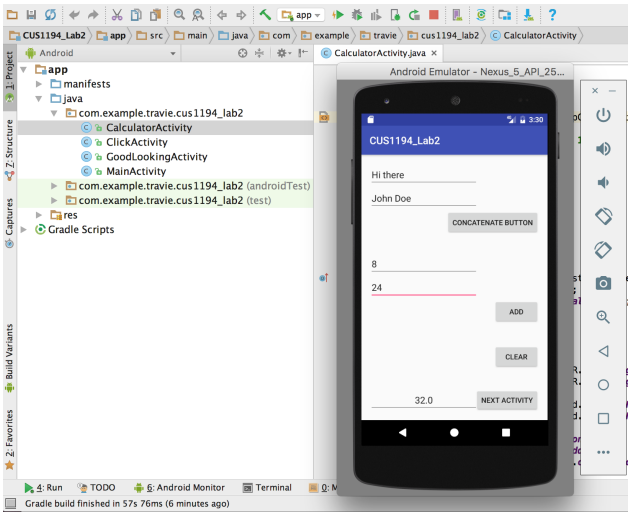

Fig. 1. Android Studio Sample Lab

- Lab4: Students set up a back-end cloud service which collected user initiated data from their application in the previous lab. This included both login and sensor information. They had to demonstrate that their application was effectively able to capture sensor data, send it to a back-end service, and receive information from there to display on their mobile application in some graphical format. They used a lecture on Google Firebase delivered to them earlier in class to accomplish this. Some students chose to use Heroku.
- Lab5: Students were asked to build into their healthcare application the ability to analyze raw sensor data streams and display it using visualization tools like graphs. They gained experience on how to integrate open source libraries like Android GraphView into their projects.

Upon completion of these labs, students had acquired the skills and techniques to effectively build a native Android platform application. They were then asked to research, design, and develop a more advanced healthcare application of their choice utilizing all the concepts they had learned in the labs.

B. Project Organization

Prior to working on their final projects, students were required to read papers describing mobile healthcare infrastructures and systems. The papers ranged from summaries on mHealth portable systems and platforms [14], to telemedicine systems for pre-hospital emergency services [10], to product line architectures for a mobile patient monitoring system [15]. The intention behind this was to give students a well rounded view on mHealth technologies in existence and the key factors to consider when engineering these systems. Students were asked to submit answers to several questions based on these readings as part of the course grade. Questions were designed to push students to think about the papers in a non-superficial way, and garner a deeper understanding of challenges and open

issues in current mHealth technologies. Some examples of the questions asked were:

- Summarize the paper in two paragraphs highlighting the main points
- What differentiates a smartphone from earlier generation phones?
- What are the key differences between apps designed for hospital workflow management versus those for medical references?
- Would you classify a smartphone as a wearable device? Why? Give examples of wearable devices
- What according to the authors makes the system design novel?
- Discuss two limitations of the current technologies used to realize this system
- Describe the main components of the Mobile Patient Monitoring (MPM) system architecture
- What are the shortcomings of existing MPM Applications?
- Describe one case study given in the paper
- What are the shortcomings and important future directions for this work?

In-class discussions critiquing these technologies, their limitations and novelties were held to foster more active participation. Students were then grouped into teams of no more than three for the purposes of the project. They were given specific topic areas from fields as diverse as proactive patient health monitoring, health record systems, tools to affect cognitive disorders, and were asked to choose projects related to these. There were several milestones and deliverables in the project.

The students were supposed to choose a healthcare need for their project. One team chose to implement a cloud based mobile service for physicians to prescribe and monitor the medication regimen of patients. As mentioned in the background section of this paper, Academic Service Learning (ASL) projects for the Ronald McDonald house were chosen by two student teams. They worked on implementation of a mobile run tracking application for donation runs and marathons allowing users to be tracked on a geographical map in real time, while allowing for social interaction using chat interfaces for family and friends. This application also allowed users to set their fitness goals and allow for intervention if they were falling behind these goals. Two student teams, comprising of three students each, with four female and two male participants, focused on developing gaming applications for cognitive testing and training based on the initial research ideas proposed by their faculty mentors.

Once a specific healthcare project was chosen, students had to submit a project proposal. The proposal asked the teams to designate roles in the project to simulate a real world industrial software team. The proposal specifically asked the students to cover the following components:

- A descriptive title for the project
- The names of students in the project team designated to the roles of: Team leader, front end/UI Engineer, back-end engineer, data analytics/visualization lead
- A motivation and problem statement (in no more than two paragraphs)
- A description of the proposed solution/approach (in no more than two paragraphs)
- A list of requirements to complete this project (hardware needs, development environment, programming language, tools, sensors, other devices, etc.)

Upon completion of the project proposal, students got feedback about the feasibility of their idea. The feedback from the instructor took the form of an in-class group discussion with each project team. The teams communicated their project ideas and were critiqued. Suggestions on making some projects more focused were conveyed. A couple of teams were asked to pivot to make their project more relevant to healthcare analytics. Some sample feedback that was provided to them is mentioned below:

"Your idea is great, however, I think you can make it much more interesting by providing support for physicians, nurses, and actual end-users with different functionalities. A physician should have the power to view all patients assigned to him/her, and be able to graphically view the consistency in medication adherence using a visual representation. You can use graphs, or charts to make this register more quickly."

"I think you would get more out of this project if you created an analytics interface that looks at how a user has performed on previous cognitive tests. If their performance is below a threshold you should be able to see this."

Once students got this feedback, the next deliverable was to submit a project design document incorporating these suggestions. Students were asked to submit the following functionality in a preliminary mobile application together with their design document:

- Basic user login and signup functionality
- User interface (UI) skeleton setup, showing transition between application screens on a mobile device (Samsung Galaxy tab) provided to the students
- A functional back-end cloud service to demonstrate basic interaction with the mobile application e.g., sending data from a UI screen and showing that it is being registered in a cloud database

In-class feedback was again delivered to separate groups, and some screen design issues were discussed to make the final application cleaner and clutter free. For the cognitive testing applications, the use of clear instructions before each game were suggested, together with the ability to randomize game input screens to prevent performance enhancement through repetition. An analytics interface for performance measured longitudinally over time was also suggested.

Project implementation was the next step. The students had eight weeks to accomplish this. There were active coding sessions set aside in class to promote team building. The instructor actively helped in debugging any problems encountered during software development. Some groups faced problems with getting used to version control using GitHub, but

others who had experience with it from other classes helped in resolving these issues. One group decided to implement their ASL project for Apple iOS, and support material was made readily available to them to accomplish this. They also successfully integrated chat into their application.

In the final class, students gave presentations and demos to the rest of the class. They delivered all their final source code on GitHub for the instructor to test, and also submitted their presentations with screenshots of their apps.

The remainder of this paper describes the two successful Android cognitive training gaming applications that were developed by student teams.

C. Course Projects for Cognitive Testing

1) Motivation: Approximately 5.1 million Americans may have Alzheimer's, a form of dementia that causes problems and issues with one's memory, behavior, and how they think. Dementia is a very common mental illness that describes a wide range of symptoms, such as decline in memory, thinking, and social skills, that interferes with daily functioning. Every year, there are three million new cases of dementia in America, and cannot be cured. As the sixth leading cause of death in the United States, Alzheimer's is a rising disease projected to affect as many as 13.8 million people by the year 2050. Despite this, recent studies have shown that cognitive training through games offers a viable approach to dementia prevention, since these have the potential to increase wellness in reasoning, verbal learning, and activities of daily living.

Research shows that the mental decline of one's brain with an increase in age occurs in part due to the "altered connections among brain cells". The problem we face is how to keep the vitality of the brain and the brain cells. In order to help combat early onset Alzheimer's, precautionary measures must be taken to build our brain strength up. Keeping the brain active and engaged can become a preventative measure used to help protect and strengthen our neural connections. Parkinson's disease indicators can also be detected and tested for by similar techniques

The proposed functionality of the mobile applications submitted by the two project teams are highlighted here:

- Hinder: *Hinder* is a mobile application that has three different brain exercises designed to prevent cognitive decline. These games are designed to be unique every time they run. A user's performance is analyzed through collecting the time and number of errors it takes to complete each exercise. These games are adapted from tried and tested games and activities that have yielded positive results within a six month period.
- BusyBrain Games: Similar to *Hinder* with the added functionality of a puzzle game where users have to create ordered patterns. User's performance is measured by the number of moves taken to complete a game.

There was an overlap in two of the games that were designed for both of the projects. Mentors tracked student success in project implementation at various stages of the systems development life cycle (SDLC).

2) Game Design: For all games, users are evaluated based on: the number of moves it takes to finish the game; the time taken to complete the games; correctness of the user input when solving game problems. An important feature is giving feedback to a user about their performance after the games are completed. The description of the specific games follow below:

- Memory game: The user is asked to identify matching pairs of picture cards after being shown images once the cards are flipped over one at a time by the user. These pictures will remain the same, however the order of the cards will be shuffled each time the game runs. Fig. 2 shows screen snapshots from both project teams. Once two consecutive similar figures are flipped, the cards disappear. If dissimilar images are flipped, the cards are flipped back to hide the images. The objective of the game is to remember where similar images are, and make all cards disappear. This exercise helps with memory function.

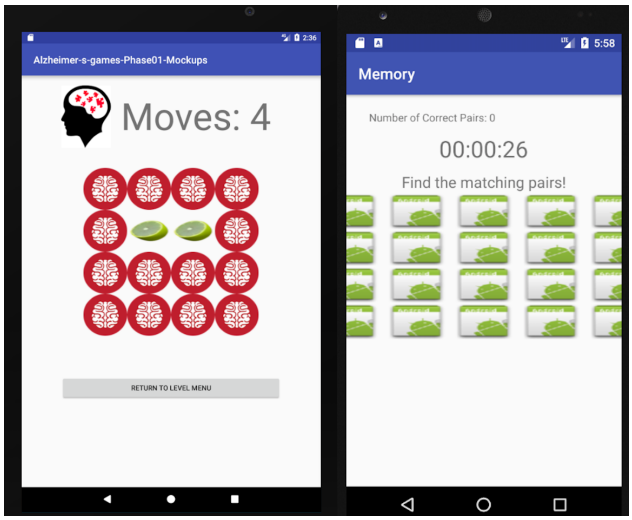

Fig. 2. Memory game. BusyBrainGames project screen (L) showing two matched images. Hinder project screen (R) with unflipped cards

- Reasoning game: The user is asked to tap all the words that has a specific color among several displayed color-words (e.g. the word "red" "blue" might be of the color green, therefore when asked to choose the color green, the user will be expected to tap the words "red" "blue"). *BusyBrain* games implemented a simpler interface as shown on the left of Fig. 3 with four color options, while the *Hinder* project team implemented a more complex matrix. Both applications measure the number of correct entries hit. A timing mechanism to measure performance was also built into both applications. As shown in the screen shots, this feedback is provided to the user as the game is being administered.
- Math and puzzle solving games: The *Hinder* project implemented a game comprised of fast math problems where the user is asked to solve simple questions (e.g.,

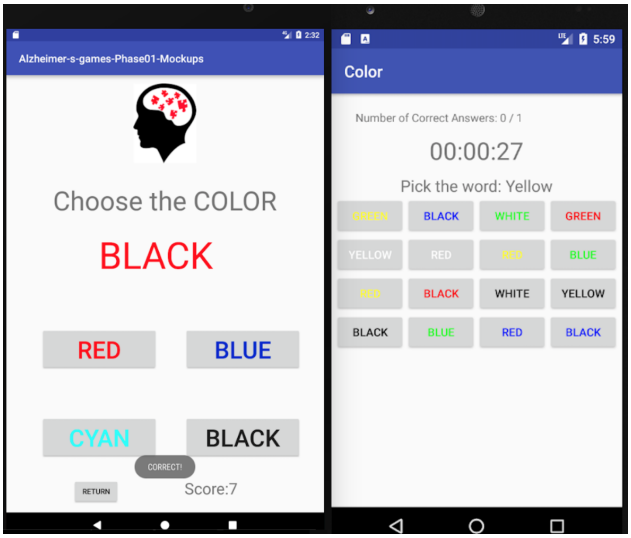

Fig. 3. Color and word matching game. BusyBrain Games project screen on the left. Hinder screen to the right

14-7) as quickly as possible. Fig. 4 shows a sample screen. This exercise is designed to help with cognition and basic problem solving skills. It assumes that the user is proficient in elementary maths at the minimum. The *BusyBrain* Games application implemented a puzzle

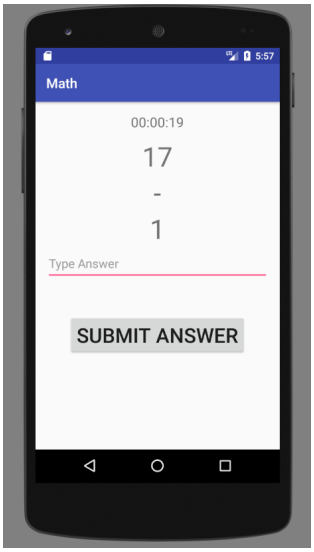

Fig. 4. Math testing game implemented in the Hinder application

solving game, which asks users to shift numbered blocks to order them, with only one vacant block position to shift to each time as shown in Fig. 5.

3) Back-end Design: The games implemented recorded scores for each user (number of moves, and time taken to complete games) on a back-end cloud service. The *BusyBrains* team decided to use Firebase cloud storage [4], while the *Hinder* team chose *Heroku* [6]. Both these cloud storage services proved to be ideal in that they were easy to set up,

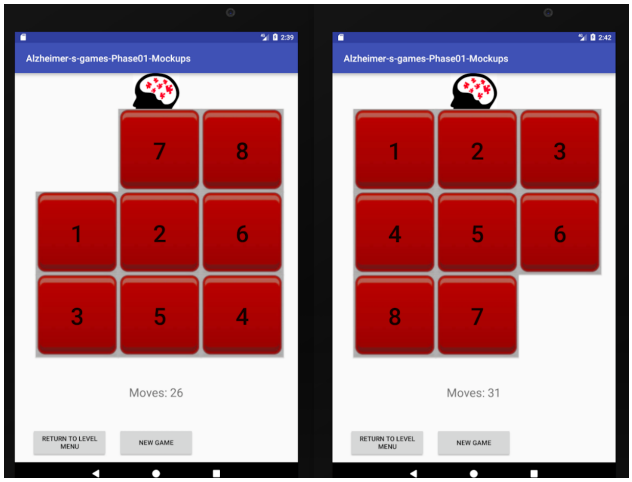

Fig. 5. Puzzle game to order numbered bricks implemented in the BusyBrain Games application (shown almost solved here)

and there was ample documentation to allow students with moderate programming backgrounds to effectively use them.

The *Firebase* cloud service provides application developers an application programming interface (API) that allows application data to be synchronized across clients and stored on Firebase's cloud. Firebase provides client libraries that enable integration with Android applications seamlessly. Heroku does the same.

4) Data Analytics: One of the requirements for the project was to integrate data analytics functionality in the projects. The *Hinder* application effectively implemented this, allowing for a graphical representation of performances in the past. The application also allowed for setting a threshold risk value in case game performance falls. This feedback is effectively conveyed to the user using graphs and in-app toast boxes after the cognitive games have been administered. Fig. 6 shows a sample result for a subject who has performed worse than their previous scores in the math game.

Both of these applications were implemented successfully by the two teams. Mentors recorded close to 40% more proactive engagement with these teams than the rest of the class. This was captured by recording the emails and time spent answering relevant technical questions from these teams. The fact that healthcare applications were developed with potential for wide ranging impact on the elderly seems to have had a positive impact on engaging these predominantly female teams.

IV. Evaluation

The two cognitive testing projects described in this course were assessed based on successful application implementation and ranked in the top 10 percentile of the class. The end of term student course evaluations for this course were very favorable, with 12 out of the 14 students responding. Fig. 7 shows a summary of the results obtained for the course. Even though evaluations were anonymously filled, these responses can be taken as a measure of success for the teams comprising

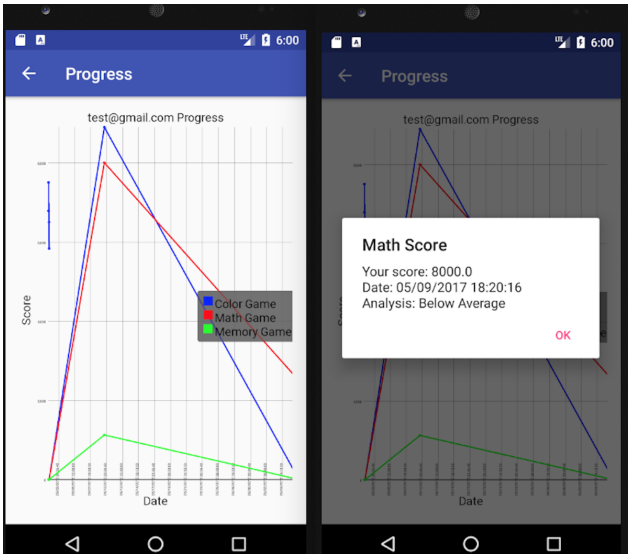

Fig. 6. In-app analytics showing performance over time for a single subject. The right screen shows feedback provided as "below average" based on aggregate analysis of previous scores in the math game

of a majority of females working on the brain training games. The ratings were consistently high across the board. 92% of the students felt the course was well paced and projects and class activities were well organized. All students (100%) agreed that their critical thinking skills and understanding of the mHealth space were increased as a result of this course. Female students make up only about 20% of all undergraduate computer science and related majors at this institution. Contrary to this proportion, the teams working on the projects described in this paper constitute of 67% females. Students mentioned how they liked working in groups simulating a work environment with real world job titles assigned to them.

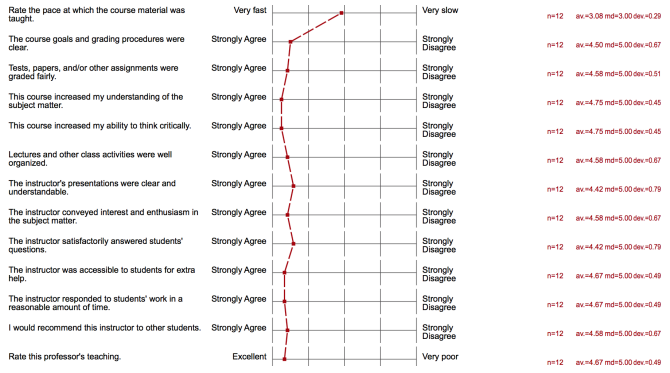

Fig. 7. Student Evaluation Results

V. Discussions and Summary

The projects were presented at our university student research day drawing great questions and ideas for future developments. The future goal of this course and the projects is to test these mHealth applications on human subjects who may have early onset of dementia, Parkinson's or Alzheimer's disease. They could also be used to perform a trial study on those who may be susceptible to these diseases.

Female participation was increased through this course as evidenced by high enrollment rates, levels of engagement, and evaluation results. In the future, more metrics to quantify female STEM population participation in courses combining healthcare aspects offered in our division will be worked upon. This will allow us to make more concrete validations about female enrollment.

For future courses, diverse student teams (similar to the teams developing the brain training games) could be assigned to research if existing and similar games halt, ease, or improve the symptoms normally associated with memory and cognitive decline. Additionally, teams may develop mHealth applications to include some newer brain strategy games that would be recommended by medical professionals to use as the trial and tests for the patients. The brain training games developed can be assessed and compared to commercial solutions offered by *Lumos, Posit Science and Nintendo amongst others*. The course plans to run in the future each year as it has attracted and increased female enrollment. In conclusion, the mentors can validate that students enhanced their programming and systems building skills while adapting it to the medical profession, and the student evaluations of this course were excellent.

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