Capstone Project Phase A

Personalized Recommendation System for a Learning Environment

Project Number: 21-2-D-27

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Abstract: *With the prominence of remote learning and novel learning technologies in the modern age, new challenges arise for students as they struggle with limited information channels and a multitude of distractions in their personal home environments. In this project, we aim to create a system that will tailor recommendations to each specific user based on their profile for an optimal learning environment, as well as a combination of various physiological and behavioral measurements, using a Virtual Reality simulated classroom as a substitute for a physical one, which has multiple advantages.*

1. Introduction

The identification and diagnosis of distractions in a student's study environment is an area of growing interest and research, especially in a post-COVID 19 world where remote learning is becoming increasingly important and said environment is no longer necessarily the traditional classroom.

Different students may find certain types of distractions more harmful than others, depending on their own sensibilities and learning preferences.
As such, methods to identify the most harmful distractions and allow the individual student to work towards a solution can be very helpful to both individual students and education institutions alike. Such methods exist in the form of traditional monitoring and observation in either the real world or artificial mock up environments, but these have several drawbacks.
In this project, we propose a novel VR (Virtual Reality) and physiological sensor based method to achieve this by simulating a classroom environment, collecting & analyzing data and producing a personalized report for each individual user.

2. Background and related work

2.1 Classroom distractions

The rise of technology, and especially portable technology, has expanded the growing list of distractions in the modern classroom and renewed discussion around it.
A distraction in a classroom environment can be anything from external distractions such as another student sneezing or a light bulb flickering, to self-produced distractions such as playing a game or on a smartphone or talking to another student during class.

The common hypothesis on classroom distractions is that external distractions such as chatter between other students or an uncomfortable room temperature are more potent than self-produced ones, and that such distractions are particularly disruptive when they interrupt the flow of information from the instructor to the student. A 2011 study found evidence supporting this hypothesis [5].

2.1.1 Learning styles and their relation to distractions

Learning styles are the various ways and methods in which individual students learn and process new information. It has become an increasingly significant concept in education over the last few decades and has been studied extensively.
One aspect of learning styles that has been studied is how they pertain to classroom distractions. A 2012 study found evidence that students with different learning styles are

more strongly affected by certain distractions than others [6]. As such, a connection can be drawn between the preferences and learning style of each individual student, and the distractions that are likely to affect them.

2.2 Virtual Reality

Virtual Reality (VR) is a virtual experience designed to simulate real-world environments. Using a VR headset, the user is presented with an artificial, three-dimensional world that they are physically present in and can interact with in various ways.

VR has emerged as a method to assess the user's mental and physiological condition, including in education to assess students' tendencies and learning habits.
Using VR for this purpose can be superior to traditional methods in numerous ways – the operational costs and logistical concerns involved in monitoring patients in the real world or in physical mock-up environments are often higher than what could be achieved with VR, and VR also provides a way to simulate environments that are almost impossible to simulate in the real world, such as driving or aircraft simulations. In addition, arguably the biggest benefit of VR methods is the fine level of control it offers over the three-dimensional space within which behavioral and physiological data is measured and recorded. Stimuli and distractions presented to the user can be controlled with extreme precision, making it an ideal method of measuring the user's response to such stimuli.

2.2.1 VR Programming in Unity

Unity is a proprietary 3D engine developed by *Unity Technologies* and is an extremely popular tool for the development of mobile iOS/Android games and virtual reality applications. While Unity was originally released in 2005 with video game development in mind, it has since seen use in many industries including film, automotive and engineering, and has been widely used for development of VR environments and simulations in many different fields rather than purely entertainment.

Programming in Unity is done through its C# scripting API. The engine itself is capable of building and rendering its 3D VR environment frame-by-frame and processing the information of its scenes, but scripting from the programmer is required to define the behavior of the objects within this virtual world, and how they interact with both the user and each other.

Unity supports a number of VR platforms such as Oculus, Steam VR, and various other platforms from Sony, Apple, Google and Microsoft.

2.2.2 Virtual Classroom

The Virtual Classroom is a head-mounted display (HMD) based VR system designed to provide a VR scenario where cognitive and behavioral processes (particularly those related to attention difficulties) can be assessed and measured. Head-mounted displays are very well suited to providing a fully controlled environment where various distractions and external stimuli exist and can be accurately created, such as a classroom.

In a clinical trial performed in 2006, a Virtual Classroom HMD system was tested for assessing ADHD in children. It was tested using a user-centered design, where the user group provides feedback in the early stages of development. The user group in this trial was 18 male children aged 6-12 – eight were diagnosed with ADHD and their results were compared to those of the remaining 10 who were not.
The result data from the trial concluded that the Virtual Classroom provided a more reliable, efficient and cost-effective method of assessing ADHD in children than existing, traditional methods, thanks to the more precisely controlled environment and built-in tracking technology in HMDs [1].

2.2.3 Oculus Quest 2

Oculus is a division of Facebook that develops and produces virtual reality headsets. Oculus' latest release is the Oculus Quest 2 headset, which features a new SoC (system on a chip), more memory and support for higher refresh rates than its predecessor [8].
Like most VR headsets, the Quest 2 uses an Android-based operating system.

Figure 1: Oculus Quest 2 VR headset

2.3 Measurements and Sensors

2.3.1 Heart Rate Variability (HRV)

Heart Rate Variability (HRV) is the variance in heart rate, or the time between individual heartbeats. A healthy heart does not beat evenly, with equal-sized chunks of time between heartbeats – tiny variations exist, and these can be measured and used to detect diseases and heart conditions. HRV has also been shown to indicate a person's mental condition and stress in particular, as the behavior of the nervous system while stressed directly affects HRV [4].

HRV is measured using the waveform produced by standard electrocardiogram (ECG) measurements. For detecting mental stress, the required length of a HRV excerpt has been debated, and a 2019 study concluded that HRV excerpts as short as 2-3 minutes can still accurately detect mental stress [4].

In an ECG waveform signal, of particular interest to HRV measurements are the *R-peaks*. These R-peaks are the peaks in signal amplitude, one of the three components (along with the Q and S waves) of the *QRS Complex* which is the most visually striking and notable part of the ECG waveform signal and can be seen in **Fig. 2**.
HRV is measured from the ECG waveform as a series of Inter-Beat Intervals (IBI), or the time intervals from one heartbeat to the next. In the ECG waveform, these inter-beat intervals are defined as the intervals between R-peaks [6]. An example series is shown in **Fig. 3**.

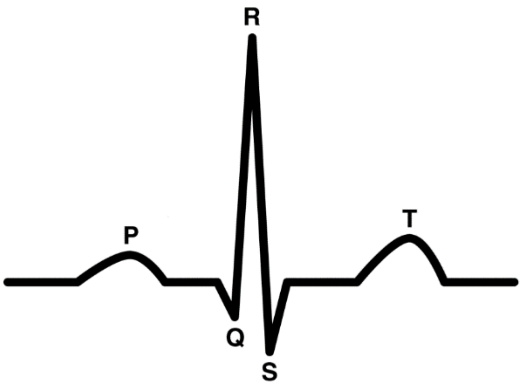

Figure 2: QRS Complex and associated R-Peak in ECG waveform

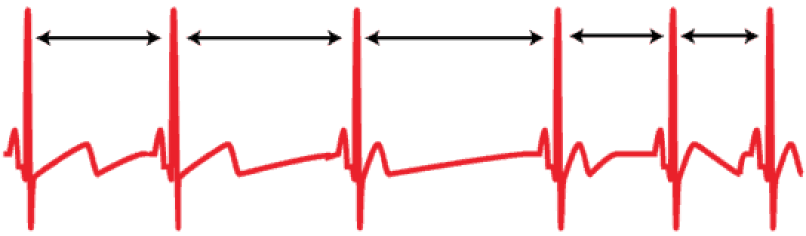

Figure 3:Interbeat Interval (IBI) series in ECG waveform

2.3.2 Galvanic Skin Response (GSR)

Galvanic Skin Response (GSR) is the change in electrical conductance of the skin in the palms and feet due to sweat. It is used to detect emotional responses that it correlates with, such as stress, and has been used as one of the primary indicators in lie detectors.
GSR is measured using a device comprised of two electrodes placed on the fingers, with an electrical current running between them. Fluctuations measured in the conductivity of the skin can then be used to detect stress and other emotional responses [2].

In 2012, a trial was conducted to test the efficacy of GSR in detecting and measuring differences in a person's emotional condition – in particular, going from a relaxed state to a stressful or nervous one, or thinking hard about a problem. The trial managed to detect these changes with a high success rate of over 90% [3].

Understanding the emotional and psychological state of the subject using GSR is done using the electrodermal activity (EDA) signal reported by the sensor (**Fig. 4**), in which this activity is measured using the electric conductance unit micro-siemens (uS). Sharp increases in this signal (and thus skin conductance) are often the result of external stimuli and are referred to as Skin Conductance Responses (SCRs) [7].

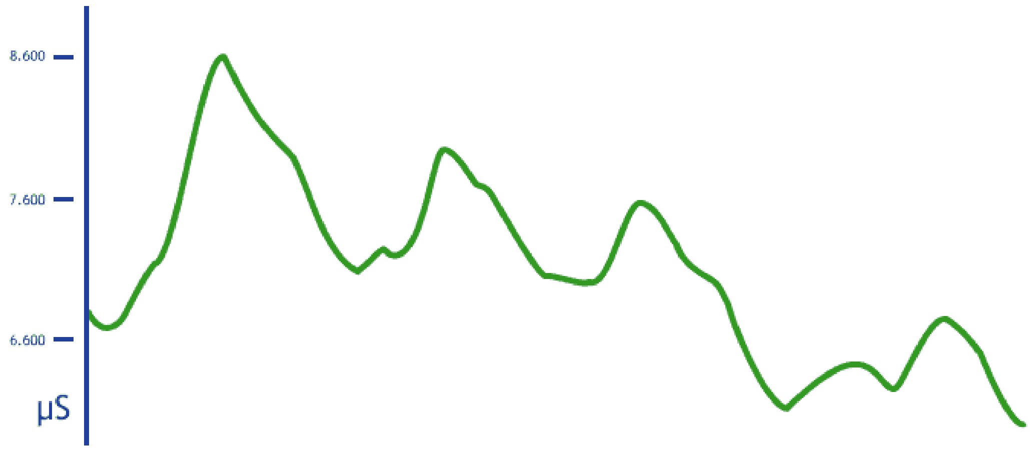

Figure 4: EDA signal, with peaks known as skin conductance responses (SCRs).

2.3.3 Head-tracking technology

Head movements while performing a task (such as listening and paying attention to an instructor in the classroom) have also been shown to indicate the response to external stimuli and distractions, and to identify various disorders such as ADHD [1].
The movement and position of the head when presented with a stimuli could therefore be used to assist in analyzing the response to classroom distractions.

Head-tracking technology exists in most modern VR headsets, as the position of the HMD (head-mounted display) in Euclidean space and, as such, the position of the user’s head, is required in order to provide an accurate virtual environment to the user.

3. Expected Achievements

The desired and expected outcome of this project is a software system that is able to –

a) Produce a virtual study classroom.
b) Simulate the learning process of a foreign language within said environment while simultaneously presenting the user with a variety of distractions.
c) Monitor the user’s physiological response to said distractions using sensors and head tracking.
d) Produce an evaluation report that gives the user recommendations on optimal learning environment.

The system must be able to produce a functional virtual classroom, with the sensors and head-tracking technology being used to provide concrete results.
These results will allow the system to provide the user with an evaluation report and

personalized recommendation for their learning environment, according to their specific needs.

3.1 Unique features

- The system will involve Unity programming for virtual reality.
- The system will use physiological sensors (HRV, GSR) and head-tracking technology to collect and process physiological and behavioural data.
- The system will create and analyse the recommendations for each user.

4. Engineering Process

4.1 Process

For this project, we decided to begin with going over and attempting to understand existing academic research in three key areas –

- Virtual learning environments (the Virtual Classroom).
- Distractions in the learning environment, and how they relate to individual learning styles.
- Sensor-based methods to measure the physiological response to distractions.

Our objective is to bring this research together into one, cohesive solution to a prominent challenge in this day and age – understanding how to achieve an optimal learning environment that allows each individual student to learn to the best of their abilities.

From this research we understood that the virtual classroom is in many ways superior to traditional methods of assessing the learning environment and a student’s ability to learn within it, and that a VR-based method is feasible for our project.

We also found that the specific sensor-based methods for measuring physiological response that would meet availability constraints were the Heart-Rate Variability (HRV) and Galvanic Skin Response (GSR) sensors, as well as VR headsets’ head-tracking technology. The necessary equipment and hardware for these will be available at Ort Braude College.

We aim to develop a system that combines the Virtual Classroom (projected using said VR headset) with a sensor-based approach to collecting data.
The system presents the user with a virtual classroom in which they must learn certain material (presented by the application) while the application is producing various distractions of different types – visual, auditory, both, or none.
After a certain period of learning, the user is assessed in an exam, and is provided with an evaluation report with a recommended learning environment based on his exam results and physiological response to distractions.

For the learning material, we chose teaching new words in a foreign language as a simple, easy to understand and implement learning material, which is also straightforward enough to write an exam for.
For the sake of simplicity, a Latin language with a Latin alphabet would be used.

The system will also allow the production of statistical reports based on users' personal details for the purpose of potential future research or use by an expert.

4.1.1 Methodology

To produce meaningful and correct recommendations to the end user, we must understand the meaning of various statistics that can be derived from the HRV and GSR measurements, and how they correlate to the mental stress experienced while being distracted in the learning environment.

With regards to Heart Rate Variability (HRV), existing literature and previous studies have definitively shown that HRV decreases under stressful conditions and increases under relaxed conditions [4]. In other words, mental stress leads to an overall lower variance in beat-to-beat (R-peak) intervals.

In this project, however, we are interested in detecting changes to stress levels on a relatively small scale, and as such can't examine HRV data produced from hours-long ECG recordings. The BioLab analysis software we will be working with in this project is able to produce various statistics from HRV excerpts, and we will be examining a few in particular – SDNN (Standard Deviation of N-N intervals), AVNN (Mean average N-N interval) and HF (high-frequency band). Note that N-N in these statistics is another way of saying R-R intervals, or the time intervals between R peaks as shown in the Background and Related Work section of this project. These HRV features were all shown to correlate with mental stress even when taken from short HRV excerpts [4].

For Galvanic Skin Response (GSR), things are simpler – the GSR sensor produces an EDA signal and as discussed in Background and Related Work, sharp peaks in this signal (called Skin Conductance Responses – SCRs for short) are a physiological response to stressful stimuli and appear between 1.5s to 6.5s after the event [9]. The BioLab analysis software is able to classify these SCRs as either non-specific or event-related [7], and in this project we are mostly interested in event-related SCRs (ER-SCRs) as they are the ones that follow a specific event – in our case, a distraction in the virtual environment.
The precise manner in which the data statistics will be weighted to produce recommendations is subject to preliminary tests to be conducted in the early stages of Phase 2.

The working assumption in our project is that the user is feeling well - not sick or sleepy, and that will be confirmed with the user prior to beginning a run of the system.

4.1.2 Challenges

It was clear from the research that a system incorporating a VR-based virtual classroom with sensor-based physiological measuring could be designed, but a particular challenge in our research was that there was little to no existing research on such systems – much research exists on individual components of the system proposed in this project, but very little on how they would potentially interact with each other.
As such, the system developed in our project would be relatively novel.

Another challenge is that there is little to no previous experience in Ort Braude College in working with the hardware involved in our project, specifically the HRV and GSR sensors. Our project is one of the first to make use of such sensor-based methods for measuring physiological responses.

There is also the challenge of precisely understanding the parameters of the learning session and exam in our system, e.g how many and which words should be taught, how the exam should be structured, its difficulty level, etc.
Preliminary research, experimentation and gathering feedback will need to be conducted in the future to understand this better.

One implementation-level challenge will be mapping the physiological responses to the exact distractions that caused them. This will require the sensors component and the VR app component to interact in a specific way which we are currently unable to determine as we have not yet been able to get hands-on experience with the sensors.

4.2 Product

Our project is comprised of two main components –

- Virtual Reality Application – the Virtual Classroom, developed in Unity Engine for use with an Oculus Quest 2 VR headset.
- A separate Java desktop application that interacts with the user and the hardware.

In the desktop application, the user begins by filling out a form of personal details such as name, age, gender, and contact details, as well as diagnosed learning disabilities such as ADHD, Dyslexia etc.
At this stage, these details are only used for the production of statistical reports.

This desktop application also interfaces with the HRV and GSR sensors used in our project to measure users' physiological responses to distractions and collect relevant physiological data, and is later responsible for the processing of this data, the final exam results, and the production of an evaluation report with recommendations.

Once the sensors and Oculus Quest 2 VR-headset are equipped and the user has filled out their personal details, a short calibration run will be started, during which the system will establish a baseline for the specific user to which it can compare future results to. This helps in understanding the user's predisposition.
Afterwards, the VR application presents the user with the virtual classroom and begins the

learning session.

The learning material is new words in a foreign language delivered in 3 sessions, and an exam is done after each learning session. The learning session is continuous and not controlled by the user, with each word being taught for a fixed amount of time before moving on to the next word.

The exam questions are presented as multiple-choice questions with 4 possible answers and only one correct answer. Each question in an exam is equally weighted and worth the same portion of the score.

During each learning session, the VR application will produce various distractions attempting to distract the user. Distractions can be visual (such as a bright light), auditory (such as a loud noise) or a combination of both, and the system must be convincing in their application – they must feel natural and plausible within the virtual classroom.
Different types of distractions, including no distraction at all, will be mapped to sets of words, with care taken that the same distractions do not awkwardly repeat with successive words being taught.

Once all 3 exams are completed, the system will produce its recommendations in the form of an evaluation report. The report will include short, easy to understand recommendations on what to pay special attention to and what to avoid in the user's personal learning environment, as well as more a more detailed breakdown of key data and measurements gathered by the system via its physiological sensors for more advanced users.

The results are stored in our database and can be accessed by both the user (via logging in to the system) or an administrator. The administrator can also choose to produce a statistical report, which will aggregate statistics based on the conditions they define such as dates, pre-existing learning disabilities, etc.
Note that at this stage this is the only use of the learning disabilities entered by the user during registration.

4.2.1 Design Documents

4.2.1.1 System Architecture

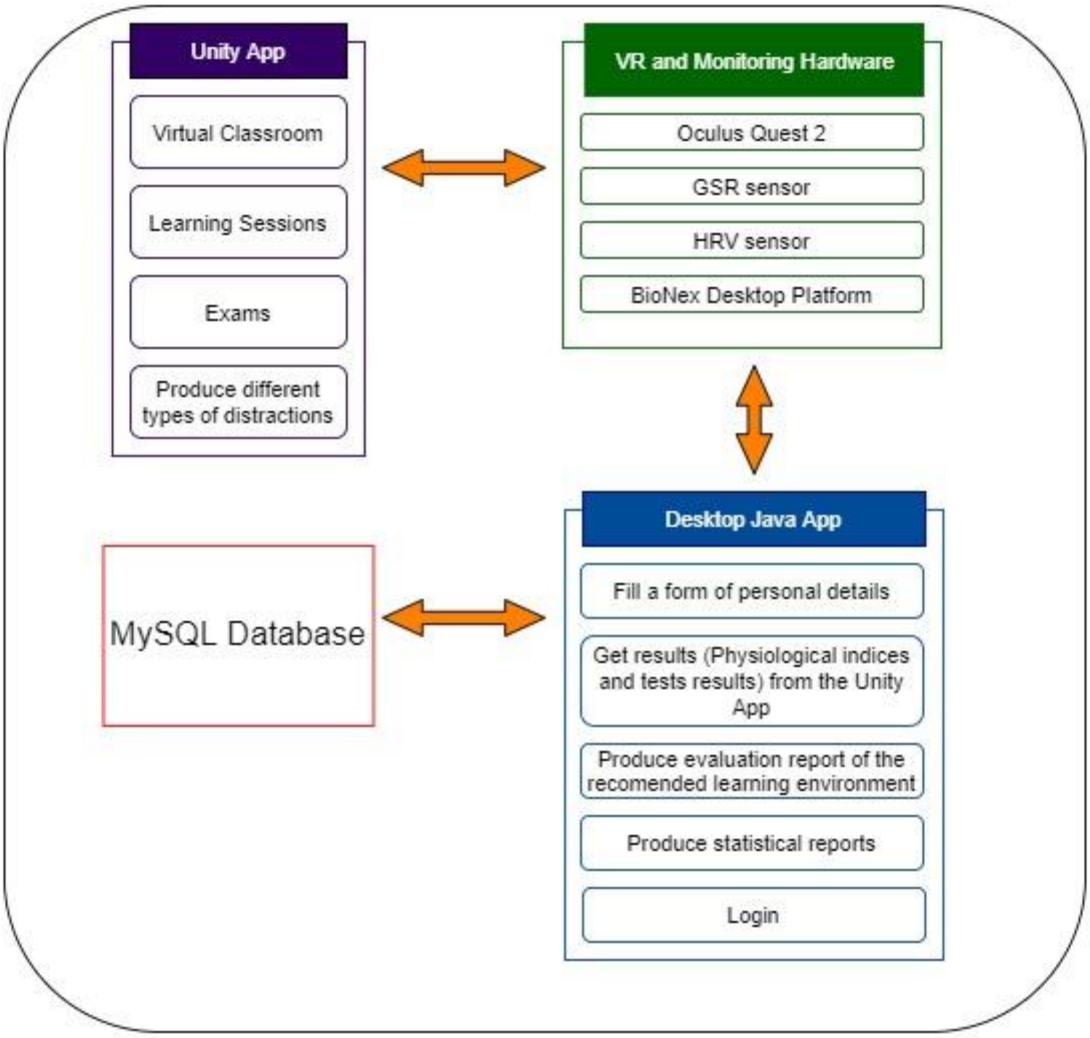

Figure 5: System Architecture

4.2.1.2 Project Flow Chart

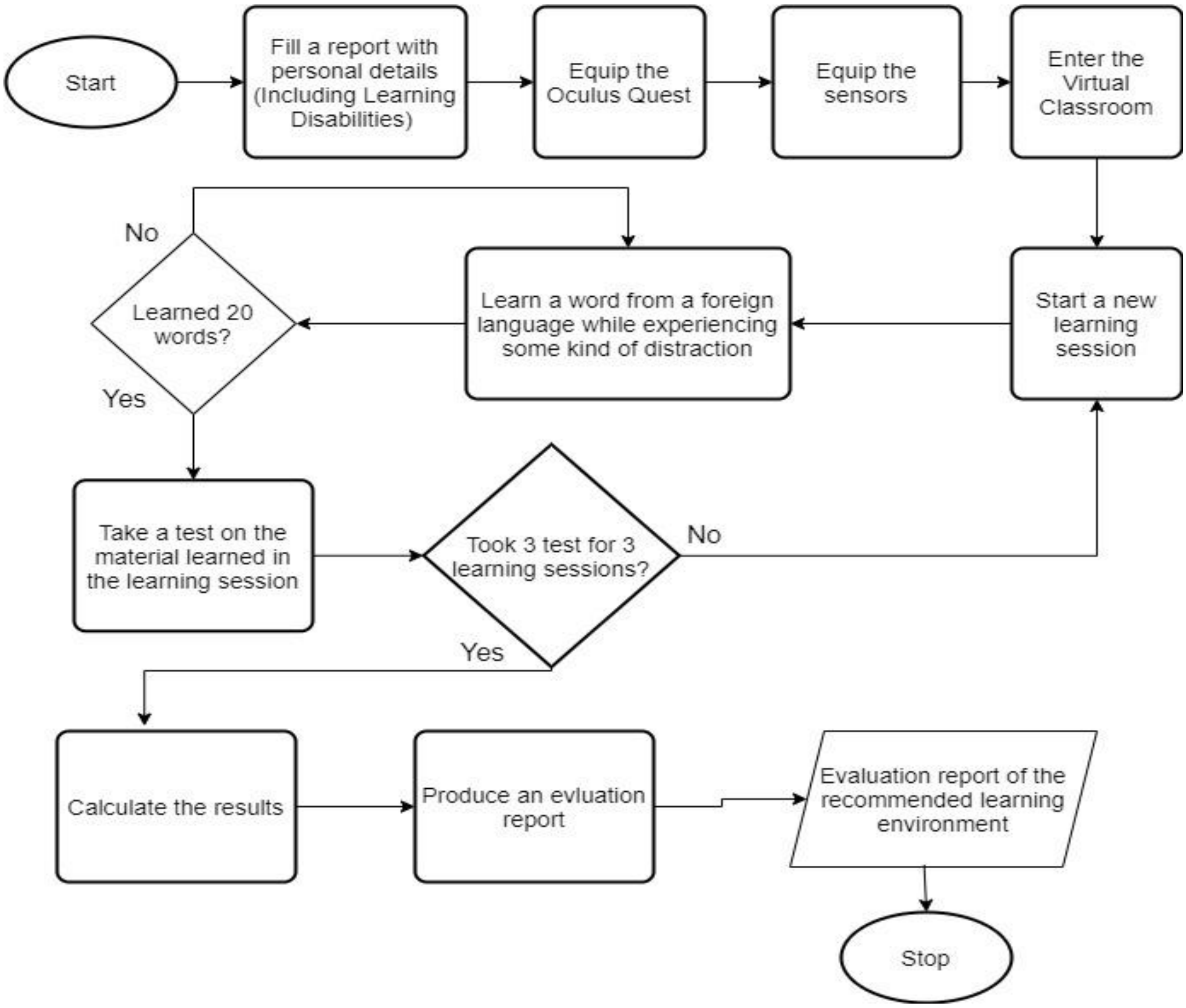

Figure 6: Project Flow Chart

4.2.1.3 Project Use Case Diagram

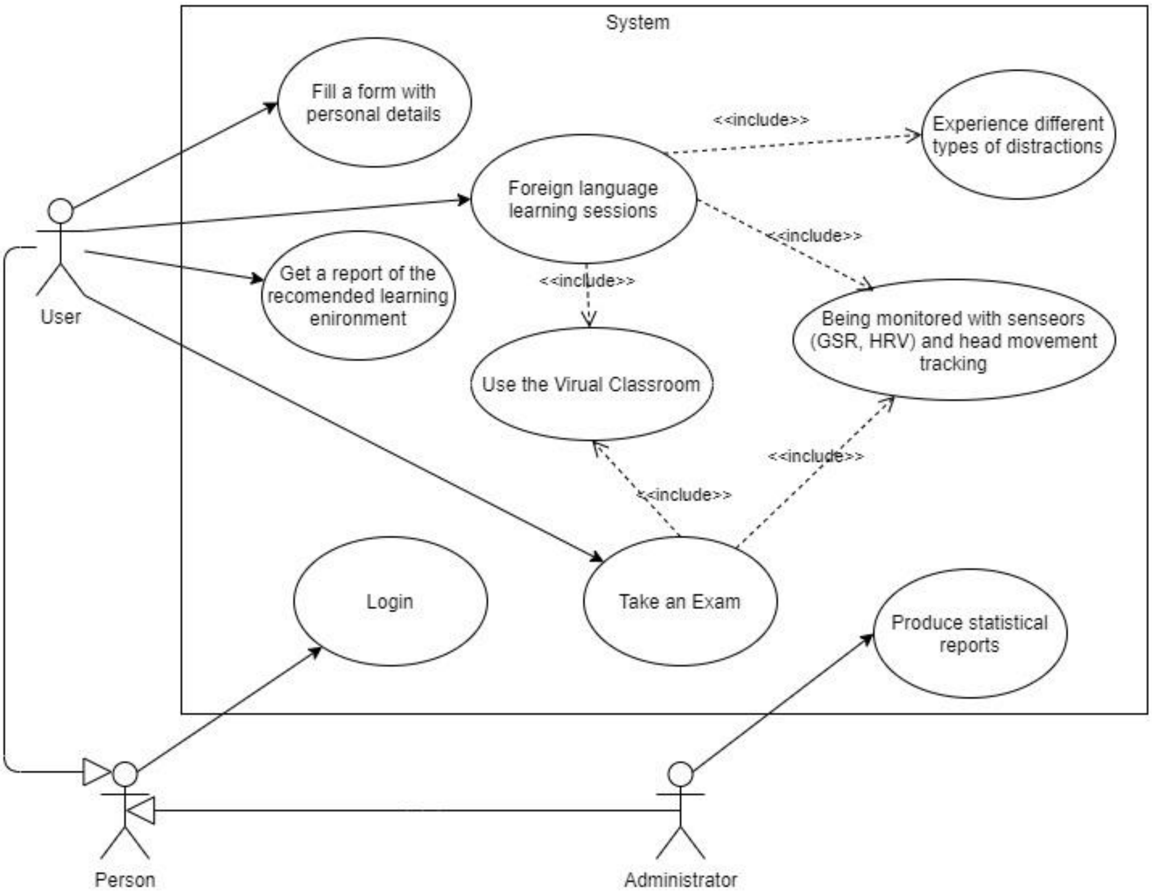

Figure 7: Use Case Diagram

4.2.1.4 Class Diagram

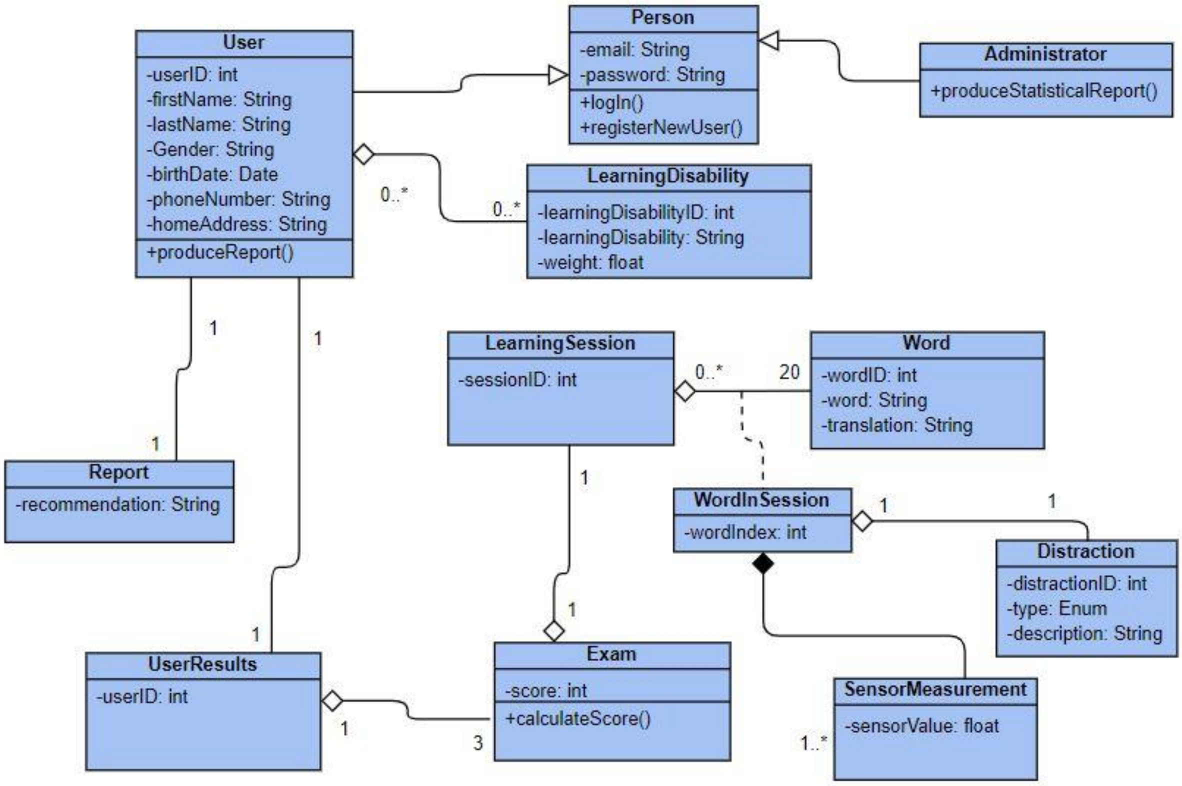

Figure 8: Class Diagram

4.2.2 GUI

All Virtual Reality GUI screenshots (the Virtual Classroom) are taken from the work of Skip Rizzo, as they appear in his paper *A Virtual Reality Scenario for All Seasons: The Virtual Classroom By Albert A. Rizzo, PhD, Todd Bowerly, PhD, J. Galen Buckwalter, PhD, Dean Klimchuk, BA, Roman Mitura, MSc, PEng, and Thomas D. Parsons, PhD.*

Due to Virtual Reality being a fairly new technology at this point in time, there is still a lack of tools to draw up VR mockups, and so Rizzo's work provides an example of what the Virtual Classroom may look like.

Figure 9: VR-Classroom

Figure 10: A distraction in the VR-Classroom.

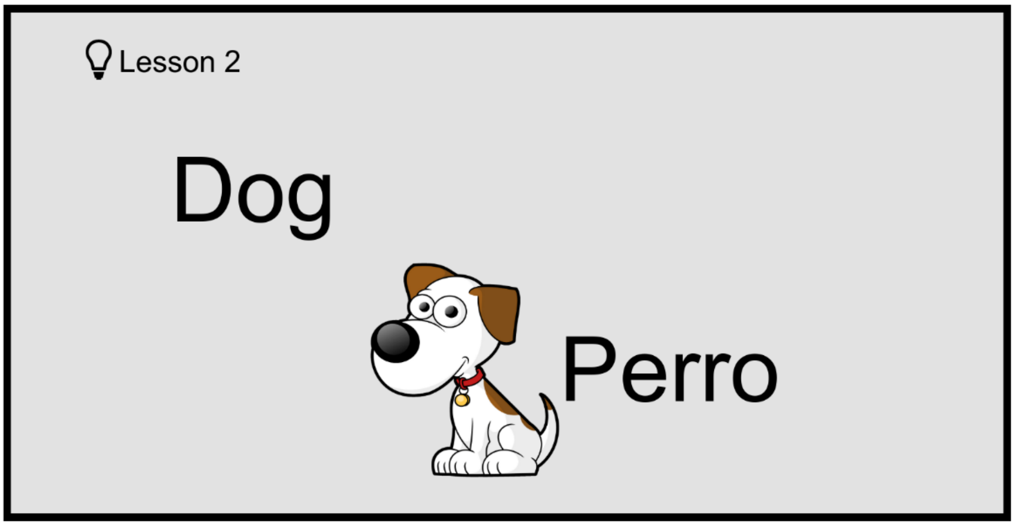

Figure 11: Individual word lesson in VR classroom

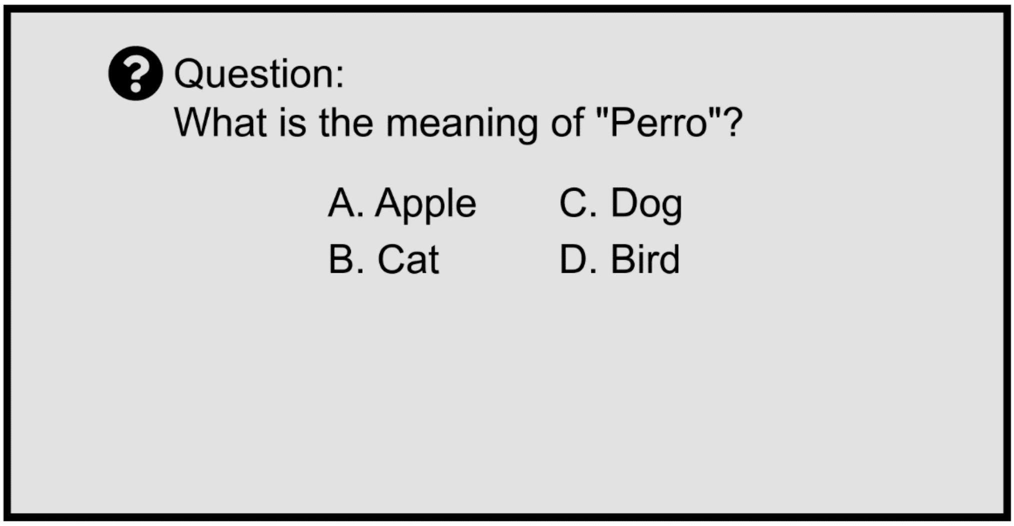

Figure 12: Example question from an exam

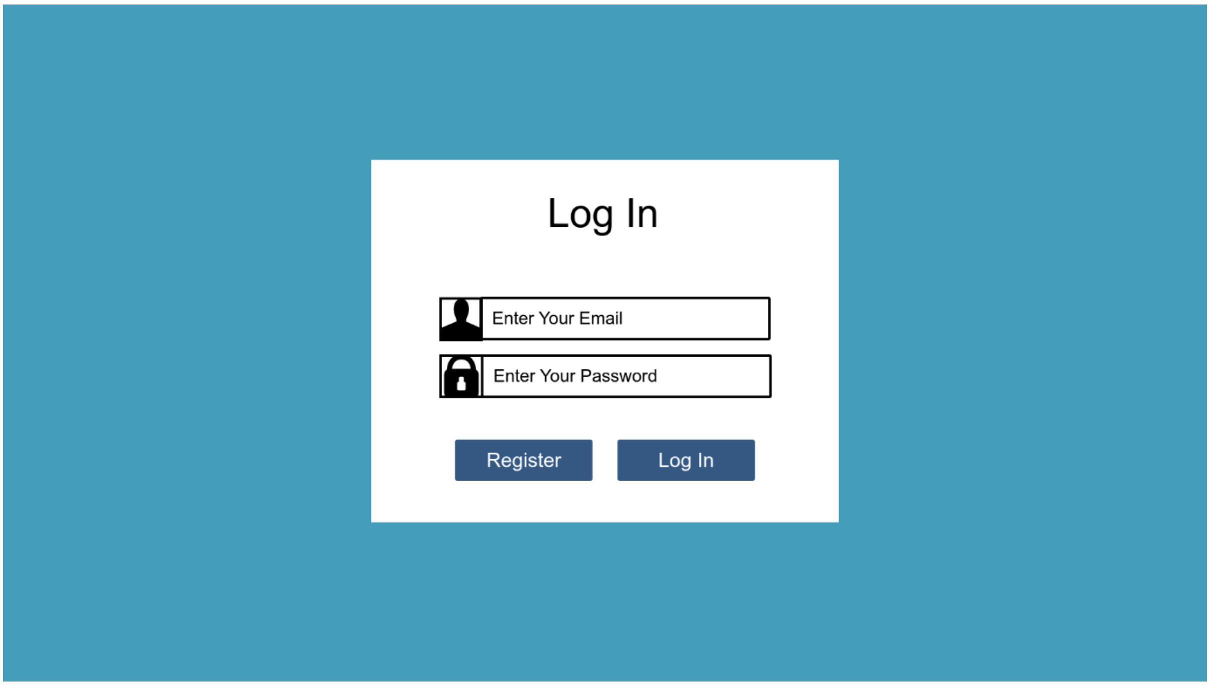

Figure 13: Log-in screen

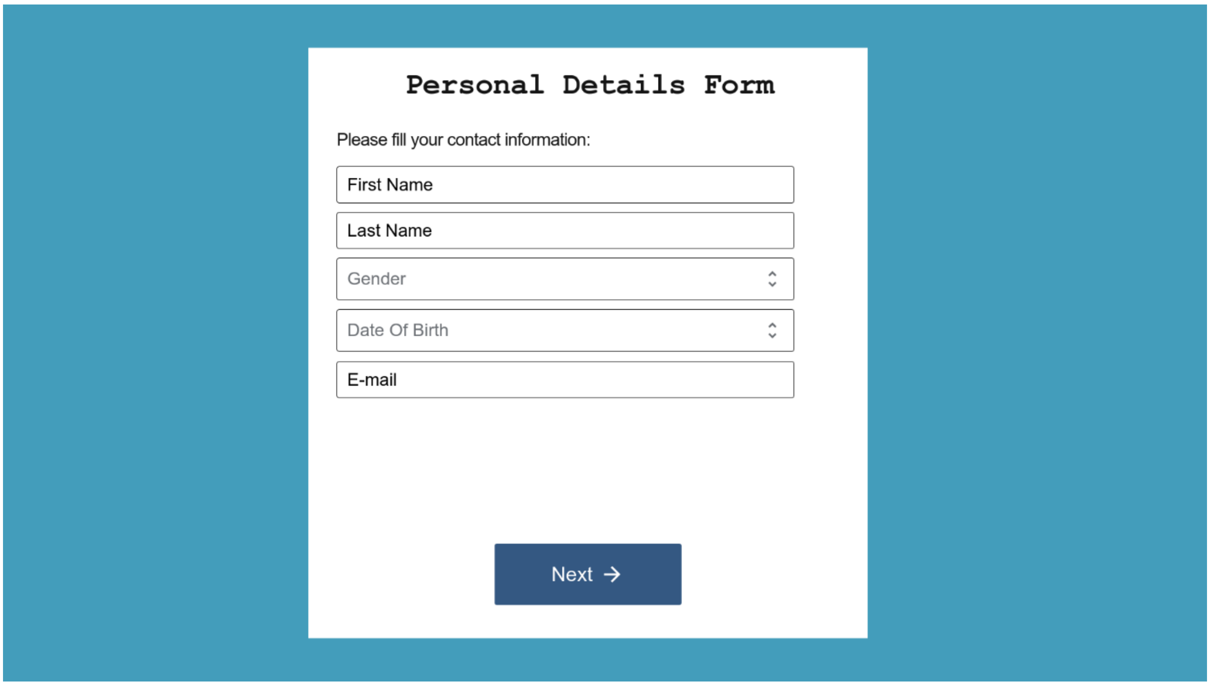

Figure 14: Personal details form

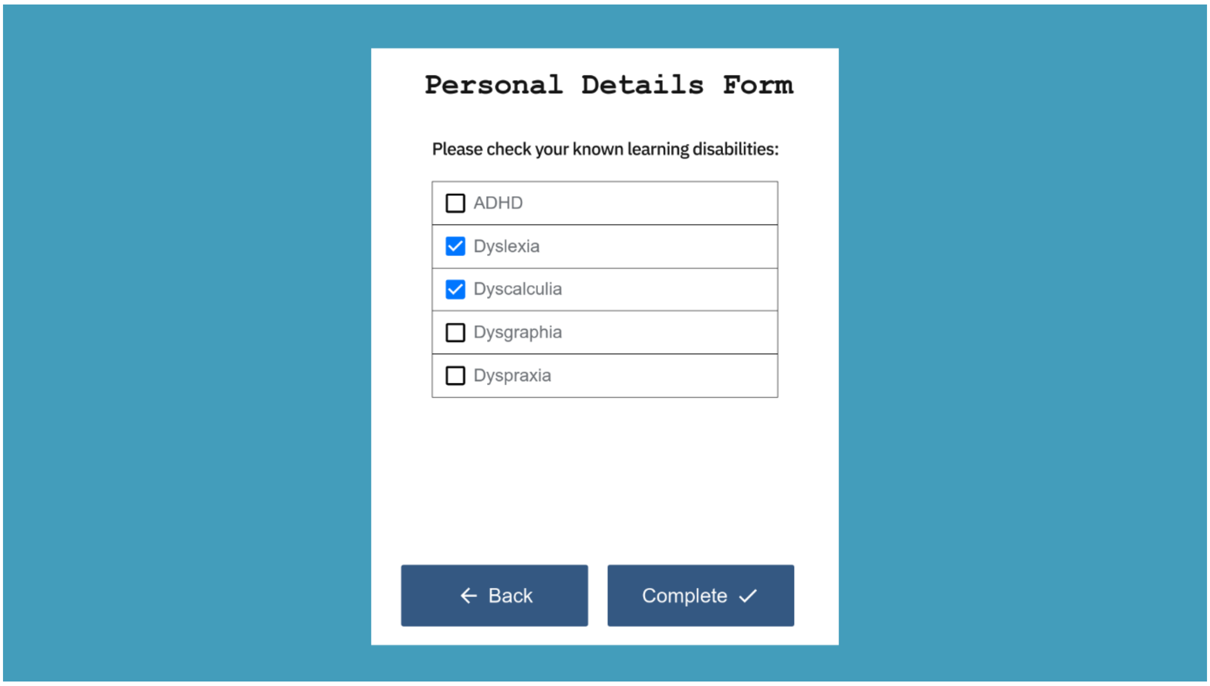

Figure 15: Learning disorders form

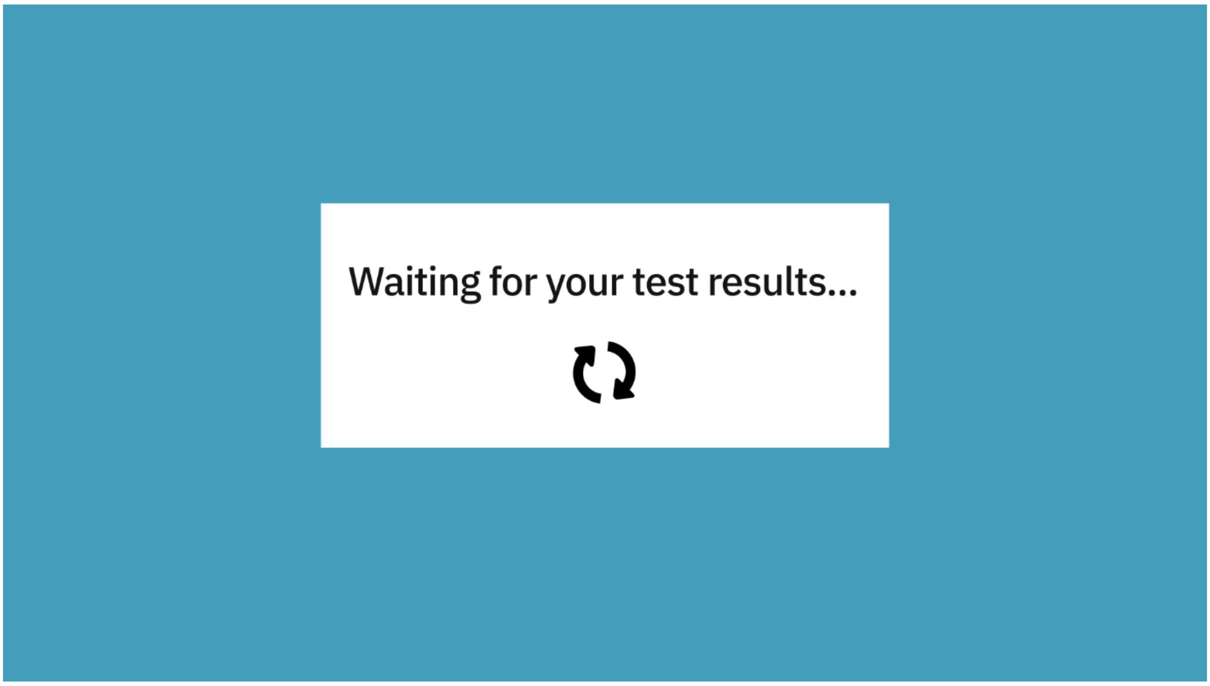

Figure 16: Idle waiting window

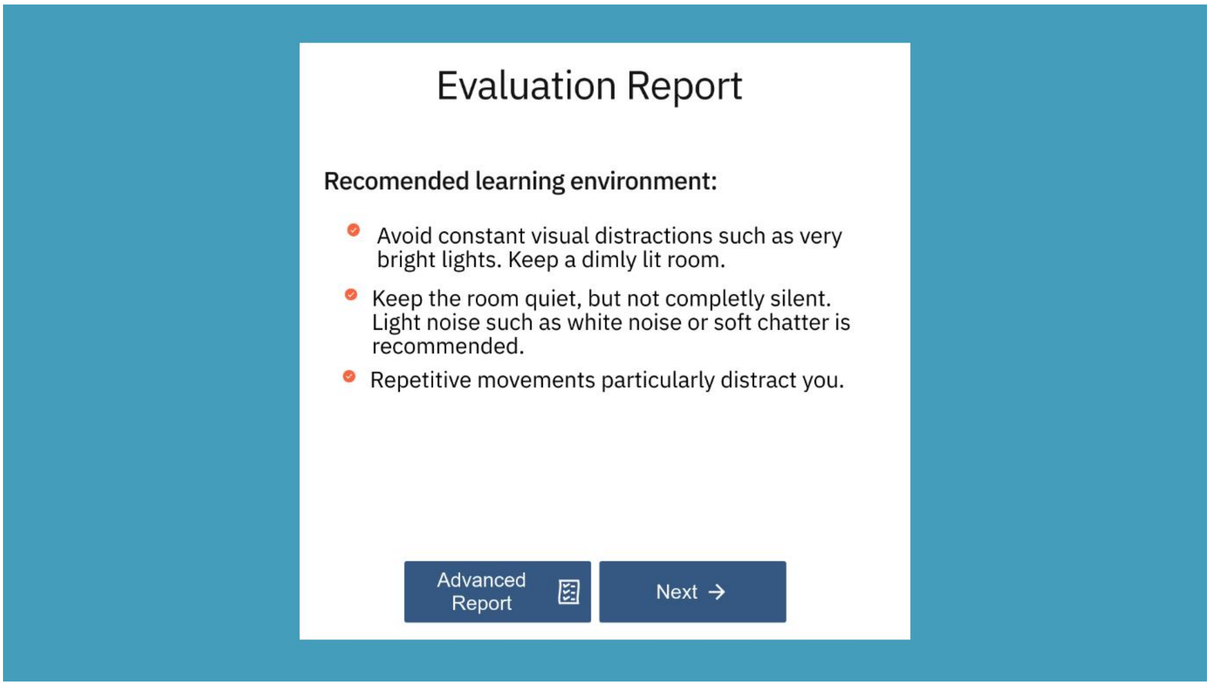

Figure 17: Basic evaluation report

Figure 18: Advanced evaluation report data

5. Evaluation/Verification Plan

5.1 Testing and Verification Overview

In this project, we will employ various methods of testing the system's stability and smooth operation as well as correctness of the results being produced. As the system architecture is quite large and involves multiple moving parts and thus multiple points of failure, our testing plan will combine isolation testing of individual components as well as the smooth operation and correctness of the system as a whole.

5.2 Acceptance Testing

Acceptance testing is a form of software testing done by the client to ensure that the system and its features are all working as intended and satisfy the requirements of the end user.
We will employ acceptance testing based on the project's Use Case Diagram.

Login

Test ID	Description	Expected result	Precondition	Comments
LoginSuccessful	In "Login" screen. email: baranvz@gmail.com Password: 12345 Press "Login".	User logged in to the system.	User exists in DB.	Password is correct.
WrongPassword	In "Login" screen. email: baranvz@gmail.com Password: 33333 Press "Login".	Error message – "wrong password".	User exists in DB.	Password is incorrect.
UserNotExist	In "Login" screen. email: somethingwrong@gmail.com Password: 12345 Press "Login".	Error message – "User does not exist".		User does not exist.
MissingInfo	In "Login" screen. email: Password: Press "Login".	Error message – "Missing email\password".		One or both fields are empty.

Table 1: Login testing

Personal Details Form

Test ID	Description	Expected result	Precondition	Comments
MissingInfo	In “Personal Details Form” screen. First name: Last name: Gender: DOB: E-mail:	Error message – “missing information”.		One, multiple or all fields are empty.
InvalidChars	In “Personal Details Form” screen. First name: בר Last name: Gender: DOB: E-mail:	Error message – “Invalid characters”.		One, multiple or all of First name, Last name, Phone, Address contains invalid characters.
InvalidEmail	In “Personal Details Form” screen. First name: Bar Last name: Israel Gender: Male DOB: 23/03/1993 E-mail: baranvzgmailcom	Error message – “Invalid email address”.		E-mail does not satisfy format.

Table 2: Personal form testing

Exam Question

Test ID	Description	Expected result	Precondition	Comments
CorrectAnswer	In exam question screen. Selected answer. Press “Confirm”.	Flagged by system as correct answer.		Selected answer is correct.
IncorrectAnswer	In exam question screen. Selected answer. Press “Confirm”.	Flagged by system as incorrect answer.		Selected answer is incorrect.

Table 3: Exam question testing

5.3 Recommendation Correctness Testing

In order to validate the correctness and overall coherence of the report and recommendations put forward to the user, we must first conduct preliminary testing and establish baseline results to serve as points of comparison.
For example, the system will need to be tested, and produce results for, a user who identifies as being very sensitive to auditory distractions and stimuli such as loud noises. These results will provide a baseline for the physiological responses we expect to see in users suffering from sensitivity to noise in their learning environment and assist in identifying those for producing recommendations to the end user.

5.4 Initial Sensor Testing

In the initial stages of testing the system, we plan to perform preliminary testing of the sensors and measurements they provide to both gain a better understanding of how to work with them hands-on, and ensure they are calibrated correctly and working as expected.
For this purpose, a short test will be conducted where a series of pictures will be shown to a test user, some of them relaxing and others stressful to view, while they are being monitored by the sensors and measurements are being recorded. In this test, we expect to see appropriate physiological responses as described in the Background and Related Work section of this project, such as SCRs in the EDA signal corresponding to being shown a stressful picture. This process will confirm that the sensors are working as expected and also provide us with experience with the sensor data and the sensors' BioLab analysis software.

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