ALERT: Smart Lecture Room

Monitoring students' concentration levels and providing feedback and stimulation, to improve learning quality

Myungwon Youn

Creative Technology, EEMCS

University of Twente, Enschede, Netherlands

Supervisor: Mannes Poel

Critical Observer: Max Slutter

Abstract

This thesis introduces the development of "ALERT," a technology aimed at monitoring students' concentration and stimulating their alertness during face-to-face lectures. The main objective was to address the challenge of identifying and improving concentration levels in a non-distracting and non-demotivating manner. The ALERT system utilizes a webcam and two screens to collect and analyze data on eye blinking, yawning, and head direction, predicting concentration levels on a scale of 1 to 7. Real-time feedback is provided through color-coded displays, stimulating alertness and promoting self-motivation. Evaluation of the prototype demonstrated its effectiveness in helping students monitor and regain concentration during lectures. The potential impact of the ALERT system extends beyond university students, offering possibilities for integration into the broader educational field and future research in Smart Lecture Rooms.

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Chapter 1 - Introduction

1.1 Context & Problem

Most students have experienced losing concentration during a lecture, especially if it lasts for hours, it is the afternoon lecture after lunch, and the lecture contents are not engaging. Students may find themselves drifting off, spacing out, or even dozing off, despite their best efforts to pay attention to lectures. This is especially true in the afternoon when students have already had lunch and their body naturally feels more relaxed [1]. Still, both students and teachers want a lecture to be inspiring and engaging. Therefore, in recent years, there has been an increasing interest and various attempts in the field of education to improve the quality of learning and teaching. To provide an inspiring lecture and effective information delivery, there have been various developments and integrations of technology in the education field, such as tablets, Chromebooks, interactive whiteboards and projectors [2]. Additionally, some technologies have been developed in order to improve student engagement by providing interesting interactions and learning methods [3]. For example, high school students work together on class activities using a tablet during a history class, as shown in Figure 1.

Figure 1*. High school students work together on a tablet during a history class [50]*

Despite some integration of technologies into the education field, maintaining students' concentration can be challenging, especially in lecture-style teaching where students easily become passive and disinterested [2]. This can be identified from the recent past. The Covid-19 pandemic has changed education dramatically, with the increase in online lectures [4]. As a result, the teaching method has changed to online lectures during this pandemic but it is another challenge to maintain students' concentration [5]. In addition, after the release from Covid-19, education has returned to normal but still students have struggled with maintaining their concentration in lecture-style teaching [4]. For this reason, during Covid-19, the education curriculum has changed rapidly and both students and teachers have to adapt to this rapid transition from face-to-face lecture (class) to distance learning format. Although teachers tried to ensure learning quality and maintain the curriculum, there is less consideration for students, who face challenges in adapting to the change back to face-to-face lectures [6]. This rapid change has happened in post-Covid19 as well and students still have struggled with the challenge to maintain their concentration on the learning method changed to face-to-face lecture again. Thus, losing concentration during lectures is one of increasing interest that has gained particular attention in the field of education.

In particular, alertness has been identified as a critical factor that can influence students' concentration. Lack of alertness can lead to decreased attention span, reduced cognitive function, and decreased concentration levels [1, 7, 8]. According to the book by John Medina [1], students' attention levels start to decline around 10 minutes into a lecture. Medina identified that decreased attention levels highly affect students' concentration levels, by stating that many students all looked at the clocks and checked the remaining time after 10 minutes of his lecture.

Teachers attempt to address this issue by engaging students' participation and concentration by making use of, for example, interesting content, media, and teaching methods. Despite these efforts, it is difficult for teachers to notice that students are losing their concentration during lectures. It is also difficult to stimulate students' alertness by individually identifying their concentration levels. According to Freeman [2], lecture-style teaching makes it difficult to notice students' concentration levels and alertness because it has limited interaction which can result in less engagement and passive involvement in the learning process. In terms of university lectures, large sizes of lecture rooms can be a reason. Moreover, with the widespread use of mobile phones and laptops in lecture rooms, students may appear to be engaged with the lecture when they are, in fact, distracted by technology. If teachers cannot notice that students are losing their concentration and so they cannot provide the alertness stimulation, this can lead to a decrease in students' academic performance. Hanh [9] states that concentration is one of the most influential factors in learning quality and low concentration levels lead to a challenge to achieve high academic performance. Students' concentration also affects academic engagement. One study conducted by Ghasemi *et al* [10] supported that low levels of students' concentration influence low engagement, by emphasizing that student engagement affects individual motivation and interest, self-directedness in learning, and learning- satisfaction. Besides, low levels of students' concentration can make it hard for teachers to maintain their enthusiasm for teaching [9]. Thus, there is a clear need for help regarding monitoring the concentration levels of students.

The technology called 'Smart Lecture room' can help to address these problems. Some technologies have already been developed to monitor students' concentration levels, especially since Covid-19. Because it is difficult to identify students' concentration levels during online lectures, AI technologies have been developed to help identify students' concentration levels by monitoring from webcams or external cameras. Besides, wearable technologies have been developed to monitor students' concentration levels and alertness. However, there is no existence of technology to stimulate students' alertness based on monitoring concentration levels. In addition, most existing technologies focus on addressing the challenge to identify students' concentration levels during lectures but not considering non-distracting and non-demotivating ways.

This graduation project will try to address these issues, prioritizing non-distracting and non-demotivating methods. To monitor concentration levels, many technologies attempt to measure the brain data, typically electroencephalogram (EEG) [11, 12, 13] in **Figure 2**. These brain-measuring technologies which address the challenge to identify concentration levels are typically head wearables and instruments, which can distract students and demotivate students' learning.

***Figure 2**. EEG brain-measuring headband "FocusCalm" [11]*

Considering non-distracting and non-demotivating methods, the factors which will be taken into account in this project are sleepiness and fatigue level, as an indicator of concentration level. This is because they can be monitored in a non-intrusive way and they are the main uncontrollable factors for losing students' concentration during lectures (will be explained more in ch2).

This graduation project has two goals. First, it aims to develop a technology that can provide feedback to the students and the teacher by monitoring their concentration levels. Second, it aims to stimulate the students' alertness during the lecture based on the feedback given by the technology. In this regard, the feedback provided by technology should be clear and not be distracting and demotivating for the teacher and students. Besides, the stimulation given by technology should not be distracting from the lecture itself.

1.2 Research question

The goal of this graduation project is outlined above. It leads to the following main research question and sub-questions.

"How can monitoring technology identify students' concentration and stimulate alertness during physical lectures, by giving feedback to students and teachers in a non-distracting and non-demotivating way?"

- *What are the factors that contribute to sleepiness and fatigue, leading to the loss of concentration during lectures?*
- *What are the methods for measuring sleepiness and fatigue, in a non-distracting way, in a lecture room environment?*
- *What are the methods for stimulating students' alertness, in a non-distracting and non-demotivating way, in a lecture room environment?*

The first sub-RQ will aim to identify the underlying factors that cause sleepiness and fatigue in students during lectures. By deeply understanding these factors, the technology which will be developed in this project can address the problem to address in this project in many different ways.

The second sub-RQ will explore the various methods for measuring sleepiness and fatigue levels. Then, this RQ will analyze those methods based on their suitability in the lecture room environment considering the non-distracting way. By understanding and analyzing each method, technology can provide the most appropriate one for measuring students' sleepiness and fatigue levels in a lecture room environment.

The third sub-RQ will explore the methods for stimulating students' alertness. Then, this will analyze those methods based on their suitability in the lecture room environment considering the non-distracting and non-demotivating way. The answers to this question are expected to give more insight into various methods to stimulate students' alertness in this project.

Chapter 2 - Background Research

The background research was conducted mostly following the sub-research question. The first section will explore the underlying meaning of 'concentration' and 'alertness', and identify the relation between sleepiness and fatigue, and losing concentration. This section will provide more insight into why sleepiness and fatigue are chosen as indicators of concentration levels. The second section will identify the factors that contribute to sleepiness and fatigue in students during physical lectures, leading to losing concentration. This will answer **the first sub-RQ** and provide the relation to the context of this project. The third section will identify the various methods for measuring sleepiness and fatigue. These various methods will also answer **the second sub-RQ** by being analyzed based on the suitability for a lecture room environment in a non-distracting way. This will be connected to how these suitable methods can be used in this project. The fourth section will identify the various methods for stimulating alertness. These methods will also be analyzed based on their suitability, non-distracting, and non-demotivating way. These suitable methods will be discussed in relation to how they can be used in this project. The next section will discuss the state-of-art identifying some existing technologies which try to address the same or a similar problem dealt with in this project. Lastly, the findings of this background research will be discussed and the sub-RQs will be answered.

2.1 Sleepiness, fatigue, and losing concentration

2.1.1 Definition of 'attention', 'concentration' and 'alertness'

During lectures, it can be observed that students have lost their concentration or cannot pay attention to the lecture. In real life, these two words seem to be used in a similar sense, meaning that students cannot focus on the lecture or activities during the lecture. However, these should be defined and understood clearly, in order to monitor student concentration levels (by measuring sleepiness and fatigue levels) and stimulate student alertness in this project.

A number of studies have been conducted to identify attention and concentration [1, 14, 15, 16]. Based on these studies, “attention” can be briefly defined as the ability to focus on a task or subject. Hanh [9] defined attention in detail, as “a process that encodes language input, keeps it active in working and short-term memory, and retrieves it from long-term memory”. Every individual possesses this ability, and they can consciously or unconsciously choose to focus their attention on something or not. Medina [1] emphasized that the brain encodes and retains information more elaborately as it pays more attention to a stimulus. He suggested that a stimulus can be a memory, individual interest, awareness (five senses), and emotions. Thus, this is why it is told to “pay” attention.

“Concentration” can be replaced with the word “attention span”. Concentration briefly refers to the ability to maintain attention. Murphy [14] defined concentration, as “an attentional process that involves the ability to focus on the task at hand for a certain amount of time, while ignoring distractions”. Maintaining concentration can be explained that stimulus keeps drawing attention and enable one to maintain an attentional state [1, 9, 14]. Rosario-Rueda [16] emphasized, in the neuroscience approach, the individual difference in concentration levels, explaining the challenge to measure individual concentration levels. In this regard, monitoring student concentration levels needs to consider individual differences and it means that the technology which will be developed in this project should provide the customization if the system considers the individual difference in concentration levels. Regarding the time-limitation of this project and the limitation of brain-measuring in the lecture room environment (mentioned in Chapter 1.1), this project will not measure student concentration levels itself, but monitor sleepiness and fatigue levels to indicate concentration levels. However, it is important to recognize that it is necessary to research the relationship between sleepiness and fatigue, and student concentration, in order to use sleepiness and fatigue levels as an indicator of concentration levels.

“Alertness”, according to the Cambridge Dictionary, is the state of active attention to see, understand, and act in a particular situation. Medina [1] states that the brain’s first system functions are surveillance and alert, called the Alerting or Arousal Network. This network monitors sensory awareness to have a general level of attention, termed Intrinsic Alertness. Therefore, alertness can be explained as the state in which the brain is awake to prepare for being active attentionally in any situation. Medina [1] emphasizes that attending stimulus (memory, interest, awareness, emotions) can activate the second network and ultimately stimulate alertness to activate attentional awareness.

In summary, attention refers to the ability to focus on a particular task and the quality of this ability can be improved by the alertness stimulus. Concentration is defined as the ability to maintain attention for a certain amount of time and there are individual differences in concentration levels. Alertness refers to the state of active attention to prepare to pay attention in any situation.

Given these definitions, it is relevant to consider how attention, concentration, and alertness relate to the focus of this project. It can be explained that losing concentration means attention distracted, and low alertness can be expressed as an inactive state of a student's brain and completely out of attention on the lecture. Considering Medina's statement above, technology can provide an alertness stimulus to students. This means that it activates the first brain's network and makes students' brains bounce back to a general level of attention at least. However, it is a different challenge to span this level of attention and maintain concentration levels. Despite stimulation from technology, there are still various distractions to decline concentration levels and distract attention leading to low alertness, because lecture-style teaching is likely to make students passive and disinterested [2]. This is why technology needs to monitor concentration levels during the lecture and simultaneously give persisting feedback to students and teachers.

2.1.2 Relationship between sleepiness, fatigue, and losing concentration

As mentioned above, the relationship between sleepiness, fatigue, and concentration levels should be identified, in order to use these two factors as an indicator of concentration levels in this project. Before identifying the relationship, it is important to define and distinguish sleepiness and fatigue because sleepiness and fatigue are often confused.

According to Shen *et al* [17], sleepiness and fatigue are interrelated, but distinct phenomena. Sleepiness refers to the desire to fall asleep, sometimes referred to as drowsiness. In the brain-science approach by Medina [1], sleepiness is related to the accumulation of a chemical messenger, or neurotransmitter, within the brain called 'adenosine'. The higher levels of adenosine will lead to low levels of alertness, which means the brain becomes inactive. In light of this, sleepiness during lectures means that students already become unable to pay attention to the lecture and levels of student alertness start to decline, which means a loss of concentration. In fact, Alapin *et al* [18] investigated the influence of sleep deprivation on daytime sleepiness, fatigue, and concentration levels with the participation of university students and older adults. As shown in **Figure 3**, sleep deprivation can lead to daytime sleepiness and university students show higher concentration difficulty in the lecture than those with less sleepiness. Although **Figure 3** shows that other factors still contribute to losing student concentration (as can be seen in the concentration difficulty of good sleeper students), students are likely to lose concentration when they feel higher levels of sleepiness. **Figure 4** supports this correlation between sleepiness and losing concentration, as 50% for the participation group of students. On the other hand, students can feel sleepiness during lectures not due to sleep deprivation, such as uninteresting lecture content and lecture room environment. Other studies [8, 17, 19, 20, 21] support that sleepiness in students during lectures, beyond sleepiness from sleep deprivation, affects losing concentration.

	Good sleepers	Poor sleepers
Sleep parameters		
Total Sleep Time (h)		
Older adults	6.84 (0.99)	5.04 (1.46)
Students	7.28 (1.15)	6.14 (1.48)
Fatigue (0–7 days/week)		
Older adults	0.76 (1.53)	3.45 (2.39)
Students	2.70 (1.57)	4.95 (1.57)
Sleepiness (0–7 scale)		
Older adults	2.17 (1.33)	2.88 (1.35)
Students	2.72 (1.29)	3.70 (1.32)
Concentration difficulty (0–7 days/week)		
Older adults	0.45 (1.14)	2.05 (2.03)
Students	1.81 (1.42)	4.35 (1.27)

Figure 3*. Sleep hours, fatigue, daytime sleepiness, and concentration [18]*

	Fatigue	Sleepiness	Concentration
Fatigue			
Older adults		.27	.68
Students		.43	.70
Sleepiness			
Older adults	.27		.36
Students	.43		.50
Concentration			
Older adults	.68	.36	
Students	.70	.50	

Figure 4*. Correlation among measures of daytime functioning [18]*

Fatigue is different from sleepiness and it can be defined as a lack of energy and motivation [17]. Fatigue can be accompanied by physical activities, emotional stress, boredom, or sleep deprivation [21]. In this regard, students can feel fatigued because of not only less physical energy, but also less motivation and interest, such as from lecture content and learning methods. Because fatigue is interrelated with sleepiness [17], both can be accompanied by each other. According to a study by Alapin *et al* [18], sleep deprivation can lead to daytime fatigue, and university students show higher concentration difficulty in the lecture when having high fatigue. Additionally, the correlation between fatigue and concentration levels was identified as higher than one between sleepiness and concentration levels. Besides fatigue from sleep deprivation, generally, fatigue will bring a negative impact on cognitive performance impairment, especially concentration ability [22]. In the medical approach [23], a high level of fatigue will let students often experience cognitive impairment referred to as “brain fog”. Brain fog will lead to forgetfulness, cloudiness, and difficulty concentrating, thinking, and communicating. The most frequent reason for brain fog is fatigue at **91%**. This implies that fatigue is one of the factors that highly contribute to losing concentration.

In summary, sleepiness refers to the desire to sleep and fatigue refers to a lack of energy and motivation. Both sleepiness and fatigue highly correlate with losing concentration. Considering the context of this project, if technology monitors and measures a high level of sleepiness, it is implied that a student already loses concentration (cannot pay attention to the lecture) and show low alertness, meaning that a student needs the alertness stimulation. If a student shows a high level of fatigue, it means that a student is struggling with concentration in the lecture. Although sleepiness and fatigue are interrelated, technology should notice that both are not always monitored together as the main reason for losing concentration. This is why these two factors have to be used simultaneously and analyzed together to indicate concentration levels.

2.2 Factors affecting sleepiness and fatigue

There are many reasons that students lose their concentration in the lecture, such as family background, physical health, mental state, diet, relationship, learning environment, and lecture content. Through background research, these can be divided into three main factors: internal, external, and biological factors (**Figure 5**).

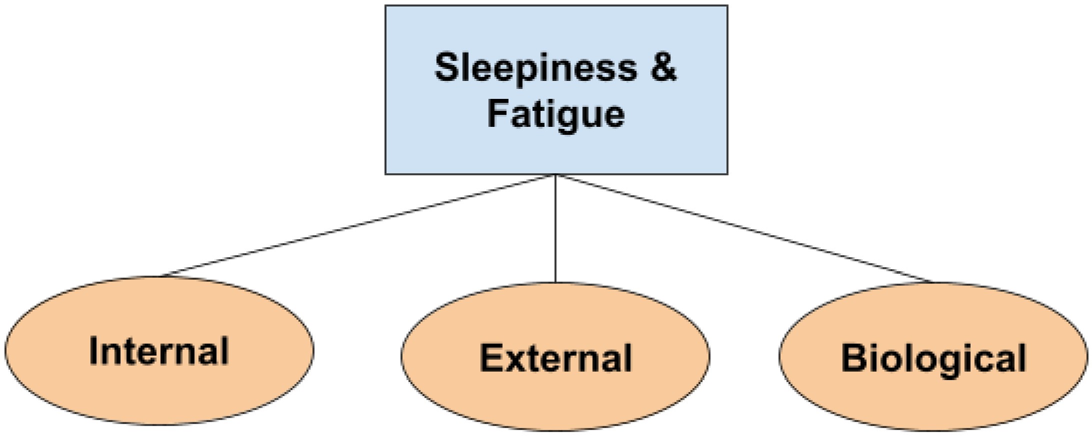


Figure 5*. Three factors affecting sleepiness and fatigue*

Internal factors refer to those that are inherent to students themselves. They are controllable and can be changed. One example of internal factors is the **daily routine**. Jackson [24] states that people who are engaged in a repetitive task can easily accumulate mental fatigue and this can highly accompany sleepiness during a work shift or lecture. A possible example of a repetitive task for a student could be studying or completing assignments on a daily basis. This could cause mental exhaustion and reduce the student's ability to concentrate during lectures [25]. Attending the same lectures at the same time every week could also be considered a repetitive task for a student, which may cause a lack of engagement or interest in the lecture content. Especially, students with repetitive early morning lectures cannot attain the last 1 - 2 deep sleep periods, leading to sleepiness and fatigue during the lecture [25]. This internal factor is controllable and can be changed by a student. With a different mindset or motivation, a student can change their daily routine which can negatively affect their concentration levels during a lecture. Also, it can be changed with external help, for example, from education organizations and parents. **Sleep deprivation** is one of the internal factors that contribute to sleepiness and fatigue during lectures. According to a study by Alapin [18] (mentioned in Chapter 2.1.2), sleep deprivation highly influences daytime sleepiness and fatigue in students, especially fatigue. As shown in **Figure 3**, although students who have enough sleep still show a little sleepiness and fatigue, it shows that lack of sleep leads to high levels of fatigue and sleepiness. Sleep deprivation could be related to daily routine so this internal factor is also controllable by students themselves. The last example of internal factors could be **physical health**. If students suffer from fatigue from physical activities such as workouts or sports associations, it will accompany daytime sleepiness and fatigue during the lecture because their body is not rested enough to enable them to absorb knowledge [9]. On the other hand, some of the internal factors are not uncontrollable and can't be changed by students themselves. **Low interest** can be another example of uncontrollable internal factors. As mentioned above, if a student is interested in the lecture, then this means that a student's brain becomes activated and a student prepares to pay attention to the lecture [1]. However, if a student is uninterested, it is difficult to pay attention and a student's brain becomes inactive, which means low alertness. According to studies by Hanh, Hershner and Chervin [9, 25], one of the main causes of sleepiness during lectures is boring lecture content which cannot draw attention and maintain concentration. This internal factor is uncontrollable by students themselves and teachers as well.

Considering the context of this project, internal factors are difficult to be considered because it could be students' privacy and if technology takes this into account, students can feel that they are infringed. However, regarding that internal factors are controllable by students themselves, feedback from the technology can motivate them to change their mindset towards the lectures and maintain their concentration.

External factors refer to objective factors around both students and teachers and affect sleepiness and fatigue during lectures. External factors are normally uncontrollable compared to internal factors. In this sense, there are numerous external factors, but two examples of external factors are reviewed in this background research. The first is the **lecture room environment.** Rautkyla *et al* [26] investigated the effect of light in the lecture room. During 90 minutes lecture, the post-lunch dip effect appeared more strongly in students exposed to the light by 4,000K, compared to those with 17,000 K. The post-lunch dip effect is a period of time in the mid-afternoon (around 3 pm) when transient sleepiness can be experienced (this is one of the biological factors so it will be explained in detail below). As a result of the investigation, students are likely to experience sleepiness during lectures when they are exposed to low light density in the lecture room. Besides light, also the room temperature of the lecture has an influence. Krauchi [27] supports that room temperature affects student sleepiness and fatigue during the lecture. Krauchi states that the low temperature in the lecture room can make students lose body heat. Losing body heat highly leads to sleepiness during the lecture [27].

The second external factor is the **teachers' teaching methods**. According to Hanh [9], students who are already used to their teachers' teaching methods can be aware of what content or activity will come next. This makes students have low interest in the lecture and can cause sleepiness during lectures. Considering the context of this project, adjustment of these external factors can be feedback from the technology to teachers, as a suggestion to help students recover sleepiness and fatigue during their lectures. In other words, external factors can assist a clear and systematic understanding of possible factors to come up with ways to minimize their effect. For example, the technology can send feedback to a lecturer that students show rather high levels of sleepiness and fatigue so a lecturer can notice that students are losing concentration. Then, the technology can suggest that a lecturer can adjust the room temperature to a little higher or light up more in the lecture room. However, this requires integration and interaction with other technologies in the aspect of a ‘Smart lecture room’. In this respect, integration with other technologies in the lecture room seems difficult because of time limits in this project, but it is a fact that it would be an interesting aspect that suggests further research.

Biological factors refer to underlying factors that contribute to daytime sleepiness and fatigue. In other words, biological factors refer to the physiological processes and systems in the human body that can influence sleepiness and fatigue. According to studies in brain science and sleep medicine [1, 28, 29], the sleep-wake cycle is regulated by two biological mechanisms: sleep-wake homeostasis and circadian rhythm, introduced by Alexander Borbely (a sleep researcher in the 1980s) in Medina’s book [1]. Sleep-wake Homeostasis refers to Process S to accumulate sleep-inducing substances in the brain. This accumulates more sleep pressure when a brain is awake longer during the day and reduces sleep pressure during sleep [1, 29]. The circadian rhythm is known as Process C, regarded as the alert drive to regulate the body’s internal biological processes and alertness levels. The circadian rhythm regulates the body’s sleep patterns, feeding patterns, body temperature, hormone production, and brain wave activity [28, 29]. These two processes work together in the brain to create the balance of the sleep-wake cycle.

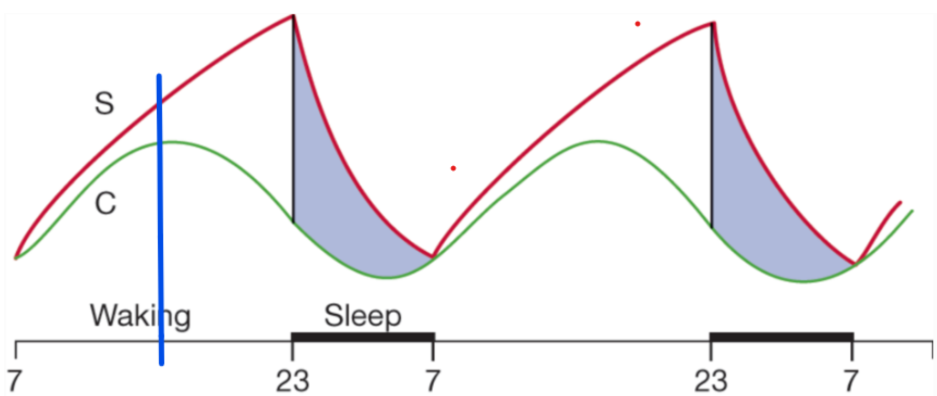


Figure 6. The graph of the signal of sleep-wake homeostasis (Process S, red line) and the circadian rhythm (Process C, blue line) for 2 days. [29, 30].

Figure 6 indicates the signal of sleep-wake homeostasis (Process S) and the circadian rhythm (Process C). The blue line is around 14 - 15 pm when humans can normally experience the 'post-lunch dip effect'. The 'post-lunch dip effect' holds that humans are likely to experience sleepiness after lunch around 14 - 15 pm, sometimes called 'afternoon sleepiness and 'afternoon nap zone'. As shown in **Figure 6**, process S gradually increased until sleep but process C starts to decline after around 14 - 15 pm. The decrease in process C can be regarded as the decline in alertness level. According to Medina [1], it is easier to experience the 'post-lunch dip effect' if the rise in process S is not counteracted by process C. He emphasized that this effect is inevitable and it might be nearly impossible for humans to do something during this period. Another biological factor is called the '10-minute rule', which refers to attention span naturally declining after about 10 minutes of focusing on a single task as can be in **Figure 7** [1, 7, 24].

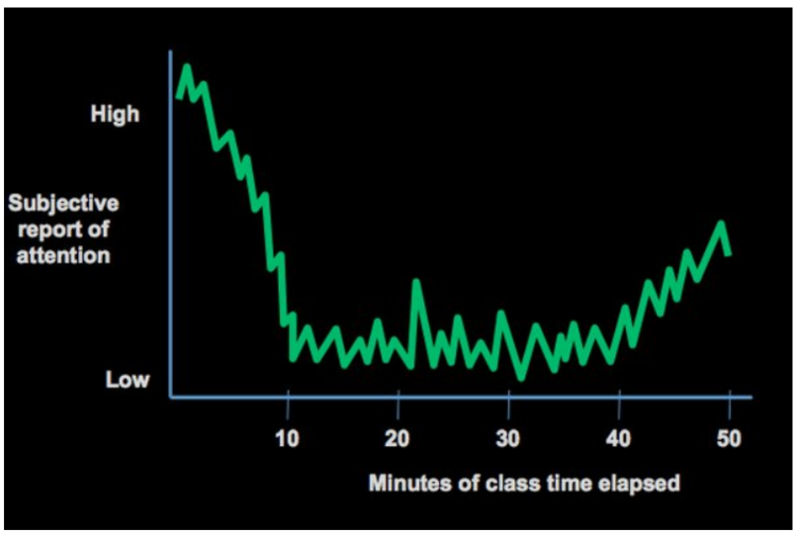


***Figure 7**. Attention level in lecture time [1]*

This factor does not directly affect sleepiness and fatigue during lectures but this factor can be considered as a biological factor, regarding that attention span decline leads to low alertness and sleepiness during lectures [1]. Interestingly, there is an increase in attention span after 40 minutes. This is because this experiment was conducted during a 50-minute lecture and students show an increase in attention span when students know that there were 10 minutes left in the lecture. There are several reasons for this attention span decrease after 10 minutes [1, 8]. One is that the brain has a limited capacity for processing information. When people are exposed to much information too quickly, their brains would be overwhelmed. Another reason is that our brains are wired to respond to novelty and change. When people are exposed to the same stimuli for a long period of time, their brains become accustomed to it, and they become less sensitive to it. This can result in a decrease in alertness levels.

Regarding the context of this project, this biological factor ‘post-lunch dip effect’ can be offset to some degrees by the technology providing the alertness stimulation interesting enough to stimulate process C, leading to counteract the sleep pressure by process S. At least, technology can give feedback or mention that the post-lunch dip might have an effect during an afternoon lecture. Real-time monitoring can be a method to monitor the effect of biological factors on sleepiness and fatigue during lectures. Additionally, by giving feedback to both students and teachers, students can notice by themselves that sleepiness and fatigue make them unable to concentrate and teachers can notice that interesting stimuli are needed to increase attention span and at least stimulate alertness, although the post-lunch dip effect’ is inevitable.

In summary, the factors that contribute to sleepiness and fatigue during lectures can be divided into internal, external and biological factors. Internal factors are inherent to the students themselves, such as daily routine, sleep deprivation, and physical health, and they are controllable and can be changed by the students themselves or with external help. But, some of the internal factors are not uncontrollable such as interest in the lecture content. External factors are on the outside of both students and teachers, such as the lecture room environment and teachers' teaching methods, and they are normally controllable. Biological factors are the physiological processes and systems in the human body that can influence sleepiness and fatigue. The ‘post-lunch dip effect’ and ‘10-minute rule’ can be examples of these factors. Understanding the factors that contribute to sleeping and fatigue during lectures gives more insight into how these factors can be considered and integrated into the technology to address the problem in this project.

2.3 Approaches to measuring sleepiness level and analysis of the applicability

There are many approaches to measuring sleepiness and fatigue levels. Because human health has been a field that has received attention recently and sleep has a close relation to health, several sleep measurements have been designed and developed. This section will provide insights into the existing approaches for current sleepiness measurement and analyze those approaches in terms of whether they could be applicable in the educational venue and in a non-distracting way.

According to several studies in brain science and sleep medicine [30, 31, 32, 33], there are two existing approaches to sleepiness measurement: objective and subjective measures. **Objective measurements** refer to measurements that can be obtained through external observation or physiological monitoring. The representative examples of objective measures are the Multiple Sleep Latency Test (MSLT) and the Maintenance of Wakefulness test (MWT) [30, 31, 33]. The MSLT is one of the first and still most widely used measurements of objective sleepiness. The MSLT measurement involves calculating the duration from turning off the lights to the commencement of the first epoch of any sleep stage. The MWT is another objective sleepiness measure which is the most widely accepted measurement. Compared to the MSLT which measures the individual ability to fall asleep, the MWT measures the individual ability to remain awake. These two measures should be conducted in the laboratory, because participants need to fall asleep or remain awake in a comfortable place and simultaneously researcher needs to conduct measurements and monitoring with reliable measuring devices for a long period (as shown in **Figure 8**).

Figure 8. The MSLT measures (left, https://www.medicalnewstoday.com/articles/multiple-sleep-latency-test) and the MWT measures (right, https://www.verywellhealth.com/maintenance-of-wakefulness-test-3015117)

In this respect, objective measurement is the verified measurement approach and has the reliability to provide an unbiased and precise assessment. However, objective measurement still shows the limitation of availability to the real world [33], because it can be expensive and invasive, and it is necessary to accompany the measuring equipment.

Considering the context of this project, objective measurements are difficult to apply to this project. As mentioned above, it shows the limitation of availability to the real world. Especially, the disadvantage of being invasive is not suitable for part of the goal of this project: measuring in a non-distracting way. Although objective measurements provide better accuracy and reliability, it is not prioritized to provide measuring accuracy and reliability, but prioritized to measure sleepiness and give feedback to notify teachers that their students are losing concentration. However, MWT measurement which assesses the individual ability to remain awake is an interesting approach to measuring awake hours instead of falling asleep. This is highly related to the relationship between sleepiness and awake hours of the day, which is mentioned in the previous section. Considering the context of this project, this approach can be used in this project to analyze student sleepiness and fatigue by monitoring students' awake time during lecture time, instead of measuring sleepiness and fatigue itself.

The subjective measures mainly rely on sleepiness self-evaluated rating scales [30, 31, 32]. These measures are typically based on a person's subjective feelings and perceptions of their level of alertness or sleepiness. The most widely used examples of subjective measures are the Standford Sleepiness Scale (SSS) and the Epworth Sleepiness Scale (ESS). The SSS measurement is a self-reported scale that asks individuals to rate their level of sleepiness and fatigue on a scale of 1 to 7 (**Figure 9**). Participants rate their level of sleepiness and fatigue on a scale of 1 to 7, for each time of the day or each day of the week. The ESS measurement is a questionnaire that asks individuals to rate their likelihood of falling asleep in different situations (**Figure 9**). In the light of self-reporting or self-evaluating, subjective measures show better applicability to the real world compared to objective measures, because of several advantages: easy to be conducted and administered and can be used in various settings. However, self-reporting and evaluating are likely to lead to biased results or assessments and less reliability and accuracy.

Given the context of this project, the subjective measure is a little challenging to be used for this project. Monitoring sleepiness and fatigue should be real-time monitoring so that technology can provide feedback and teachers notice whenever students are losing concentration. In this respect, if subjective measures are used, students should report or evaluate their sleepiness and fatigue during the lecture. This can truly distract students from the lecture, and also this can distract and demotivate teachers. However, the self-reported scale of the SSS measures seems an interesting approach in this project. This scale can be used as a kind of feedback instead of a measurement method. With the SSS scale or self-designed scale, technology can simply provide feedback to students and teachers about how sleepy and fatigued students are during lectures.

Degree of Sleepiness	Rating
Feeling active, alert, wide awake	1
Functioning at high levels, but not fully alert	2
Awake, relaxed, responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy, losing interest, slowed down	5
Sleepy, woozy, fighting sleep	6
Sleep onset, having dream-like thoughts	7
Asleep	8

Epworth Sleepiness Scale

Name: ____________________ Today's date: ____________

Your age (Yrs): ____________ Your sex (Male = M, Female = F): ________

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired?

This refers to your usual way of life in recent times.

Even if you haven't done some of these things recently try to work out how they would have affected you.

Use the following scale to choose the **most appropriate number** for each situation:

0 = would **never** doze
1 = **slight chance** of dozing
2 = **moderate chance** of dozing
3 = **high chance** of dozing

It is important that you answer each question as best you can.

Situation	Chance of Dozing (0-3)
Sitting and reading	___
Watching TV	___
Sitting, inactive in a public place (e.g. a theatre or a meeting)	___
As a passenger in a car for an hour without a break	___
Lying down to rest in the afternoon when circumstances permit	___
Sitting and talking to someone	___
Sitting quietly after a lunch without alcohol	___
In a car, while stopped for a few minutes in the traffic	

THANK YOU FOR YOUR COOPERATION

Figure 9. The SSS self-reported scale (left, https://pipelineperformancegroup.com/how-to-recognize-signs-of-fatigue/) and the ESS self-questionnaire (right, https://epworthsleepinessscale.com/about-the-ess/)

Sleepiness and fatigue can be measured indirectly by analyzing other factors. The first indirect measuring approach is measuring **Heart Rate Variability (HRV)**. Before figuring out this approach, it is important to notice the difference between heart rate and heart rate variability (HRV) because heart rate and HRV are often considered similar metrics. Heart rate refers to the number of heartbeats over a period of time and HRV refers to the specific changes in time (or variability) between successive heartbeats. Heart rate can provide information about the level of sleepiness, but generally HRV is considered a more reliable indicator of sleepiness and fatigue [34]. According to several studies [35, 36, 37], HRV tends to increase when a person feels sleepy and fatigued. During sleep, the autonomic nervous system shifts from sympatholytic towards parasympathetic dominance, and the parasympathetic nervous system leads to increased HRV. Higher HRV holds that the variation between successive heartbeats takes a longer time and it can seem that heart rate in time decrease [35, 36]. In this regard, sleepiness and fatigue can be measured by analyzing HRV or HRV taken from heart rate.

Considering the context of this project, HRV is a good measuring approach to use in this project. Although directly measuring HRV needs a reliable measuring device or sensors attached close to the heart, HRV taken from heart rate is a good measuring method, regarding that heart rate can be measured in a non-intrusive way by the sensors wearable on a wrist or ankle where the artery is placed. However, it is important to notice that other measuring factors should be used and analyzed together to measure sleepiness and fatigue because HRV is not an indicator of sleepiness and fatigue level which can be used solely. Also, it should be noted that measuring sleepiness and fatigue is for predicting the student's concentration level. For example, it can be imagined that a student feels sleepy and fatigued during the lecture so a student buys a cup of coffee during the break. Caffeine consumption affects HRV increase (will be explained in the next section about caffeine as stimulation). If only HRV is considered to determine sleepiness and fatigue for predicting the concentration level, this can be seen as HRV increasing from sleepiness and fatigue, and so it means that a student is losing concentration.

The second indirect measuring approach is measuring **eye, yawns, and body movements**. Eye movements can be an important indicator of sleepiness. A study has shown that sleepiness can affect the frequency and pattern of eye movements during the day [38]. According to this study by Tran *et al* [38], blink duration and frequency, and pupil dilation range increased whilst being sleepy. Other studies also found that during sleepiness, eye movements will become slower and less frequent, with longer periods of fixation on a single object [39, 40]. yawning is highly related to sleepiness and fatigue. In addition, Ibrahim **et al** [41] state that sleepiness and fatigue are the most common trigger for yawning, and emphasizes that identification of fatigue and sleepiness would be helped if yawning is detected. Body movements are also a great indicator of sleepiness. Most people experience involuntary movements during sleepiness, such as head nods or jerks. These head movements are definitely a clear indicator of sleepiness [42]. Some studies have found that sleepiness might lead to slower body movements and reaction times, because sleepiness leads to a decrease in the physical activity level and less energy to engage in physical activities [43, 45].

Considering the context of this project, eye and body movements are good measuring approaches to use in this project. In the aspect of eye movement, eye-blinking and eye-movement patterns can be measured and monitored in a non-distracting way, such as monitoring from Webcam and analyzing in OpenCV-based Python. In the aspect of body movements, although taking the lecture normally does not need much physical activity and body movements for students, body movements are also good measuring approaches to use in this project. For example, a webcam connecting to OpenCV-Python can monitor small body movements (such as crossing arms or legs, fixing sitting posture) and students' habits (shaking a leg, biting nails) to analyze sleepiness and fatigue levels. The sensor which can capture small body movements can be used to connect to Arduino and the Arduino data can be sent and analyzed in Python. However, it is important to notice that other measuring factors should be used and analyzed together to measure sleepiness and fatigue, because eye and body movements are not indicators of sleepiness and fatigue level which can be used solely. Because considering various factors is helpful for the accuracy of the prediction of the concentration level and also can be evitable for some situations like this: For example, it can be imagined that a student spaces out during a lecture whilst looking towards a teacher but yawning. The direction of the student's eyes, head, and body is to the teacher, so the system can mention that this student shows concentration, but in fact, it is not. In this case, yawning can be considered as another factor to consider for measuring sleepiness and fatigue, because yawning is highly related to sleepiness and fatigue. In addition, Ibrahim *et al* [41] state that sleepiness and fatigue are the most common trigger for yawning, and emphasizes that identification of fatigue and sleepiness would be helped if yawning is detected.

Measurement	Method	Pros	Cons	Analysis
Objective sleepiness measurement	measurements that can be obtained through external observation or physiological monitoring.	- Reliable and accurate - Used for diagnosis and treatment - Unbiased and precise	- Expensive and invasive - Limited availability - Should be conducted in the laboratory	- Shows limitation of availability in the lecture room and educational field. - Measuring awake hours during lecture time is an interesting approach
Subjective sleepiness measurement	Self-reporting by individuals with a self-reported scale or a questionnaire.	- Easy to be conducted and administered - Can be used in a variety of settings	- Prone to bias - Less reliable and accurate - Usefulness for diagnosis and treatment	- Will distract students and teachers - SSS scale can be used for feedback from technology
Heart rate and Heart rate variability (HRV)	HRV tends to increase when a person feels sleepy and fatigued	Not intrusive way to measure in the lecture room	HRV is not an indicator of sleepiness and fatigue level which can be used solely	- Wearable sensors can measure HRV, connecting to the Arduino. - Send Arduino data to Python to analyze sleepiness and fatigue levels. - Other factors should be used together to analyze sleepiness and fatigue levels
Eye, yawns, and body movements	- blink duration and frequency, and pupil dilation range	Can be measured in non-distracting way in the lecture room.	Better to consider another factor and analyze together for	- monitoring from Webcam and analyzing in

	increased whilst being sleepy. - During sleepiness, eye movements will become slower and less frequent, with longer periods of fixation on a single object. - sleepiness might lead to slower body movements and reaction times.		measuring sleepiness and fatigue	OpenCV-based Python - The sensor which can capture the small body movements can be used

Table 1. An overview of the methods for measuring sleepiness and fatigue levels including pros and cons, and analysis

Table 1 gives an overview of the approaches to sleepiness and fatigue measurements including pros and cons, and analysis in the context of this project. Investigating and analyzing these measuring methods give insight into how sleepiness and fatigue can be monitored and measured in a non-distracting way during the lecture. Answering the **second sub-RQ**: *What are the methods for measuring sleepiness and fatigue, in a non-distracting way, in a lecture room environment?*, objective measurements are difficult to apply to this project. However, MWT measurement which assesses the individual ability to remain awake is an interesting approach to measuring awake hours instead of falling asleep. This approach can be used in this project to analyze student sleepiness and fatigue by monitoring students' awake time during lecture time, instead of measuring sleepiness and fatigue itself. The subjective measure is a little challenging to be used in this project. However, the self-reported scale of the SSS measures seems an interesting approach in this project. This scale can be used as a kind of feedback instead of a measurement method. With the SSS scale or self-designed scale, technology can provide feedback to students and teachers about how sleepy and fatigued students are during lectures. HRV is a good measuring approach to use in this project. HRV taken from heart rate can be measured in a non-intrusive way by the sensors wearable on a wrist or ankle where the artery is placed. Eye and body movements are also good measuring approaches to use in this project. These can be measured, for example, from a webcam and analyzed in OpenCV-Python. The sensor which can capture small body movements can be used to connect to Arduino and the Arduino data can be sent and analyzed in Python.

2.4 Approaches to students' alertness stimulation and analysis of the applicability

It is difficult to stimulate alertness in order to bring back concentration, especially when students already lost their concentration and have lower alertness. Still, the teacher can stimulate students' alertness and make students concentrate again by giving some interesting lecture content and engaging students' participation with interactive teaching methods. These are the stimulation by the teacher's ability, new teaching method, or lecture content. This section will provide the approaches to students' alertness stimulation and then discuss these approaches which can be applied to the project or not.

The first approach which most students have used is drinking coffee to stimulate alertness with caffeine. It is a common scene in the short break for students to buy and drink a cup of coffee. Besides coffee, caffeine is a natural compound found in coffee, tea, and caffeine drink called 'energy drinks' [47, 48]. It has been proved by many experiments and studies that caffeine is able to make people remain on higher alertness. In fact, studies have shown that low to moderate doses of caffeine around 40 - 300 milligrams can improve energy availability, physical performance, wakefulness, reaction time, and the ability to concentrate and focus attention as well as decrease fatigue and sleepiness [44, 47, 48]. Caffeine is also able to provide significant alerting and long-lasting beneficial mood effects [46]. Furthermore, caffeine is effective stimulant to offset physical and cognitive decline due to lack of sleep [49]. This is the reason why many students bring a cup of coffee before the lecture or during the short break. However, excessive caffeine over around 400 milligrams will cause side effects of caffeine effect. Well-known downsides are anxiety, insomnia, digestive issues, and rapid heart rate [45, 47].

Considering the context of this project, having coffee breaks is a good method to stimulate students' alertness and regain attention levels. If feedback from the technology shows rather high levels of students' average sleepiness and fatigue, teachers can suggest coffee breaks or technology can send a suggestion for coffee breaks. However, it is important to notice students that caffeine can have side effects that can affect the next lecture or lectures on the next day. Sleep deprivation from the caffeine effect can truly cause sleepiness and fatigue in the lecture. Additionally, if HRV is used to measure sleepiness and fatigue, having coffee breaks is not a suitable method, because caffeine can cause rapid heart rate and this can cause confusion in measuring HRV to analyze sleepiness and fatigue levels.

The second approach is skin temperature. As mentioned in the previous chapter, a low temperature in the lecture room, leading to reduce skin temperature, is one of the factors that contribute to sleepiness in students during the lecture [27, 50]. The temperature of the lecture room does not influence sleepiness and alertness directly, but sleepiness is related to body heat loss and alertness is related to skin temperature [27, 51]. According to a study by Fronczek *et al* [51], high skin temperature can lead to increased time to maintain significant alertness, while lower skin temperature can cause sleepiness and a low level of alertness. In the detail aspect of biology science, the experiment from that study [51] showed that distal skin temperature affects the ability to remain alert - distal skin warming causes an increased time on task by 25% and decreased reaction time, and distal skin cooling causes an increased time to maintain alertness by 24%. Here, the distal skin refers to the skin that is located away from the center of the body, typically on the extremities (arms, hands, legs, feet).

Considering this project, temperature control is a good method for student alertness stimulation in the aspect of non-distracting and non-demotivating ways. For example, if students show rather high levels of sleepiness and fatigue on average, technology can suggest or adjust directly the higher temperature in the lecture room. This should need integration with the technology of temperature control in the lecture room, so the feasibility of integration requires further investigation. Additionally, a heat generation sensor attached to the student's desk can make the air around students warmer so that warmer air around students can lead to alertness stimulation and ultimately regaining attention levels. This sensor connecting to Arduino should be operated based on measuring individual sleepiness and fatigue levels. However, the temperature changes during the lecture can be distracting to the students, especially the students who are sensitive to heat and cold. Also, it is important to figure out the moderate warm temperature by conducting several testing.

There are other approaches to alertness stimulation suggested by brain science. According to the book by Medina [1], the brain constantly assesses some events for their potential interest or importance and then the more important, interesting events are given extra attention. It is also a great way to stimulate alertness by stimulating sight. Sight is only one stimulus to which the brain is capable of paying attention [1]. On the other hand, emotional events are the best-processed external stimulation. He mentioned that universally experienced stimulation comes directly from evolutionary heritage, so they hold the greatest potential for use in education and business.

Considering the context of this project, providing emotional stimulation is difficult to be used in this project as student alertness stimulation. However, visual stimulation can lead to various insights into how technology can provide alertness stimulation in this project. For example, it can be imagined that there is a small wooden box in front of the student and a small screen is attached to show sleepiness and fatigue levels. The background of this screen turns red or yellow if a student show rather a high level of sleepiness and fatigue during the lecture. From Medina's statement [1], this can stimulate their alertness and attention. However, strong and intuitive change can distract and demotivate students. It is important to figure out the moderate change by conducting several tests. For example, technology can show a piece of interesting visual information or suggest this to teachers. This visual information should be played or displayed during a break from the lecture because this can distract students and teachers as well if it is played or displayed during the lecture. Also, the visual information should be related to the lecture content so that it cannot distract and demotivate students.

Stimuli	Method	Pros	Cons	Analysis
Caffeine	Moderate doses of caffeine(40 - 300 milligrams) can improve wakefulness, the ability to concentrate and focus attention, and decrease fatigue and sleepiness	- Long maintaining stimulation - A certain and well-known stimulation	- excessive consumption cause side effects ex) anxiety, insomnia, digestive issues, rapid heart rate	- teachers can suggest coffee breaks or technology can send a suggestion for coffee breaks - partially unsuitable if HRV is used to measure sleepiness and fatigue levels.
Skin temperature	High skin temperature can lead to increased time to maintain significant alertness	- distal skin cooling causes an increased time to maintain alertness by 24%	- Individual difference	- temperature control in the lecture room - heat generation sensors attached to the desk to warm the air around students - It is important to figure out the moderate warm temperature by conducting several testing.
Stimulation in the aspect of brain science	- Visual stimulation is effective - Emotional events are the best-processed external stimulation	- Effective stimulation	- strong and intuitive change can distract and demotivate students	- limitation of availability to use emotional stimulation - visual stimulation based on measuring

			-	- Interesting visual information related to the lecture content

Table 2. An overview of the methods for alertness stimulation including pros and cons, and analysis

Table 2 gives an overview of the approaches to stimulating student alertness including pros and cons, and analysis in the context of this project. If technology indicates high levels of student sleepiness and fatigue, teachers can suggest coffee breaks or receive suggestions from technology. However, it's important to consider that caffeine may have side effects that can impact subsequent lectures. Additionally, using HRV to measure sleepiness and fatigue may be hindered by coffee breaks, as caffeine can lead to increased heart rate and affect accurate HRV analysis. Temperature control is a good method for student alertness stimulation in the aspect of non-distracting and non-demotivating ways. This can be used in this project in various ways such as integration with temperature control in the lecture room and heat generation sensors to warm the air around students. Providing emotional stimulation is difficult to be used in this project as student alertness stimulation. However, visual stimuli can lead to various insights into how technology can provide alertness stimulation in this project, such as visual change of screen background or providing interesting visual information related to the lecture content.

2.5 State of the art

This section aims to investigate state-of-the-art solutions to the problem dealt with in this project. Because few existing state-of-the-art solutions show the realization and integration with the real physical lecture room environment, the section has an extensive review of various educational fields from university lectures to sports classes or training, regarding monitoring concentration and alertness.

One example is a student alertness monitoring system, called '**Acuity**'. **Acuity** was designed and developed by Kheni et al [5], to provide automated feedback and monitoring tool for teachers by measuring student behaviors. This system aims to address the same problem dealt with in this project but during online lectures. **Acuity** captured the student's facial gaze, head motion, and body postures from a webcam and measure student sleepiness levels. As a result, **Acuity** shows rather a high accuracy of more than 90% and provides a detailed analysis to the teacher so that they can gain knowledge as to which student is paying attention (left, Figure 10) and who is not (right, Figure 10). This system gave deep insight into how measuring eye and body movements can be implemented in this project and what should be considered if they were measured.

Comparing to **Acuity**, this project is dealing with face-to-face lectures. This means that students look towards the teacher, a large screen in front, or a whiteboard. **Acuity** monitors the student's face based on the frontal face and it detects no concentration if the direction of eyes and head is not towards the screen. Given how this state-of-the-art solution can apply to this project, monitoring technology can accept some degree of the direction of eyes and head. In addition, because these can vary based on the location of the student's desk, detecting the initial looking direction can be one of the methods.

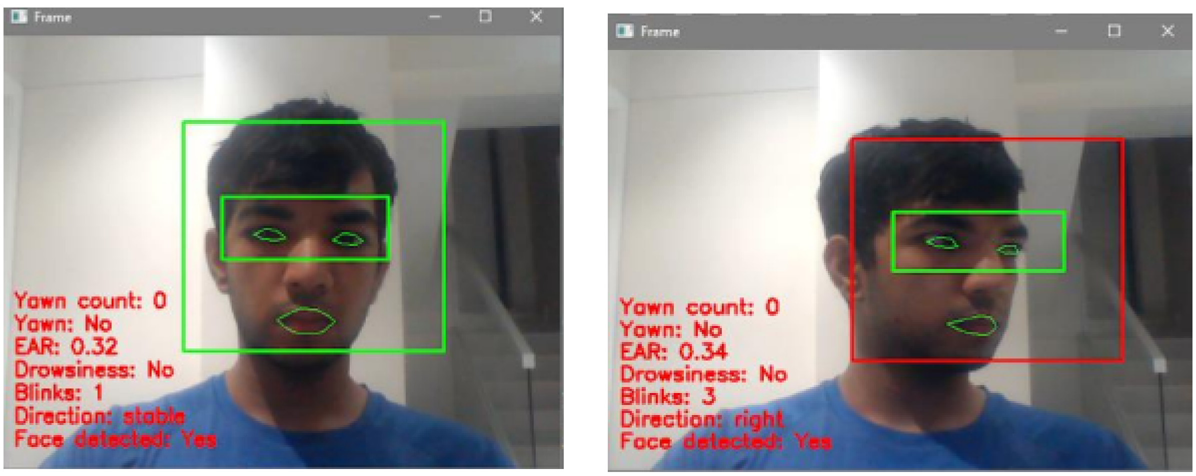


Figure 10. Acuity outcome of a student who is paying attention (left) and who is not (right).

Another example is a real-time attention monitoring system, developed by Trabelsi *et al* [49]. By using the monitoring system, a model named **'YOLOv5'**, this study aims to develop a real-time vision-based innovative classroom system to monitor student emotions, attendance, and attention levels during physical lectures. This system utilized deep learning algorithms and was tested successfully in a small group of 7 students in the actual lecture room (**Figure 11**). In addition, in further research in real lectures, this system successfully helps teachers to evaluate student concentration levels by monitoring automatically students' behavior and emotion patterns. However, this does not provide feedback to both students and teachers in real time. Only the teacher can see the feedback after the lecture from the collected data. Compared to the goal of this project, this example does not have the alertness stimulation and does not provide feedback about the student's concentration level. Though, this example can be a similar and good model case to the technology which will be developed in this project. Monitoring student emotions was not identified in the background research, and this can be one of the approaches to monitoring sleepiness and fatigue level.

Compared to this state-of-the-art solution, the system in this project will provide feedback to students about their real-time concentration levels and deliver alertness stimulation when they show low concentration levels.

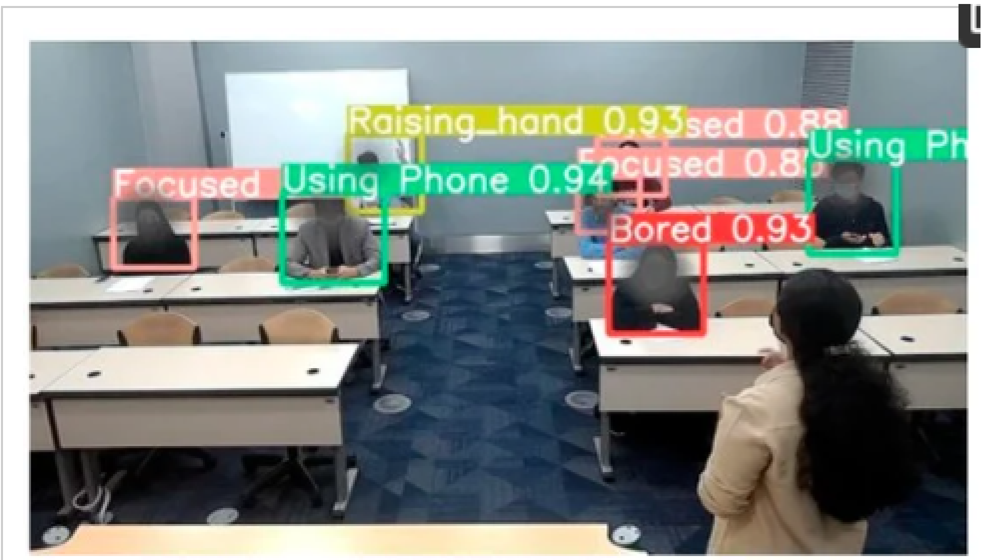


Figure 11. Test results with a small group of 7 students.

Another example is an EEG-based biofeedback system for real-time monitoring and improvement for personalized learning, called ‘**AttentivU**’ [12]. AttentivU consisted of an EEG headband ‘focus1’ (developed by BrainCo) to monitor students' participation levels by measuring concentration levels from EEG data. This system provides subtle, haptic feedback (vibrations) in real-time when the drop in engagement is detected. The usability test was conducted with the participants of 48 university students (Figure 12). The interesting point in this example is the personalization of monitoring and feedback. This discrete feedback for monitoring was identified to be able to engage student participation. It was also identified from the usability test that subtle and haptic vibrations were not demotivating students. This subtle, haptic vibration is a good example that can be used in this project as feedback or stimulation from technology. However, monitoring EEG data has some downsides. For accurate monitoring and measurement, the setup of the EEG monitoring system takes a long time and the user is recommended to use it in the paused pose, with few movements at least. In addition, EEG data is sensitive personal data. Therefore, it needs consent and an exact understanding of collecting personal data. Considering the context of this project, these downsides will definitely lead to the limitation to use EEG data in the lecture room. These downsides can be distracting and demotivating from the lecture.

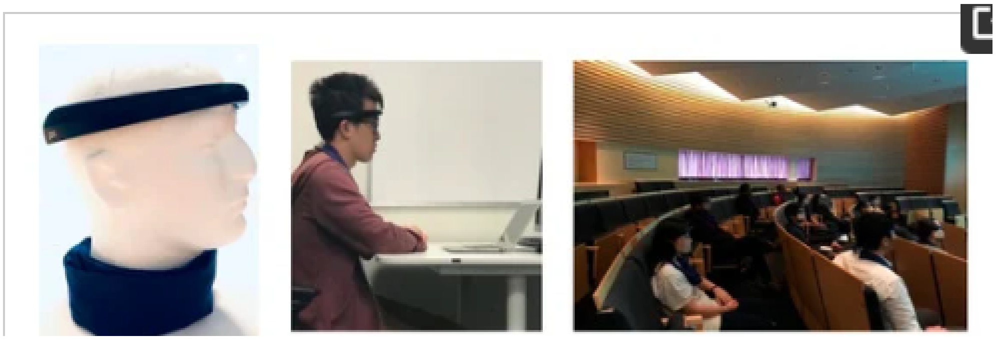


Figure 12. Focus 1 in AttentivU (left), a person who wears the AttentivU system (middle), usability test (right)

Another example in **Figure 13** is a company ‘BrainCo’ that developed an EEG band ‘**FocusCalm**’ to measure brain data and give neurofeedback to athletes, students, and employees [11]. **FocusCalm** mostly aims to train the brain for better focus and a calmer mind, especially targeted to the sports field. According to the website of this company [11], this product is verified by several reviews by an NFL veteran, pro sports breathing coach, pro mental training coach, and the head coach of an esports team.

Figure 13. A person who wears the FocusCalm (left), and a product ‘FocusCalm’ (right)

2.6 Discussion & Conclusion

This background research has delivered an extensive review of the literature regarding the definition of concentration and alertness, the relationship between sleepiness, fatigue, and losing concentration, factors affecting sleepiness and fatigue during lectures, methods for measuring sleepiness and fatigue levels and methods for alertness stimulation. The methods for sleepiness and fatigue measurements, and for alertness stimulation are analyzed in terms of availability in the lecture room environment in non-distracting and non-demotivating ways. Understanding these aspects through this background research is important for designing and developing technology to monitor student concentration levels and stimulate alertness.

The discussion will be drawn with the reflection conducted in the background research and the answer to three sub-RQs. Then, the discussion about the state-of-the-art will be delivered. Lastly, the conclusion of the background research will be provided and will provide the insights for the answer to the main RQ.

2.6.1 Discussion

To remind the RQs, the followings are the sub-RQs designed in the Introduction phase (**Chapter 1.2**).

- ***Sub-RQ1:*** *What are the factors that contribute to sleepiness and fatigue, leading to the loss of concentration during lectures?*
- ***Sub-RQ2:*** *What are the methods for measuring sleepiness and fatigue, in a non-distracting way, in a lecture room environment?*
- ***Sub-RQ3:*** *What are the methods for stimulating students' alertness, in a non-distracting and non-demotivating way, in a lecture room environment?*

2.6.1.1 Research Question 1

In **Chapter 2.2**, the factors affecting sleepiness and fatigue during the lecture can be divided into three: internal, external and biological factors. **Internal factors** include, such as, daily routine, sleep deprivation, physical health, and low interest. As the reflection referred to in **Chapter 2.2**, these internal factors are difficult to be considered because it could be students' privacy and if technology takes this into account, students can feel that they are infringed. Therefore, this project will not deal with these internal factors when the system is designed. However, regarding that some of the internal factors are controllable by students themselves, feedback from the technology can motivate them to change their mindset towards the lectures and maintain their concentration. If the feedback is designed to motivate students to change their mindset, the technology can become closer to the goal to improve student's learning quality. But, it is important to note the main goal that the feedback from the system should not be distracting students. Considering the later phase, the feedback which can motivate students to change their mindset towards the lecture can be considered as the non-functional requirement when the project is in the specification phase.

External factors include, such as, lecture room environments and teaching methods. Lecture room environments include the effect of light and room temperature. External factors can assist in a clear and systematic understanding of possible factors to come up with ways to minimize their effect. For example, the technology can send feedback to a lecturer that students show rather high levels of sleepiness and fatigue so a lecturer can notice that students are losing concentration. Then, the technology can suggest that a lecturer can adjust the room temperature to a little higher or light up more in the lecture room. However, this requires integration and interaction with other technologies in the aspect of a 'Smart lecture room'. In this respect, integration with other technologies in the lecture room seems difficult because of time limits in this project, but it is a fact that it would be an interesting aspect that suggests further research. Given the later phase, the function of the system adjusting these external factors can be one of the further research after this project and can get closer to the integration with the lecture room, in the aspect of a 'Smart lecture room'.

Biological factors include two biological phenomena. One is the sleep-wake cycle regulated by two biological mechanisms: sleep-wake homeostasis and circadian rhythm. Another is called the '10-minute rule', which refers to attention span naturally declining after about 10 minutes of focusing on a single task. As Medina's statement [1], the 'post-lunch dip effect' is inevitable, so the project will not deal with this biological factor. However, real-time monitoring can be a method to monitor the effect of biological factors on sleepiness and fatigue during lectures. In this respect, real-time monitoring technology can be one of the design choices for the ideation phase. In fact, some state-of-the-art solutions using this technology are identified in **Chapter 2.5**.

Overall, the **first sub-RQ** can be answered that there are three factors affecting sleepiness and fatigue during the lecture and they are external, internal, and biological factors. Given the context of the project, these three factors will not be directly dealt with in this project. However, the feedback which can motivate students to change their mindset towards the lecture can be considered as a non-functional requirement when the project is in the specification phase. Real-time monitoring technology can be one of the design choices for the ideation phase. Additionally, the function of the system adjusting these external factors can be one of the further research after this project and can get closer to the integration with the lecture room, in the aspect of a ‘Smart lecture room’.

2.6.1.2 Research Question 2

The measuring approaches discussed in **Chapter 2.3** can be divided into two: direct and indirect measurements. **The direct methods** are the existing measurements in sleep medicine and they are divided into objective and subjective measurements. The objective measurements refer to measurements that can be obtained through external observation or physiological monitoring, such as MSLT and MWT. These objective measurements should be conducted in the laboratory and it is necessary to accompany the measuring equipment. In this regard, objective measurement is invasive, and so it seems difficult to deal with this measuring approach in this project. The subjective measurements mainly rely on sleepiness self-evaluated rating scales such as SSS and ESS. In this regard, students reporting or evaluating their sleepiness and fatigue during the lecture will definitely be distracting. These subjective measurements are difficult to deal with in this project, but the SSS sleep and fatigue assessment can be used to send feedback about students’ concentration as a scale. For example, the system sends feedback about students’ concentration levels after predicting the concentration levels from the data of sleepiness and fatigue and indicating on a scale from 1 - 7.

The indirect methods contain measuring HRV, eye, body movement, and yawning. The indirect methods accompany the analysis of the collected data for measuring sleepiness and fatigue. In addition, it is necessary to consider more than two factors for the analysis (example in **Chapter 2.3**). Regarding the non-distracting and non-demotivating ways, the indirect measuring methods seem great to be used in this project. HRV can be measured by the heart rate sensor worn on the wrist. Eye, yawning and head movements can be measured by monitoring face detection using OpenCV. With the data of two or more factors by those methods, students’ concentration can be predicted and indicated from the analysis of the collected data.

Overall, the **second sub-RQ** can be answered that there are two methods for measuring sleepiness and fatigue during the lecture and they are direct and indirect approaches. Given the context of the project, the indirect measurements can be dealt with in this project in the aspect of non-distracting and non-demotivating ways. The collected data from measuring with the indirect methods can be used to predict students’ concentration levels. These predicted concentration levels can be indicated on a scale from 1 - 7, inspired by the SSS scale assessment.

2.6.1.3 Research Question 3

The approaches to alertness stimulation discussed in **Chapter 2.4** includes the caffeine effect, skin temperature, and stimulation in the aspect of brain science. **The caffeine effect** holds that proper caffeine consumption improves energy availability, physical performance, wakefulness, reaction time, and the ability to concentrate and focus attention as well as decreases fatigue and sleepiness. Considering that one of the main targets of the system in this project is the university students, this stimulation is one of the best approaches to stimulating students' alertness. However, it cannot be used as immediate feedback to students from the monitoring technology. This stimulating method can be used as a suggestion from the system for the break during the lecture. If the system monitors sleepiness and fatigue by measuring HRV, then this stimulating approach is not an appropriate method for alertness stimulation, because caffeine can affect the HRV decreasing.

Skin temperature can affect a student's alertness. High skin temperature leads to increased time to maintain significant alertness. In this regard, this approach can be used, for example, by adjusting the temperature of the lecture room or the temperature of the surroundings of students. Adjusting the lecture room temperature seems difficult to deal with in this project, because it needs the integration with a temperature control. Given the time limitation and feasibility, it is difficult to use this method in this project. Adjusting the temperature of the surroundings of students can be feasible by a heat generation sensor. However, regarding that it can influence other students, this could be distracting other students, especially students who are not losing concentration.

The stimulus in the aspect of brain science includes potential interest and visual information. Especially, visual information is effective to stimulate alertness. In this regard, the system which will be built in this project can send alertness stimulation by the visual information. For example, feedback on concentration levels can be sent to students with different colors. By assigning red to low and green to high, students can notice feedback intuitively and clearly. Additionally, changing green to red can be regarded as an alert and this intuitive visual information can make students come into the alertness increase.

Overall, the **third sub-RQ** can be answered that there are three methods for alertness stimulation and they are the caffeine effect, skin temperature, and the stimulus in the brain science way. Given the context of the project, the caffeine effect is not suitable to be used in the monitoring technology. The system will be designed based on real-time monitoring and feedback. In this respect, the caffeine effect cannot be used in this project as the immediate alertness stimulation. However, it includes the possibility of the usage to give the suggestion from the system for the break during the lecture. Skin temperature can stimulate students' alertness by controlling the temperature of the lecture room or the surroundings of students. The first example is difficult to feasible because it needs the integration with other technologies in the lecture room and because of the time limitation of this project. The second example could be used in this project, but this still enables students to be distracted by ever-changing temperatures. The stimulus in brain science way seems the appropriate method for alertness stimulation in this project. This can be applied to this project by displaying concentration levels with visual information. As mentioned above, the example is to display concentration levels with different colors and additionally it can be displayed by the emoji like happy or sad, or any visual intuitive information.

2.6.1.4 State-of-the-art

In Chapter 2.5, four solutions of state-of-the-art were discussed. These four solutions use real-time monitoring and feedback technology. Two solutions '**Acuity**' and '**YOLOv5'** can be regarded as the model case of the system which will be designed in this project. These two solutions monitor the students' concentration levels and provide feedback, but they do not provide alertness stimulation based on feedback, in order to regain concentration and be alert again. The solution of the alertness stimulation can be found in the third solution of state-of-the-art. '**AttentivU**' is the technology monitoring student's concentration levels and stimulating alertness in real-time. It is based on the EEG data which was decided not to use in this project, but '**AttentivU**' provide alertness stimulation by providing the small and haptic vibration when a student shows low concentration levels detected from EEG data.

2.6.2 Conclusion

In this chapter, this project conducted a thorough discussion on the sub-research questions related to factors contributing to sleepiness and fatigue during lectures, methods for measuring sleepiness and fatigue in a non-distracting way, and methods for stimulating students' alertness in non-distracting and non-demotivating ways.

Regarding **the first sub-RQ**, three main factors were identified: internal, external, and biological factors. While internal factors, such as daily routine, sleep deprivation, physical health, and low interest, are challenging to address directly in this project due to privacy concerns, feedback from technology can still play a crucial role in motivating students to change their mindset towards lectures. External factors, such as lecture room environments and teaching methods, can be adjusted to minimize their impact on sleepiness and fatigue during lectures. However, further research and integration with other technologies are needed to implement these adjustments effectively.

The second sub-RQ explored direct and indirect approaches to measure sleepiness and fatigue. Direct methods, including objective and subjective measurements, pose challenges in terms of invasiveness and potential distractions. Indirect methods, such as measuring HRV, eye movements, body movement, and yawning, offer non-distracting alternatives. These indirect measurements can be used to predict students' concentration levels and provide feedback in a non-intrusive manner.

The third sub-RQ investigated methods for stimulating students' alertness. While approaches like caffeine consumption and temperature control have their limitations and challenges in implementation, the use of visual information and feedback can be an effective way to stimulate alertness. Visual cues and intuitive displays of concentration levels can serve as a non-distracting and non-demotivating method for alertness stimulation.

Examining the **state-of-the-art** solutions discussed in **Chapter 2.5**, examples were found that monitor concentration levels and provide feedback, but do not incorporate alertness stimulation. However, the 'AttentivU' solution showcased the integration of EEG data for alertness stimulation through small haptic vibrations. While EEG data were not considered for this project, it demonstrates the potential for real-time alertness stimulation based on physiological data.

In conclusion, this chapter provided insights into the factors influencing sleepiness and fatigue during lectures, methods for non-distracting measurement of sleepiness and fatigue, and approaches for non-distracting alertness stimulation. The project will focus on leveraging real-time monitoring and feedback technology, utilizing indirect measurement methods, and incorporating visual displays to enhance students' concentration and alertness during lectures.

Chapter 3 - Methods and Techniques

This chapter explains the design methodology and techniques used in this project. It starts with a description of the design method chosen for this project and provides a brief overview of how the project follows the steps of this design method. The next section, Techniques, will explain how it is exactly applied to this project and why this design methodology has been chosen.

3.1 Design method

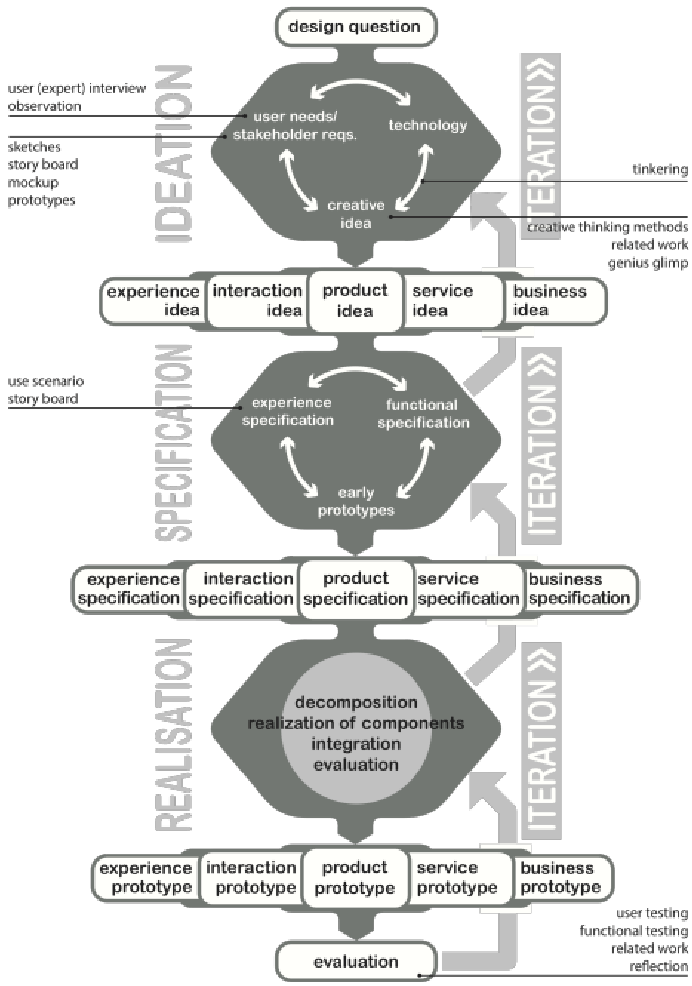


Figure 14. A creative technology design process [53]

A creative technology design process in **Figure 4** introduced by Mader and Eggink [53] is used for the design methodology. This design process contains four cyclic phases: Ideation, Specification, Realisation, and Evaluation. These four phases allow to go back to the previous or earlier phases and they do not restrict to following the order of the phase, as can be seen in **Figure 4**. In addition, each phase suggests the spiral form. The ideation phase can be started with a design question in terms of a product idea, an order from a client or stakeholders, or creative inspiration. These aspects can be considered first and moved to any aspect because of the spiral form. The specification phase focus on the functionality, and user interaction or experience, and deals with a number of prototypes to explore the design choice by applying a short evaluation and feedback loop. Three aspects of the specification also suggest the spiral form. In the realisation phase, the final version of the prototype will be implemented by following the proven methods of engineering design: decomposition of the start specification, the realisation of the components, integration of the components, and evaluation. The last phase is the evaluation phase, which evaluates the final prototype by doing user testing.

3.2 Techniques

3.2.1 Ideation phase

Based on the design process (**Figure 4**), the ideation phase has three different starting points: user needs/stakeholder requirements, creative ideas, and technology. In this project, the ideation phase starts with the **user needs/stakeholder requirements** because stakeholders of the technology which will be developed in this project seem obvious. Stakeholder identification and analysis will be outlined and stakeholder requirements will be delivered. After this, ideation moves on to the **creative idea** to come up with initial design choices for the technology that will be developed in this project. Then, **technology** will be considered based on what has been done in earlier steps, in order to choose and concrete the final design choice.

3.2.1.1 Stakeholder Identification and analysis

The power-interest grid will be used for stakeholder analysis. This method is one of the most used methods for stakeholder analysis and it is the most found analysis method when looking online for stakeholder analysis methods. Olander [54] states that stakeholders can be analyzed depending on their influence on the project and their level of interest. In **Figure 5**, the vertical axis of the grid is the power of the stakeholders toward the project, while the horizontal axis represents the level of stakeholders' interest. The power-interest grid shows the different approaches to categorizing stakeholders: Key stakeholders (high power & high interest), Keep satisfied (high power & low interest), Keep informed (low power & high interest), and Minimum effort (low power & low interest). This analysis method is one of the most used methods to show visually classify stakeholders.

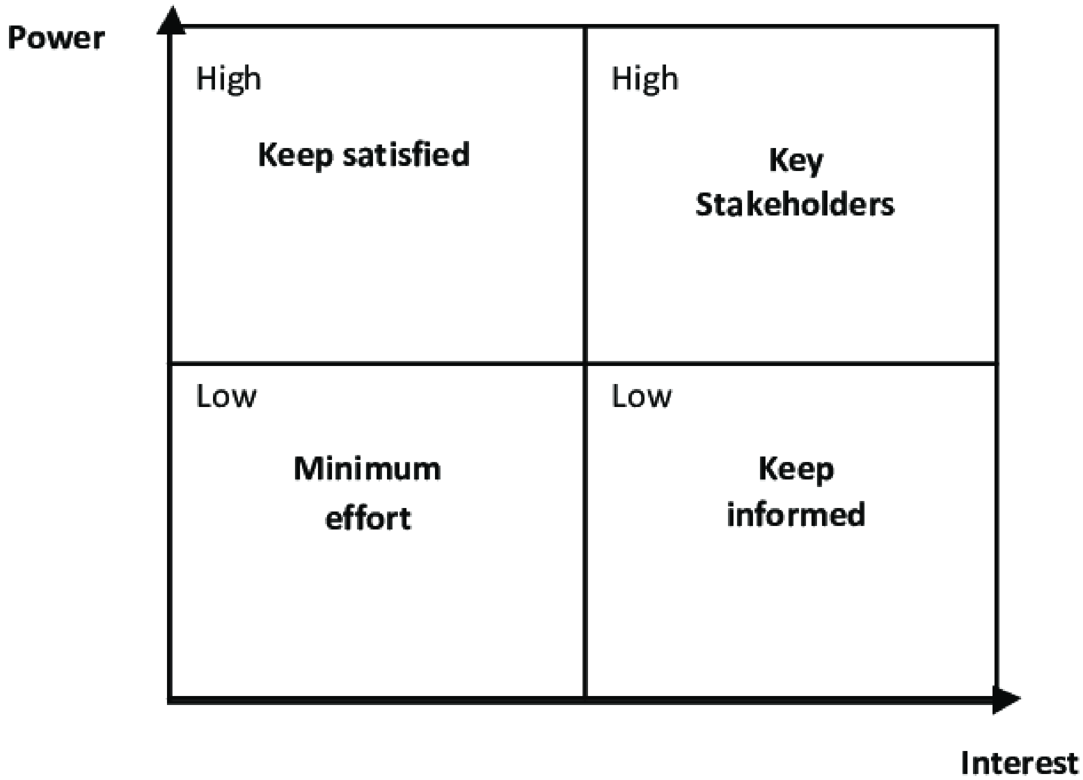


Figure 15. The power-interest grid for stakeholder analysis [54]

3.2.1.2 Stakeholder requirement

For stakeholder requirements, this project will follow a checklist of MoSCoW-priority from the knowledge gained from *Module 6 of BSc Creative Technology* [55]. The reason for using this method is when the M6 project had been in the stakeholder phase, the requirements for the primary users (as stakeholders) were drawn in detail by this method, and this gave much helpful insight into the specification phase. The MoSCoW method holds that the system Must, Should, Could or Won't offer. By doing a semi-structured interview with clients and possible users, preliminary requirements will be drawn so that this allows stakeholders to assess the value of the requirements and it helps prevent overlooking some requirements [55]. In detail for MoSCoW method, this consists of four categories mentioned above. The first category "Must offer" represents the non-negotiable needs. The second category "Should offer" hold that it is essential but not vital. The third category "Could offer" represents that it is not necessary to the core functionality and literally nice-to-haves. The last category "Won't offer" represents the requirements not included in a specific release this time, in order words not significant this time at least.

3.2.2 Specification Phase

The beginning of the specification phase will be developing the preliminary functional and experience specifications.

3.2.2.1 Preliminary Functional and Experience Specification

The preliminary functional specification will be based on the requirements of the stakeholders and the background research in **Chapter 2**. The preliminary functional specification will be based on the requirements of the stakeholders. Then, these preliminary functional and experience specifications will be categorized by the MoSCoW method mentioned above.

3.2.2.2 Early Prototype

The early prototype has the purpose to specify the functional and experience specifications, and to have a more finalized concept. For this, paper prototypes will be designed. According to Klemmer [56], the paper prototype is effective to identify the user interaction and receive feedback for the prototype. Klemmer also mentioned that the paper prototype can be designed fast meaning that multiple different prototypes can be designed. These multiple prototypes enable a designer to receive much better feedback. Additionally, a complete prototype can make participants uncomfortable giving clear feedback, but the paper prototype looks like an incomplete and easy-designed prototype so participants may feel comfortable criticizing the prototype which means much better feedback for the better design choice of the prototype.

3.2.2.2 Revised Functional and Experience Specification

Here, the preliminary functional and experience specifications will be revised based on the evaluation of the early prototypes.

3.2.2.3 System Architecture

Based on the revised functional and experience specifications, the system architecture will be delivered. The system architecture will be divided into the general system architecture and the specific system architecture. The general system architecture will deliver the diagrams of the general system architecture and the relationship between the main and sub-systems. The specific system architecture will take into account each sub-system and its architecture.

3.2.3 Realisation Phase

In this phase, the finalized concept in the specification phase will be realized into the prototype.

3.2.3.1 Components and System Overview

Before implementing the hi-fi prototype, it will be discussed which components are needed to realize, divided into the hardware and software. Then, the simplified system overview will be delivered in order to avoid the complexity and some implementation problems.

3.2.3.2 Performance

After the realization of the hi-fi prototype, several pilot tests will be conducted for some purposes - debugging, adjusting some variables, and self-evaluating the performance of the prototype. This assessment will be based on the functional requirements defined in the specification phase.

3.2.4 Evaluation phase

After the prototype is well-developed and meets the proper requirements, user tests will be conducted to evaluate this prototype. Usability tests will be conducted with 6 participants. The observation and the interview will be included in these tests. Based on the results of the observation and the interviews, the prototype will be evaluated and assess how well the prototype meets the experience requirements.

Chapter 4 - Ideation

This chapter will give the identification of the main stakeholders and their analysis. After this, the preliminary requirements are defined in order of priority, by the MoSCoW method. Initial concepts will be come up with, based on the results of the **user needs/stakeholder requirements** in the ideation phase. From the initial concepts, the final concept will be developed and decided from much insight from the previous phase.

4.1 Stakeholder Identification

Table 1 shows the identification of the four main stakeholders of this project.

Stakeholder	Role	Contact Person	Contact Methods
UT-DMB (Client)	Decision-making	Mannes Poel	Meetings Email Microsoft Teams
Supervisors	Decision-making Support Guidance	Mannes Poel & Max Slutter	Recurring meetings Email Microsoft Teams
UT Students	Primary users	-	Meetings Email Communication app
UT professors (teachers)	Primary users	-	Meetings Email Microsoft Teams
Designer	Developers in this project	Myungwon Youn	-

Table 3 Stakeholders Identification

4.2 Stakeholder Analysis

As mentioned in **chapter 3.2.1.1**, the four main stakeholders identified above will be analyzed using the power-interest matrix. In **Figure 16**, the primary stakeholders of this project are positioned on the matrix based on their level of power and interest in the project. The analysis of each stakeholder will be explained in detail below.

Figure 16. Power-Interest matrix of the main stakeholders

4.2.1 UT-DMB, Client

The UT-DMB, the University of Twente: the Data Management & Biometrics, is the client of this project. UT-DMB provides decision-making for this project and this project deals with sleepiness as a related indicator of concentration level and monitors sleepiness level based on collecting data as brain-monitoring data and management, which is the same as what UT-DMB deals with. Importantly, this project is planned to conduct by UT-DMB. Therefore, this client has considerable power and interest in this project. Overall, based on this, UT-DMB is **the key stakeholder** which has high power and high interest, and this means that this stakeholder should be managed closely.

4.2.2 Supervisors

The supervisors, Mannes Poel and Max Slutter, are also the main stakeholders. They provide decision-making in this project, and provide much support and guidance for this project. In addition, they approve the possibility to progress this project further. This means that they are highly involved in this project and thus they have significant power and interest. Based on this analysis, the supervisors are **the key stakeholders** who have high power and high interest and should be managed closely.

4.2.3 UT Students & Professors

UT students and professors are the primary users of the technology which will be developed in this project. This project aims to make the lecture become more positive and engaging for both. This definitely means that UT students and professors are highly involved in every phase of this project to figure out their needs. The main, final goal of technology is to integrate into the university lecture. Thus, UT students and professors have as considerable power as the two main stakeholders above. Comparing them, UT students and professors have high interest, but lower than UT-DMB and supervisors. First, in terms of UT students, they have already adjusted to the UT education method whether they are satisfied with it or not. Clearly, their first priority is their academic performance in this education system. This means that some students might not be interested in the appearance of new technology. However, judging from the experience in UT (many events, attempts, and changes), UT students are expected to be a little of interest in this project rather than disapproval of new technology in the UT education system. In terms of professors, not only UT professors, many professors or teachers have adhered to the traditional teaching method and tend to not welcome the appearance of new educational technology [1]. This may not matter in the implementation phase, but for the actual integration into the lecture, this issue should be considered in the project to identify the needs of this stakeholder. This is the reason that UT professors are analyzed to have the lowest interest, comparing other stakeholders. Overall, UT-students and professors are **the "key stakeholders" stakeholder**, which means they should be managed closely and their needs should be considered.

4.2.3 Designer

As the designer, Myungwon Youn is responsible for developing the technology associated with the problem that this project attempts to address. Myungwon Youn has high power but is slightly lower than UT-DMB and supervisors because the designer should follow preconditions and guidance from the client and supervisors. Overall, the designer is the "Key stakeholder", which has high power and high interest.

4.3 Stakeholder Requirements

Table 3 represents stakeholder requirements. These requirements are categorized in order of priority by the MoSCoW method mentioned in **chapter 3.2.1.2**.

MoSCoW category	Requirements	Reference	Explanation
Must	Accurate Sleepiness measurement	UT students UT professors	Provide reliable feedback by measuring accurate sleepiness levels. This requirement is essential to achieve the project goal.
	Non-distracting monitoring and feedback	Client UT students	Monitoring and feedback should be designed to avoid distractions during lectures. It should be given in a way that does not interface with students' attention.
	Non-distracting stimulation	Client UT students	The stimulation system should not be distracting or demotivating to the students. It should be designed to maintain their engagement and motivation.
	Real-time monitoring of sleepiness level	UT students	This is a core requirement of this project as it forms the basis of the feedback and stimulation system. The data must be based on real-time monitoring.
	Ethical considerations	UT students UT professors	Ethical considerations should be addressed to ensure that the technology used in the GP project is safe and respects the privacy of students. This project should ensure that the technology complies with ethical standards and the data is

			collected and used appropriately.
Should	User-friendly interface	UT students UT professors	The interface should be easy to use during lectures and understand by both students and professors. It should not require extensive training or specialized knowledge.
	Data privacy and security	UT students	All data collected should be securely stored and protected. Only UT professors, as authorized persons, should have access to the data.
Could	Customizable feedback	UT students	The feedback could be customizable to meet the needs of different professors and students. This will ensure that the feedback could be changed to the specific lecture style and teaching methods by each professor.
	Integration with existing educational technology	UT professors	The project could be designed to integrate with existing educational technology.
	Gamification and entertainment feature	UT students	The system could include gamification features, such as rewards and leaderboards, to increase student motivation and engagement in stimulating alertness during lectures.
Won't	Invasive data collection	UT students	

Table 4. MoSCoW analysis for stakeholder requirements

4.4 Initial Concepts

In the previous chapters, the project deals with the user needs/stakeholder requirements, as the starting point of the ideation phase. In this chapter, this project moves on to the next step of the ideation phase. To come up with initial concepts as many as possible, there was a short brainstorming session. This session did not consider the non-distracting and non-demotivating way to monitor sleepiness and stimulate alertness, because this could lead to limiting the brainstorming process. They will be considered in the phase to concrete and decide the final concept.

4.4.1 Installation concept

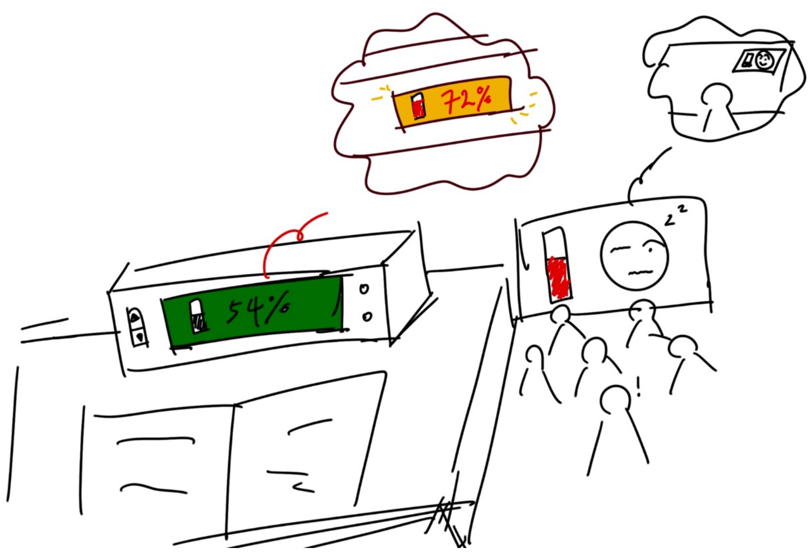


Figure 17. Brief sketches of the first initial concept

In **Figure 17**, the first of the initial concepts is a sort of installation. On the student's desk, there is a small wide box. This box consists of a screen, a small camera or a webcam, small sensors providing subtle and haptic vibration, and possibly a heat generation sensor.

The external camera will be used to capture students' eye and body movements to measure sleepiness and fatigue levels. In OpenCV-based Python, these measurements will be analyzed to predict how students are losing concentration in real-time.

This prediction will be indicated on the screen as the percentage or the scale from 1 to 7 using the SSS scale (Figure 9). Based on this indicator, the background of the screen will be decided. If a student shows a good concentration level (or not losing concentration at least), the screen background is normally green. If a student seems to start losing concentration, the screen turns yellow. If a student seems losing concentration and low alertness, the screen turns red and additionally subtle and haptic vibrations will be provided as feedback to the student. The heat generation sensor can be included in this box, to provide warmer air around the student to stimulate alertness if a student seems to start losing concentration.

For the teacher, there is a small box on the desk. The box consists of small green, yellow and red LEDs, and a small screen. Measuring sleepiness and fatigue levels and prediction of losing concentration will be measured on average for teachers. This prediction will be indicated on the screen as the percentage or the scale from 1 to 7 (same indicator with students but average value). LED works the same with the background of a screen for students (green for good concentration, yellow for starting to lose concentration, and red for completely losing concentration). Teachers can notice the average student concentration levels in real-time and teachers can find an appropriate time for breaks to enable students to regain their attention levels.

4.4.2 Wearable Concept

Figure 18. Brief sketches of the second initial concept

In **Figure 18**, the second of the initial concepts is a sort of wearable. The wearable consists of a small screen, a small vibration generator and some input buttons.

The wearable will be given to students before the lecture by the teacher. Wearable measure students' individual HRV around 10 minutes into a lecture. Based on this average HRV, the system will determine whether students losing concentration or not, by measuring the HRV and predicting concentration levels. All components in this wearable system are connected to Arduino. The Arduino program will be uploaded on the board and this will be operated when the lecture begins.

This prediction will be indicated on the screen as the percentage or the scale from 1 to 7 using the SSS scale (Figure 9). Based on this indicator, the background of the screen will be decided. If a student shows a good concentration level (or not losing concentration at least), the screen background is normally green. If a student seems to start losing concentration, the screen turns yellow. If a student seems completely losing concentration and low alertness, the screen turns red and additionally subtle and haptic vibrations will be provided as feedback to the student. The heat generation sensor can be included in this box, to provide warmer air around the student to stimulate alertness if a student seems to start losing concentration.

For the teacher, there is a small screen on the desk. Sleepiness and fatigue levels and prediction of losing concentration will be measured on average for teachers. This prediction will be indicated as the bar and simply an intelligible symbol (such as an emoji and shape). Teachers can notice student concentration levels in real-time and teachers can find an appropriate time for breaks to enable students to regain their attention levels.

4.4.3 Gamification Concept

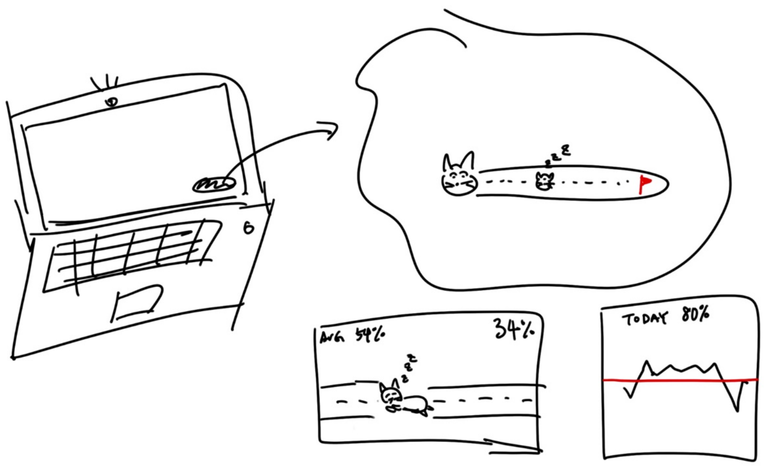


Figure 19. Brief sketches of the third initial concept

The third of the initial concepts is inspired by the Could category of the stakeholder requirements in **Chapter 4.3**. For the Could category, one participant of UT students suggests the gamification features which can engage student concentration and motivation by themselves.

In this concept, the game is inspired by the rabbit and turtle race. Students are randomly assigned to an animal before the module. The game will be played automatically when the lecture begins. The game will be designed in Unity.

Webcam on the laptop will be used to capture student eye and body movements to measure sleepiness and fatigue levels. In OpenCV-based Python, these measurements will be analyzed to predict how students are losing concentration in real-time. The value will be sent to the Unity and this will be indicated on the screen. This can be minimized as a small interface so that it cannot distract or demotivate students. This prediction will be indicated on the screen as a scale from 1 to 7 using the SSS scale (Figure 9). This scale will be the speed of the animal assigned to students and the animal will fall asleep on the road if the prediction is indicated as scale 1.

The small interface only shows the race accomplishment of how far the animal has run. 100% of this accomplishment means that a student shows an outstanding concentration level during a lecture. If this interface window is maximized, the average race accomplishment of all students and individual accomplishment will be indicated as the percentage. This can lead to a competitive spirit which can affect alertness and regaining attention.

After the lecture, Python will analyze the outcome of the race in the last 7 lectures, and the interface designed by Unity will show the graph as an individual analysis of concentration levels during the last 7 lectures.

4.5 Final Concept

Considering the initial concepts in chapter 4.4 and the stakeholder requirements in chapter 4.3, the final concept for this project will be the first initial concept (chapter 4.4.1) with some revisions. This concept was selected because it addresses the problem that this project attempts to solve and the feedback method seems intuitive and appropriate in a non-distracting way.

From stakeholder requirements, gamification features are interesting points and this is preferred personally. The small revision of the first initial concept is to add some game-like features, in order to engage student motivation by oneself.

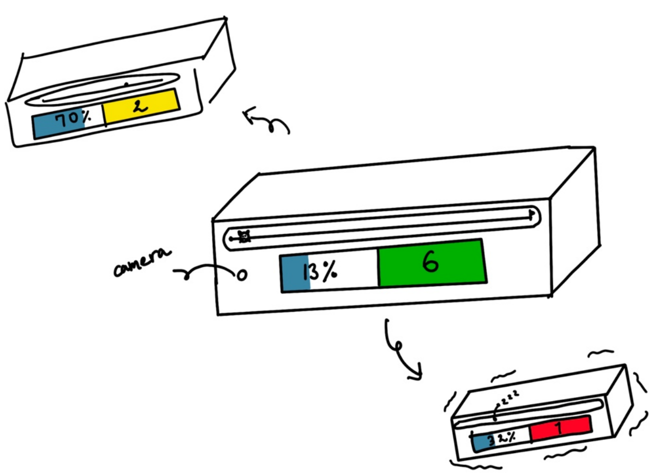


Figure 20. Brief sketches of the final concept

As shown in Figure 20, the game-like feature of the animal race is added. The race accomplishment will display on the small wide screen above a small screen for indicating the percentage of race accomplishment and the scale from 1 to 7 to concentration levels (and also can be considered as the animal's speed). The other features are identical to the original first initial concept.

However, gamification features can be removed in the later stages through lo-fi testing. If it is identified through several lo-fi tests that this feature can distract or demotivate students from the lecture itself, the final concept will be the original first initial concept or one with additional little revision. Although the gamification feature can distract or demotivate, this project will prioritize the revision of this final concept first and then will change the final concept if there is no room for improvement or change.

Chapter 5 - Specification

This chapter aims to specify the final concept. First, the global requirements (system requirements) will be given. Then the lo-fi prototype will be developed as the paper prototype. The results of several tests will be described and the global requirements will be revised based on these results. After this, the final concepts and global requirements will be revised. Lastly, the functional architecture will be delivered with the general system architecture and system function diagrams for sub-systems.

5.1 Preliminary Global Requirements

The initial global requirements (system requirements) will be defined in this chapter, including functional and user requirements. The requirements will be categorized with the MoSCoW method (explained in Chapter 3.2.1.2). These initial global requirements will help to figure out how lo-fi prototypes can be designed, what should be tested, and what should be the goal of the lo-fi tests.

Table 5 below shows the functional requirements. These requirements will be categorized into Must, Should, Could and Won’t categories (MoSCoW method).

Category	Functional Requirement	Reference

Must	The race must start when the technology starts to operate.	Stakeholders (Easy user interface and interaction)
	The camera must capture and analyze the student's **eye movements** (blink duration and frequency, and eye direction) and **head movements** (head nod, doze off).	Background research
	The analysis must predict the student concentration level in **real-time**.	Background research
	The right screen must display the scale of the student concentration level from **1 to 7**. (1 for low level, 7 for high level).	Background research (SSS scale)
	The left screen must display the student's **accomplishment of the race** in real-time.	Final concept & Stakeholders (gamification)
	The small wide screen must display the **animal's species** and the animal must **move based on the scale** of concentration levels.	Final concept & Stakeholders (gamification)
	The **background** of the right screen should be turned based on the scale of the concentration levels. For example: ● Yellow for the scale 2 ● Red for the scale 1	Background research (Alertness stimulation)
	The **average scale** of students' concentration must be displayed on the screen placed on the teacher's desk.	Final concept
Should	The **animal speed** should be in proportion to the **scale** of the student concentration level.	Final concept
	The animal species should be displayed simply and intuitively, and the animal race should be displayed intuitively.	Final concept & stakeholders (real-time and gamification)
Could	The technology could start to operate in different ways. ● Start to operate automatically when the lecture starts. ● Start to operate when the lecture starts and the teacher authorizes it to operate. ● Start to operate when the lecture starts and the student input to start if the student wants to use it.	Stakeholders (Easy user interface and interaction)
	The **vibration** could be delivered when the student shows the lowest scale of concentration level.	Background research (state-of-the-art)
	The vibration could be delivered to the teacher's desk when the average scale shows rather a high scale (maybe 6).	Background research (state-of-the-art)
	The vibration could be subtle enough to deliver subtle and haptic vibration to the student's desk.	Background research (state-of-the-art)
	The average scale of students' concentration levels could be	Project goal

	displayed as simple.	(non-distracting and non-demotivating)
Won't	The light on the screen will not be turned suddenly and dramatically.	Background research (alertness stimulation)

Table 5. Functional Requirements

Table 6 below shows the user requirements. These requirements will be categorized into Must, Should, Could and Won't categories (MoSCoW method).

Category	User Requirement	Reference
Must	The technology must be easy to use and interact with.	Stakeholders
	The monitoring must be done in a **non-distracting** way.	Project goal
	Two screens must display the race accomplishment and the scale of concentration levels in a non-distracting way.	Final concept
	The feedback must be delivered to the students in a **non-distracting** and **non-demotivating** way.	Project goal
	The feedback must be delivered to the teachers in a **non-distracting** and **non-demotivating** way.	Project goal
Should	The system should provide the appropriate **alertness stimulation** to help them to regain concentration.	Project goal
	The feedback about the student's concentration level should provide **a little accuracy** to the actual student's concentration level so that it is not demotivating students.	Stakeholders
Could	The system could lead to self-motivation to try to regain concentration and to change the mindset towards the lecture.	Background research

Table 6. User Requirements

These global requirements could be changed during later phases if it is needed. Especially, the main purpose of lo-fi testing is to specify the final concept and global requirements. In this project, user requirements would not be changed significantly because what is required from the technology for user experience will not be changed in later phases. On the other hand, functional requirements could be changed because, for example, it might need some changes in several lo-fi tests or there could be some challenges in the implementation phase.

5.2 Lo-fi

The purpose of this lo-fi phase is to figure out how users interact with and experience the lo-fi prototype of the technology that will be developed in this project. Additionally, it is to determine whether gamification could distract or demotivate students in practice. From the interviews for stakeholder requirements and personally asking friends as UT students, gamification would not distract or demotivate, but rather it can be an interesting feature (although the competition aspect might distract or demotivate). However, this is not identified in practice, and if it is identified to distract or demotivate in practice, there might be some reasons such as the design of gamification or gamification itself. From several tests with different versions of lo-fi prototypes, the results of them will lead to clarifying the answer to that challenge, and to further insights for specifying the final concepts and later phases of this project.

In the first section of this chapter, it will be explained how lo-fi prototypes were designed and built. The next section will describe the purpose, plan, and setup of lo-fi tests in detail. Lastly, the evaluation of lo-fi tests was delivered and discussed to clarify the global requirements and final concept.

To evaluate the results of **Test 1** and **Test 2**, the research questions for both **Test 1** and **Test 2** were briefly defined. The main purpose of **Test 1** is to determine whether the gamification feature is distracting or demotivating in practice, therefore this was the main research question. Some sub-questions were followed up to get more insights from two different prototypes. The research questions for **Test 1** were the following:

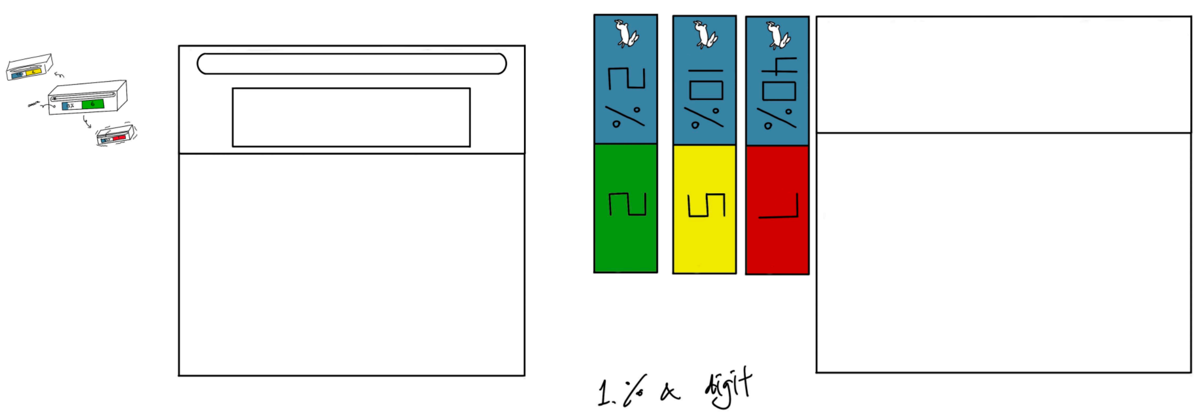
- **Main RQ**: How much does the gamification feature distract or demotivate students during a lecture in practice?
    - **Sub RQ**1: How do the students feel if the feedback about their concentration levels was sent to both teachers and students themselves, or only students themselves?
        - Can it be distracting or demotivating from a lecture?
    - **Sub RQ2**: Apart from the gamification feature, how much do other features of prototypes distract or demotivate students in practice?

The main purpose of **Test 2** is to investigate users' preferences for screen displays, therefore this was the main research question. Some sub-questions were followed up to get more insights from three different designs of race accomplishment and concentration level. The research questions for **Test 2** were the following:

- **Main RQ**: Which interface for each is preferred by primary users?
    - **Sub RQ1**: What is the reason for choosing as the preference and not choosing others?
    - **Sub RQ2**: Which interface could distract or demotivate from a lecture?

5.2.1 Lo-fi Prototypes

To test different versions of lo-fi prototypes, the paper prototype was used in this project as the lo-fi. For the reason of this choice, the paper prototype is low cost and multiple designs can be presented and evaluated by users [57]. In addition, designers and developers tend not to become committed to a specific design early on and users feel more comfortable giving feedback or criticizing the interface when they see that not much work has been done yet [57].



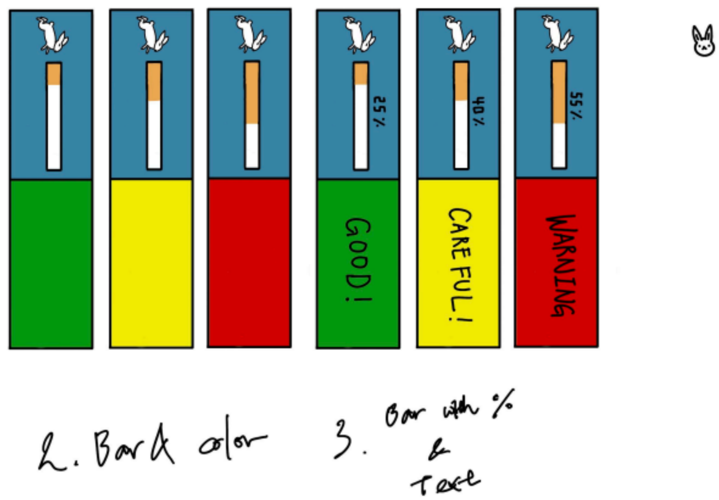


Figure 21. The picture of the design of the lo-fi prototypes

As shown in **Figure 21**, the drawings are the design for the different versions of the lo-fi prototype. The paper lo-fi prototype was built by printing these drawings out and building (Figure 22). The first version of the lo-fi prototype used for **Test 1** consists of two sorts of paper prototypes. One was the paper prototype of technology without the gamification feature and another was one with that feature. In the race progress screen of the prototype with the gamification feature, the animal was attached to the paper stick so that it is movable to seem racing during a lecture. The outcome of these two prototypes was seen in **Figure 22** and these prototypes were to determine whether gamification could distract or demotivate students in practice.

Figure 22. The picture of the first version of the lo-fi prototypes

For Test 2, different interfaces were designed to determine which indicators were the best way to display the race accomplishment and the scale of concentration levels. The different screen displays were printed. The sorts of these displays for concentration level were the following:

1. Scale from 1 to 7 with different colors of screen background (green yellow, red)
2. Classify the scale into three different states and display them as texts (Good: 1 - 4, Careful: 5 - 6, Warning: 7), with different colors of screen background (green yellow, red)
3. Only the colors of the screen background (green yellow, red)

The sorts of displays for race accomplishment were the following:

1. Percentage %.
2. Bar.
3. Bar with percentage %.

By designing these different situations of screen displays, this second version of the lo-fi prototype is to get feedback from participants and gain more insights into which can be distracted or demotivated, or which is appropriate for the lecture room and students. The outcome was seen in **Figure 23**.

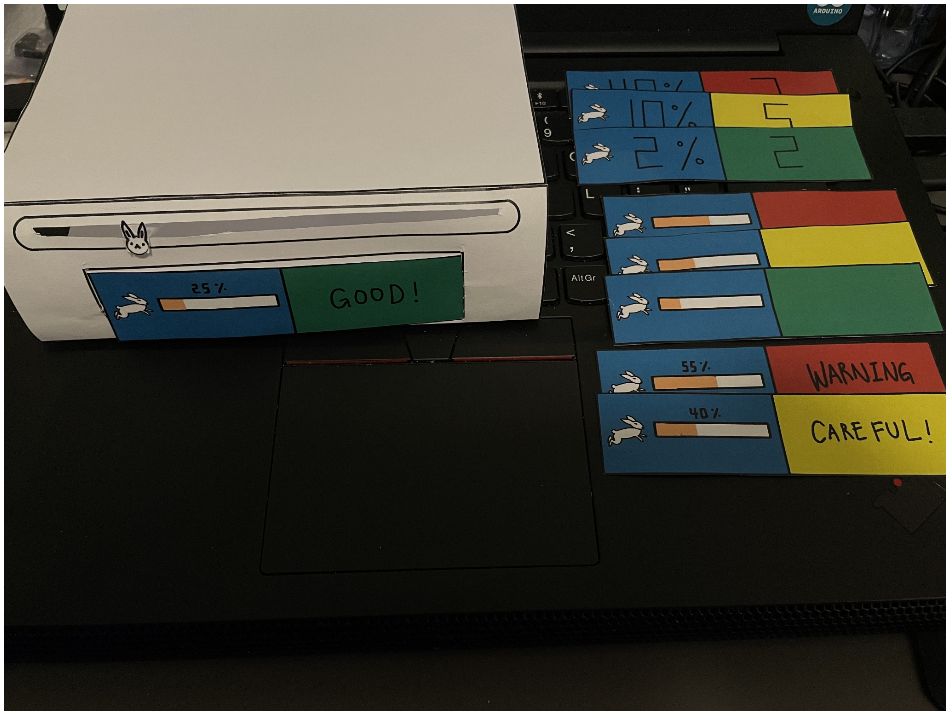


Figure 23. The picture of the second version of the lo-fi prototypes

5.2.2 Plan and Setup of the Lo-fi Tests

For both the lo-fi **Test 1** and **Test 2**, the participants should correspond with the primary user group, UT students. To recruit quickly and gather enough sizes of participants, they were preferentially recruited by asking friends, who are UT students and take the lecture on campus. Test 1 was conducted with 4 participants and Test 2 was conducted with 6 participants (the same participants were not used for both Test 1 and Test 2 so basically lo-fi tests were with 10 participants).

For **Test 1**, two different versions of the lo-fi prototype were built to determine whether the gamification feature is distracting or demotivating in practice. Because worrying that it can take much time to use both versions of the prototype, a short online lecture [58] for around 6 minutes was used. Including the short questions before and after testing, Test 1 was conducted for 15 - 20 minutes. For receiving much feedback from different perspectives, some open questions were asked before and after testing. Sub-questions were asked if it needs to be asked. Interviews were conducted based on semi-structured interviews, but following a little strict order of questions. Because, Lazar [59] states that semi-structured interviews are more appropriate for asking for clarification, adding questions, or following interviewee comments, but the conversation can be out of focus and purpose. In this regard, the main purpose of Test 1 is to investigate whether the gamification feature is distracting or demotivating in practice. Therefore, interviews followed the order of prepared questions if participants give answers out of this purpose. Interview questions for **Test 1** were the following:

<u>Before testing</u>

Q1. Have you experienced losing concentration during lectures?
  Q1.1 What do you think are the reasons for losing concentration?

Q2. Do you think sleepiness and fatigue affect losing concentration during lectures?
  Q2.1 How much? How do they impact?

Q3 What do you think if the technology monitors your concentration level in real-time during a lecture, to give feedback to yourself?

<u>After testing</u>

Q4 Does the accomplishment feature distract or demotivate you from the lecture?
  Q4.1 If yes, how does it distract or demotivate you?

Q5 What do you think if the race accomplishment will be used for the competition between students? (could be individual competition in a lecture, competition between a neighbor, or competition between friends).
  Q5.1 Do you think it will distract or demotivate you?

Q6 Is there anything from the prototype that distracts or demotivates you?

Test 1 was conducted in the following plan:

1) Explain this project, the lo-fi prototype, and the purpose of the test
2) Ask questions before testing
3) Setup lo-fi prototype and prepare to play an online lecture
4) Testing
    a) Play an online lecture [57]
    b) At the same time, the animal starts to run by moving the connected paper stick (manually).
    c) On the timeline of 2:30, 4:00, and 5:00, the screen interface was changed (2:30 - green to yellow, 4:00 - yellow to green, 5:00 - green to red).

    d) The animal finishes racing at around 70% of race accomplishment.
    e) End of the online lecture
5) Ask questions after testing

For **Test 2**, three different interfaces for each screen were designed to identify the users' preference for displaying race accomplishment and concentration level. **Test 2** was conducted with the same online lecture used for **Test 1**, but all three interfaces were tested out during one play of online lecture (so, they were not tested out with three different attempts). The interview for **Test 2** also followed the semi-structured interview and does not comply with the strict order of questions, compared with **Test 1**. Because of the main goal of **Test 2** (identifying users' preferences), participants can answer freely and say anything about the three interfaces by asking open questions, in order to gain more insight and understanding from new aspects. Interview questions for **Test 2** were the following:

<u>Before testing</u>

Q1. The color of the screen background will be changed based on the scale of the concentration level in real-time. There are green (scale 1 - 4), yellow (scale 5 - 6), and red (scale 7). Do you think this color change can distract or demotivate you from a lecture?

Q2. Overall, how do you feel about the interface of this prototype? Is it too attractive to concentrate or motivate in a lecture? Or is it too simple?

<u>After testing</u>

Q3. What is your preference about each interface of the screen?

Q4. Do they too distractive or demotivating?

Test 2 was conducted in the following plan:

1) Explain this project, the lo-fi prototype and three screen interfaces, and the purpose of the test
2) Ask questions before testing
3) Setup lo-fi prototype and prepare to play an online lecture [57]
4) Testing
    a) Play an online lecture

b) From 0:00 to 2:00, first screen interface (% and scale 1 - 7).
c) Pause
d) From 2:00 to 4:00, second screen interface (Bar and only the colors).
e) Pause
f) From 4:00 to 5:51, third screen interface (Bar with % and text).
g) End of the online lecture

5) Ask questions after testing

5.2.3 Result

The results of **Test 1** and **Test 2** were summarized in **Table 7** and **Table 8**. Evaluation for **Test 1** and **Test 2** will be delivered in the next section based on the results in **Table 7** and **Table 8**, and the research questions.

	#1	#2	#3	#4
Q1	Yes Drowsiness, boring content, hard to understand	Yes Morning lecture, drowsiness, lunch sleepiness, boring lecture	Yes Early lectures, workouts, playing games, sleep deprivation, weather	Yes Warm weather, boring lectures, lecture time, too late break
Q2	100% yes 100%, If you start to feel sleepy, you won't listen to a lecture at all. Because the desire to sleep will be more than the ardor for studying and listening to a lecture.	Yes But not direct impact. Sleepiness and fatigue make your body and brain low level and it leads to losing concentration. But if you have caffeine, all good.	Yes 7 out of 10. Sleepiness and fatigue highly affect losing concentration. But there are many ways to overcome this. Workouts, coffee, energy drinks,	Yes A lot. I always struggle with sleepiness during lectures. It's from experience.
Q3	I think It won't feel good. But if feedback can be seen by only me, then it will be interesting. But if can be seen by both me and the teacher, then I think it will bother me during the lecture. Distracting me.	I think it's interesting. If it's not too close to me, then I think it will not bother me during the lecture. But it can be distracting if my concentration level is shown to everybody or the teacher.	I think It doesn't matter. To me, it is a similar situation like taking the lecture whilst running the laptop. I think It won't distract much. But if it will make a sound, it will be distracting. Like the operating sound. If feedback is sent to the teacher, I think it will be distracting but I think I will get used to ignoring it.	To me, It won't be a problem. My focus is on the lecture. But if feedback can be identified by others and the teacher, it will make me feel like force to concentrate.

Q4	Partially yes. It looks interesting but I think this interest can be distracting. Students can wonder how it progresses and how far the animal runs.	No My all focus is on the lecture so I think it won't be distracting a lot.	No But honestly, this accomplishment bar attracts me like makes me wonder how far she runs, and how much I concentrate.	No During testing, it was not distracting or demotivating.
Q5	Regardless of win or loss, competition can be a good motivation.	This will be distracting, I think. The purpose of the competition is ultimately the win. It sounds like I focus on the lecture to get the win with my opponents.	This will be distracting. Other accomplishments will distract me because it is a competition and I need to win. So the student will tend to keep comparing with others.	Sounds interesting. But the accomplishments of friends or other students can distract me because I will keep comparing mine with theirs.
Q6	X	X	Not for now. But when realization, the size of this technology will matter. If it's large and occupies pretty much the space of the desk, it will be distracting.	X

Table 7. The results of ***Test 1***

	#1	#2	#3	#4	#5	#6
Q1	X	X	Partially X The dramatic change will distract. Like suddenly changing green to red (skip yellow). This will be distracting.	X	X	X
Q2	It looks good. I think it is enough now.	I think the interface is simple enough to understand. Simple is the best in this case.	For me, it looks fine.	Not too attractive and not too simple.	Good. Simple enough to understand. Intuitive. Easy to understand	I think it's cool. I don't know if this small rabbit can be displayed when you do the realization of this prototype. But good.
Q3	Bar with % Color & text	Bar with % Color & scale	Bar with % Color & scale	% Color & scale	% Color & text	Bar with % Color & text

Q4	X	X	X	X	X	X

*Table 8. The results of **Test 2***

5.2.4 Evaluation

5.2.4.1 Evaluation of **Test 1**

The single task given to participants was to watch the online lecture and try to focus on their concentration as possible. **Test 1** was conducted with 4 participants: UT students - 2 CreaTe, 1 TCS, and 1 ME. As can be seen in the answer to question 4 in **Table 7**, 3 participants answered that the gamification feature was not distracting or demotivating during a lecture and they did not think it will not be distracting or demotivating in the actual lecture room. However, one participant (participant #1) and one among 3 participants (participant #3) gave new insights that it can be a little distracting or demotivating because it makes them wonder how far the animal runs and how the progress is going. Regarding the feedback, all participants want feedback to be only sent to themselves. If feedback is sent to teachers even as the average, participants think that this will bother them and ultimately it can be distracting and demotivating. Because they answered that it will make them feel surveilled and forced to concentrate on the lecture. However, one participant (participant #3) thought that this can be managed later to ignore it. 3 participants agreed that there are no other things from the prototype that can be distracting or demotivating. However, one participant (participant #3) worried about the size of this technology when this project will be in the realization phase. If it's rather large and occupies much space on the desk, then it will definitely be distracting.

Overall, the gamification feature was not distracting and demotivating and it is expected that it will not distracting and demotivating in the actual lecture room. However, the progress bar can make students wonder and attract interest, which can be distracting. Therefore, it needs to be designed as simple and not too large and wide screen, so that it will not make students wonder from the progress bar. Regarding feedback, sending feedback to teachers can make students bother, which can be distracting and demotivating. Thus, feedback about students' concentration levels should be only sent to students themselves. Additionally, the size of the technology should be considered as important and defined to some degree in the global requirements. Because students' desks can be different depending on lecture rooms and the lecture may need a laptop, technology should provide enough space to students and should not occupy much space so that it will not be distracting.

5.2.4.2 Evaluation of Test 2

The task given to participants was to watch the online lecture and try different screen interfaces to decide their preferences. **Test 2** was conducted with 6 participants: UT students - 2 CreaTe, 1 TCS, 1 CSE 1 EE, and 1 ME. As can be seen in the answer to question 3 in **Table 8**, For race accomplishment, 4 participants chose the bar with the percentage and the other 2 participants chose the percentage. For the scale of concentration levels, half of the participants chose the color and the text, and the other half chose the color and the scale from 1 - 7. All participants do not have any specific reason for the choice, and they just followed their preferences. All participants agreed that the prototype looks overall good and maintaining a simple design like this lo-fi prototype would be better. Regarding the color change of the screen for concentration levels, 5 participants thought that it will not be distracting. One participant (participant #3) partially agreed with that, but also thought that changing too dramatically can be distracting, such as changing from green to red (skip yellow).

Overall, the race accomplishment will be displayed with the bar and the percentage, following more user preferences. For the concentration level, two options were selected with the same user preferences. It will be displayed with the color and text first and it will be tried with the color and the scale if it does not look what is expected in the realization phase. Considering the answer about the overall look of the prototype, technology will be designed simply so that it is not too attractive to distract. The color change of the screen for concentration levels will not be implemented to change color dramatically. To do this, the color intensity will be adjusted.

5.3 Revised Final Concept and Global Requirements

From the evaluation of the results of lo-fi tests, it was able to gather many insights from new perspectives and more understanding of the global requirements. The final concept can be well-concreted and the global requirements can be finalized. In the next section, the final concept will be delivered and then, the revised global requirements will be discussed.

5.3.1 Revised Final Concept

Considering the evaluation of lo-fi **Test 1** and **Test 2**, the final concept was decided including a few revisions from the initial final concept (chapter 4.5). The revised final concept is the following:

The small wooden box will be placed on the student’s desk. This should be placed at the appropriate distance from a student and should not occupy the large space of the desk. This box consists of a webcam and three screens. A webcam will be used to monitor students' concentration levels. Here, face recognition will be used to capture a student's face and monitor the blinking frequency and duration, head dozing, and yawning. These data will be collected every 5 minutes and used to calculate the sleepiness and fatigue score and the concentration level will be predicted by using the sleepiness and fatigue score. The concentration level will be predicted on a scale from 1 (low concentration) to 7 (high concentration). This scale will be assigned to different texts and colors, and displayed on one of three screens: red & text 'Warning!' for scale 1, yellow & text 'Careful!' for scale 2 – 3, and green & text 'Good!' for scale 4 – 7. This color change can stimulate students' alertness. A small haptic vibration can be added for another stimulation if there is enough time to implement it. With this scale, the gamification feature is included in this concept. Students will be assigned randomly to an animal. The animal will start to run to complete the race when a lecture starts. The scale of concentration levels will be the speed of an animal. Another one of the screens will display how much the animal accomplished in the race in real-time as bar and percentage. Another screen placed above the other two screens will display the progress of race accomplishment. It will not be used for competition with others, but this can be used for competition with students themselves.

5.3.2 Revised Global Requirements

The global requirements (system requirements) were revised based on the evaluation of lo-fi tests and further insights from it. **Table 9** and **Table 10** show the revised functional requirements and user requirements.

Category	Functional Requirement	Revision	Reference
Must	The race must start when the technology starts to operate.	-	Stakeholders (Easy user interface and interaction)
	The camera must capture and analyze the student's **eye movements** (blink duration and frequency, and eye direction) and **head movements** (head nod, doze off) in real-time.	-	Background research
	The analysis must predict the student concentration level by monitoring and collecting data **every 5 minutes in real-time**.	Change to collect data every 5 minutes	Background research & Lo-fi
	The right screen must display the scale of the student concentration level from **1 to 7**. (1 for low level, 7 for high level).	-	Background research (SSS scale)

	The left screen must display the student's **accomplishment of the race** in real-time.	-	Final concept & Stakeholders (gamification)
	The small wide screen must display the **animal's species** and the animal must **move based on the scale** of concentration levels.	**Remove** this requirement	Result from **Test 1** of the lo-fi prototype
	The background of the right screen should be turned based on the scale of the concentration levels. ● Green for the scale of 4 - 7 ● Yellow for the scale of 2 - 3 ● Red for the scale 1	Assign colors to levels.	Background research (Alertness stimulation)
	The **average scale** of students' concentration must be displayed on the screen placed on the teacher's desk.	**Remove** this requirement	Result from **Test 1** of the lo-fi prototype
Should	The **animal speed** should be in proportion to the **scale** of the student's concentration level.	-	Final concept
	The **color change** should be adjusted to not be a too sudden and dramatic change.	**New** Requirement	Result from **Test 2** of the lo-fi prototype
	The animal species should be displayed **simply and intuitively**, and the animal race should be displayed intuitively.	-	Final concept & stakeholders (real-time and gamification)
	The **size of the technology** should be considered important.	**New** Requirement	Result from **Test 1** of the lo-fi prototype
Could	The technology could **start to operate** in different ways. ● Start to operate automatically when the lecture starts. ● Start to operate when the lecture starts and the teacher authorizes it to operate. ● Start to operate when the lecture starts and the student input to start if the student wants to use it.	**Remove** this requirement	The operating way does not matter much.
	The **vibration** could be delivered when the student shows the **lowest scale** of concentration level.	-	Background research (state-of-the-art)
	The **vibration** could be delivered to the **teacher's desk** when the average scale shows rather a high scale (maybe 6).	**Remove** this requirement	Result from **Test 1** of the lo-fi prototype
	The **vibration** could be subtle enough to deliver **subtle and haptic vibration** to the student's desk.	-	Background research (state-of-the-art)
	The average scale of students' concentration levels could be displayed as simple.	**Remove** this requirement	Result from **Test 1** of the lo-fi prototype
Won't	The feedback about students' concentration levels won't	**New**	Result from **Test 1**

	send to a teacher so that it won't be distracting and demotivating.	Requirement	of the lo-fi prototype
	The light on the screen will not be turned suddenly and dramatically.	-	Background research (alertness stimulation)

Table 9. Revised Functional Requirements

Category	User Requirement	Revision	Reference
Must	The technology must be easy to use and interact with.	-	Stakeholders
	The monitoring must be done in a **non-distracting** way.	-	Project goal
	Two screens must display the race accomplishment and the scale of concentration levels in a non-distracting way.	-	Final concept
	The feedback must be delivered to the students in a **non-distracting** and **non-demotivating** way.	-	Project goal
Should	The system should provide the appropriate **alertness stimulation** to help them to regain concentration.	-	Project goal
	The feedback about the student's concentration level should provide **a little accuracy** to the actual student's concentration level so that it is not demotivating students.	-	Stakeholders
	• The technology should provide enough space for the desk to students. • The technology should not be too high or too wide to be visible and distracting.	**New** Requirement	Result from **Test 1** of the lo-fi prototype
Could	The system could lead to self-motivation to try to regain concentration and to change the mindset towards the lecture.	-	Background research

Table 10. Revised User Requirements

These global requirements could be changed during later phases if it is needed. In this project, user requirements will not be changed significantly, but functional requirements could be changed because, for example, there could be some challenges or different design choices in the implementation phase.

5.4 System Architecture

The system includes three sub-systems, [monitoring & face detection], [analysis & prediction], [race progress & race accomplishment], and [display & feedback]. The main brain of the system will be Python and the sub-system for [analysis & prediction], bringing the monitoring data for the analysis and sending the prediction scale to Hardware Screen for display and feedback. The first section of this chapter will discuss the general system architecture, to be able to see the overall architecture of how these sub-systems will interact and become a whole completed system. The next section will provide the detailed system function diagram for each sub-system, such as which criteria will be used for the prediction and how students' faces will be analyzed.

5.4.1 General System Architecture

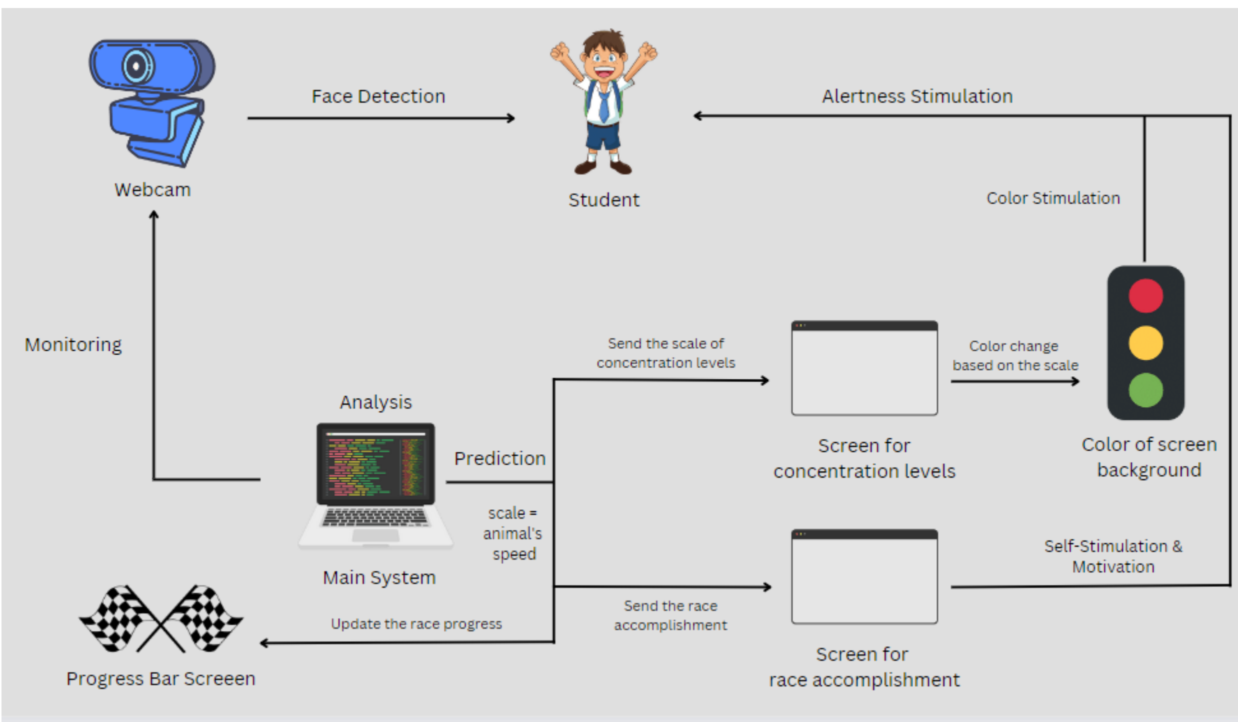


Figure 22. General System Architecture

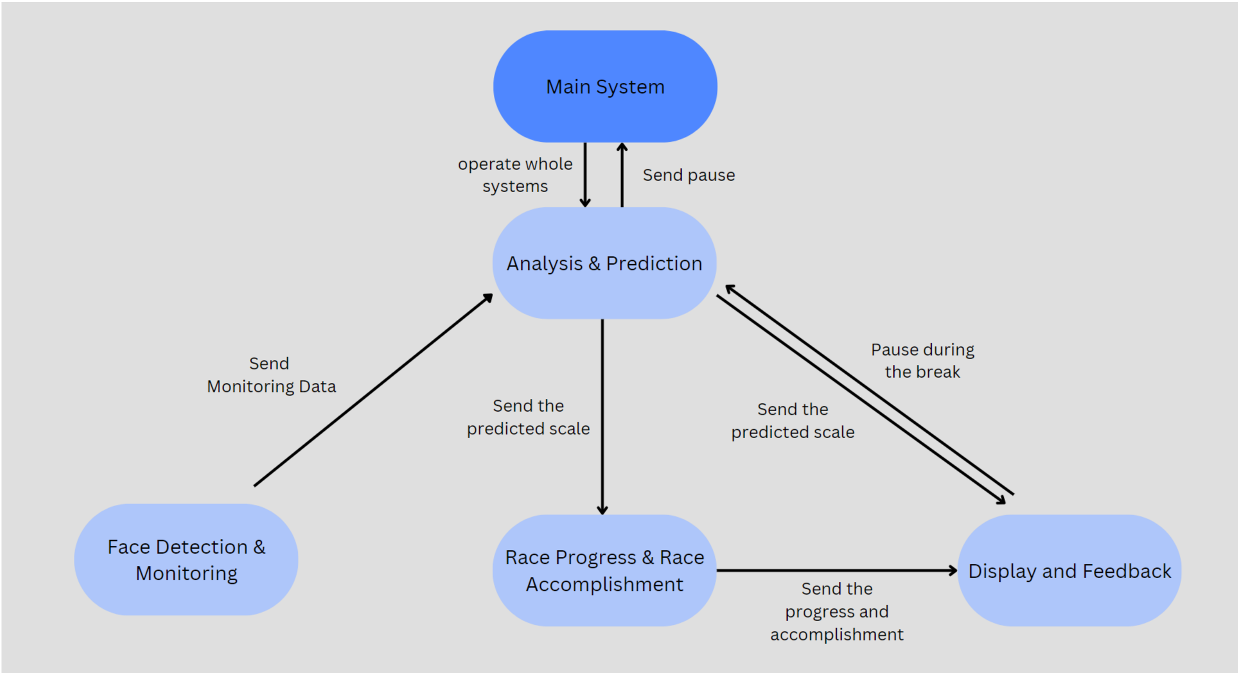


Figure 23. Relationship between the main system and sub-systems

Figure 22 shows the general system architecture and **Figure 23** shows the relationship between sub-systems. When the system has power and starts to operate at the same time as the lecture begins, the webcam will detect eye blinking, blinking duration, yawning, and head movement from the student's face. This face detection will be monitored every 5 minutes by the main system in real-time to get the data collected for 5 minutes from a student. Then, the main system will analyze the detecting data of eye blinking, blinking duration, yawning, and head movement, and predict the student's concentration level on a scale from 1 - 7. After predicting the concentration level as a scale, the main system will assign this scale to an animal as the speed for racing. From the sub-system, the race will be progressed. This race progress will be updated in real-time and displayed on the progress bar screen (top screen). Also, this race progress will be displayed as a bar graph and the percentage on the left screen, but this is not in real-time and the display will be changed every 5 minutes (like monitoring by the main system). The scale of the student's concentration level will be displayed on the right screen as text and different colors of the screen background. These texts and colors are different depending on the scale. The color change will stimulate the student's alertness if a student starts to lose concentration and the alertness level declines. The race accomplishment can be self-stimulation and self-motivation depending on how a student wants to manage this feature.

5.4.2 Specific System Architecture

This section will describe the specific system function diagram for each sub-system and explain the details of the input and output.

5.4.2.1 Face Detection and Monitoring

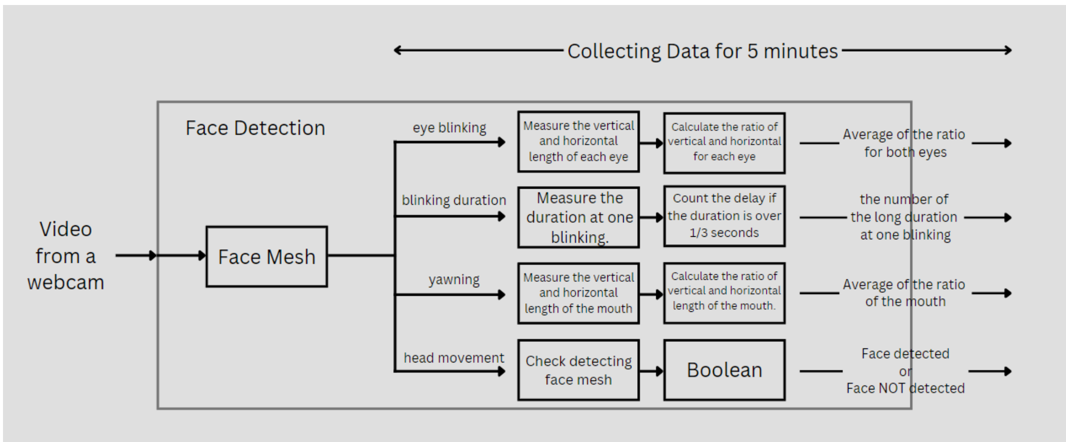


Figure 24. A system functional diagram for the sub-system of [face detection & monitoring]

Figure 23 is a system functional diagram for the sub-system [face detection & monitoring]. A webcam will be connected to the laptop. A video from a webcam will be the input of the function 'Face Detection' of this sub-system. The face captured from a video will mesh for face detection to collect data on a student's eye blinking, blinking duration, yawning, and head movements for 5 minutes. In face mesh, there are landmarks of parts of the face.

First, for the eye blinking, horizontal and vertical lines will be drawn for each eye (for example, **Figure 24**), and the length of these two lines will be measured.

Figure 25. Example of drawing horizontal and vertical lines from landmarks of each eye.

Then, the eye aspect ratio (EAR) will be calculated as the percentage by the following equation:

$$The\ eye\ asepct\ ratio\ (EAR) = \frac{The\ length\ of\ vertical\ line}{The\ length\ of\ horizontal\ line} \times 100$$

Because the vertical and horizontal lengths of eyes are definitely different for every student, considering only the vertical length as blinking can lead to discrimination from not considering different races, temperaments, and facial structure. After the calculation of EAR, the average of the EAR for both eyes will be calculated and this will be one of the outputs of the function of the sub-system [face detection & monitoring].

Second, the blinking duration will be measured when a sub-system captures a blinking. When the eyes are closed, then the blinking duration will be started to measure as seconds until the eyes are opened again. The long duration of over ⅓ seconds will be counted, according to the statement by Kwon *et al* [60] that one blinking of human adults lasts approximately ⅓ seconds. Therefore, the count of blinking with long duration will be one of the outputs of the function of the sub-system [face detection & monitoring].

Third, yawning follows a similar measurement and calculation of eye blinking. Horizontal and vertical lines will be drawn for the mouth (for example, **Figure 25**), and the length of these two lines will be measured.

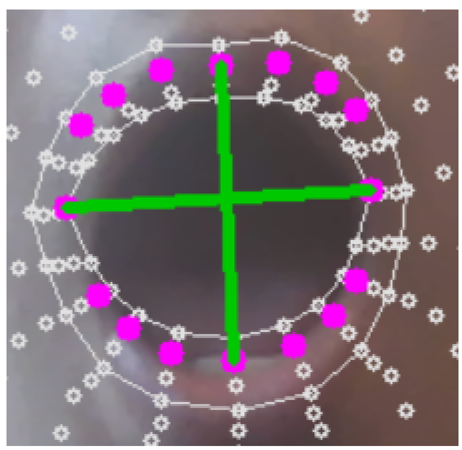


Figure 26. Example of drawing horizontal and vertical lines from landmarks of the mouth

Then, the mouth aspect ratio (MAR) will be calculated as the percentage by the following equation:

$$The\ mouth\ aspect\ ratio\ (MAR) = \frac{The\ length\ of\ vertical\ line}{The\ length\ of\ horizontal\ line} \times 100$$

Considering both vertical and horizontal lengths of the mouth follows the same reason with not considering only the vertical length for eye blinking. This MAR will be one of the outputs of the function of the sub-system [face detection & monitoring].

Last, for the head movement, the face will mesh if the face is detected. Face detection is based on the frontal face, but it can still detect even if a head turns to some degree. This is because head direction can vary depending on the desk's location. If a student is dozing off or distracted from something, a student's head direction will not be the direction to the teacher or lecture screen, and in this case the face will not be detected. In this regard, the variable 'Boolean' will be one of the outputs of the function of the sub-system [face detection & monitoring], in order to determine whether the face is being detected or not.

5.4.2.2 Analysis and Prediction

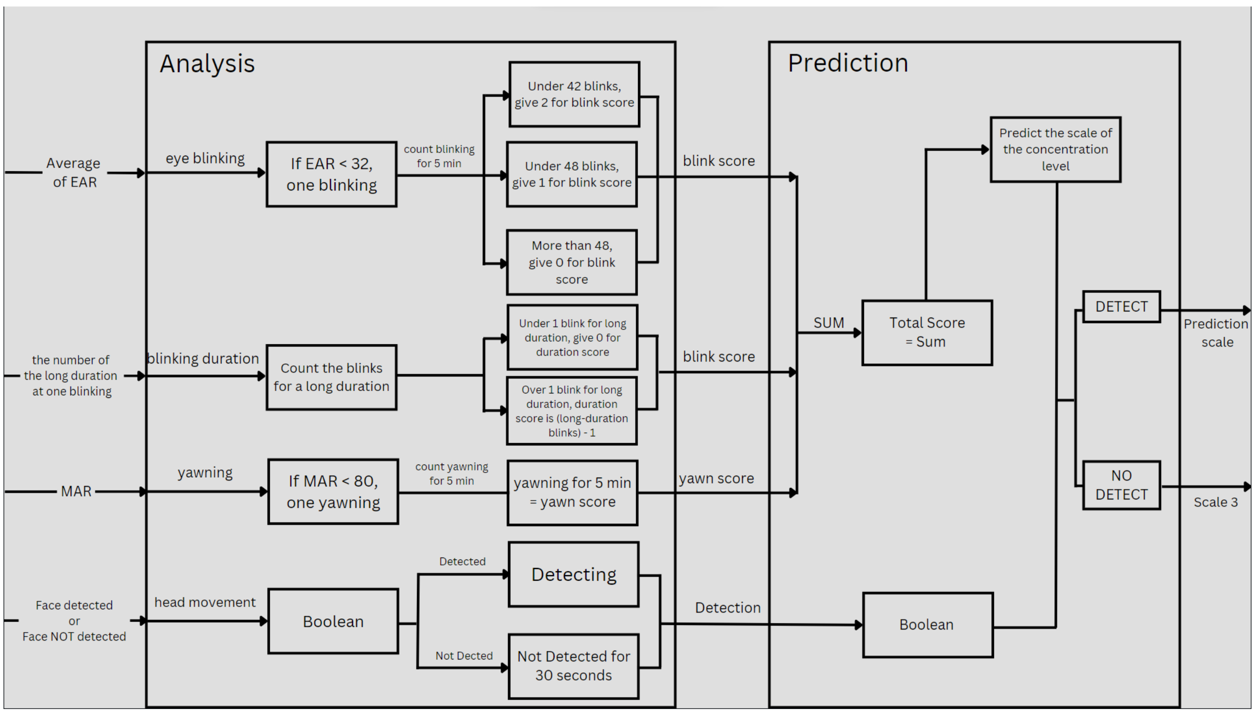


Figure 27. A system functional diagram for the sub-system of [analysis & prediction]

Figure 26 shows a system functional diagram for the sub-system [analysis & prediction]. This sub-system has two functions - one is the function for analysis and another is one for prediction. The four outputs of the sub-system [face detection & monitoring] will be the inputs of this sub-system.

The function of this sub-system will count one blinks when the average of the EAR becomes less than 32. This 32 should be adjusted to be more accurate for most students through some tests. Based on the statement by Kwon *et al* [60] that human adults blink around 12 times approximately, the count of blinking for 5 minutes will be used for the 'blink score', which is one of the outputs of the function [analysis] of this sub-system. Considering the error range, if a student blinks over 48 times per 5 minutes, then the blink score will be assigned as 0. If a student blinks less than 48 times but less than 45 times, then the blink score will be 1. If a student blinks under 45 times, then the blink score will be 2 because this can be predicted that a student blinks for a long duration and thus, a student is feeling sleepiness and fatigue during a lecture.

For yawning, the function of this sub-system will count one yawn when the MAR becomes less than 80. This 80 should also be adjusted to be more accurate for most students through some tests. Based on the background research (chapter 2), yawning is highly related to sleepiness and fatigue. In addition, Ibrahim **et al** [41] state that sleepiness and fatigue are the most common trigger for yawning, and emphasizes that identification of fatigue and sleepiness would be helped if yawning is detected. In this regard, yawning during a lecture can be regarded that a student's concentration level is starting to decline and a student shows rather a low alertness level. Therefore, the count of yawning for 5 minutes is directly related to the 'yawn score', and this 'yawn score' is one of the outputs of the function [analysis] of this sub-system.

For blinking duration, the function of this sub-system will count one long duration when the duration of blinking is over ⅓ seconds, according to Kwon *et al* [60]. Based on the background research (chapter 2), the long duration is highly related to sleepiness and fatigue. Considering that the eye fatigue from keep looking at the lecture screen or whiteboard, one or two blinks for a long duration will be admitted to assigning 0 for the 'duration score'. If a student blinks for a long duration over 2 times, then the 'duration score' is the calculation of the count of blinks for a long duration subtracted from 1. This 'duration score' is one of the outputs of the function [analysis] of this sub-system.

For head movement, the function of this sub-system will regard that a student is dozing off or not concentrating on a lecture at least if a student's face is not detected. This is because face detection can still detect a face to a little degree from a frontal face. In this regard, no detection means that a student's face is completely heading downwards or side, and this can be regarded that a student is not looking at the lecture screen or whiteboards, so a student is dozing off or not concentrating on a lecture. This will be determined based on the results of the detection for 30 seconds. Compared with the other 3 outputs, the output for head movement is not assigned as the score, but as the boolean (True or False).

These four outputs of the function [analysis] will be the inputs of the function [prediction]. The three inputs assigned as the score will be summed to calculate the total score. This total score will be the scale of the concentration level, and if the sum of these three inputs is more than 7, then the scale of the concentration level will be 7. After predicting the scale of the concentration level, the boolean for head movement will be used. If the face is detected, the predicted scale of the concentration level will be the output of the function [prediction] and the final output of the sub-system [analysis & prediction]. But if the face is not detected, the scale of concentration will be displayed as the question mark ‘**?**’ and this will be the output of the function [prediction] and the final output of the sub-system [analysis & prediction].

5.4.2.3 Race Progress and Race Accomplishment

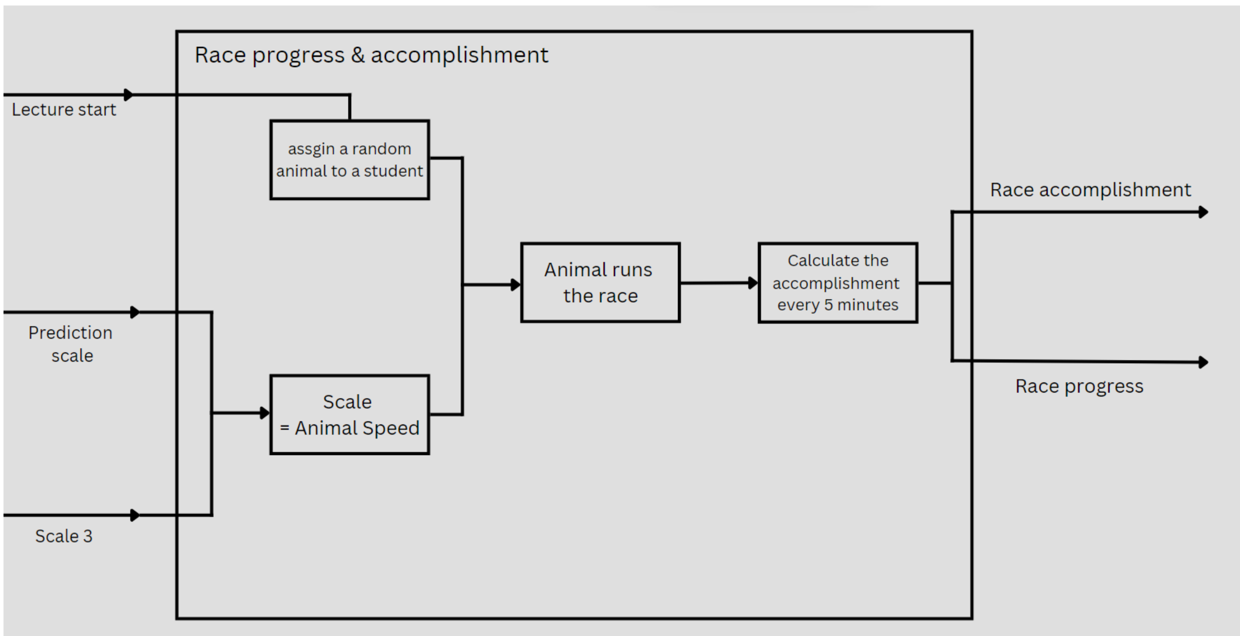


Figure 28. A system functional diagram for the sub-system of [race progress & race accomplishment]

Figure 28 shows a system functional diagram for the sub-system [race progress & race accomplishment]. The two outputs from the sub-system [analysis & prediction] are the inputs to this sub-system. There is one more input to identify the lecture start.

This input is from the main system and this input will be determined when the power is provided in the main system. When the function of this sub-system receives the input for the lecture start (when power is provided to the systems), then a student will be assigned a random animal for the race.

The two inputs from the sub-system [analysis & prediction] are the prediction of the scale of a student’s concentration level. Because the functions of the sub-system [analysis & prediction] predict this scale based on the data collected for 5 minutes, the speed of the animal will also be changed every 5 minutes. As mentioned before, this scale will be the assigned animal’s speed per minute for the race, except for the lowest scale. Scale 1 is the lowest scale of the concentration level, regarding that a student is feeling sleepiness and fatigue and already loses concentration. Therefore, if a student shows a scale of 1, then the assigned animal will fall asleep during a race, so the animal will stop running and the progress is not going further for 5 minutes.

Whilst running the race, the function of the sub-system [race progress & race accomplishment] will monitor the race progress in real-time and simultaneously get the data about the race progress every 5 minutes to calculate the race accomplishment. If a lecture takes 1 hour, then the maximum distance to run for the whole lecture time is the lecture time multiplied by 7 because the maximum scale of the concentration level is 7 and this means that an animal runs with the speed of 7 per minute. As mentioned above, the race accomplishment should be calculated as the percentage so the calculation can be the following:

$$Race\ accomplishment\ =\ \frac{Race\ prgress}{7 \times the\ lecture\ time\ as\ minutes} \times 100 \quad (\%)$$

After the function of this sub-system get the data of the race progress in real-time and the race accomplishment, these two will be the outputs of this sub-system, sending to the sub-system [display and feedback].

5.4.2.4 Display and Feedback

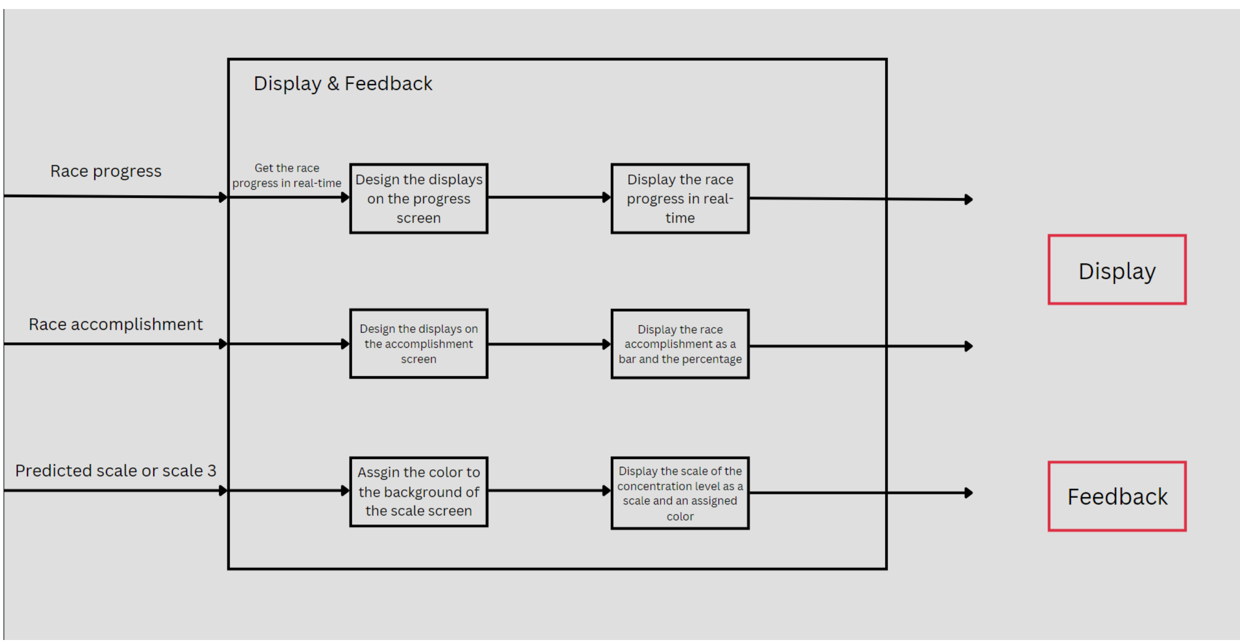


Figure 29. A system functional diagram for the sub-system of [display & feedback]

Figure 29 shows a system functional diagram for the sub-system [display & feedback]. This sub-system will receive three inputs. Two of them are from the sub-system [race progress & race accomplishment] and these two inputs are about the race progress in real-time and the race accomplishment. Another one input is from the sub-system [analysis & prediction], which is the scale of the concentration level. These three inputs will be used to display on the screen and give feedback about the concentration level to the student.

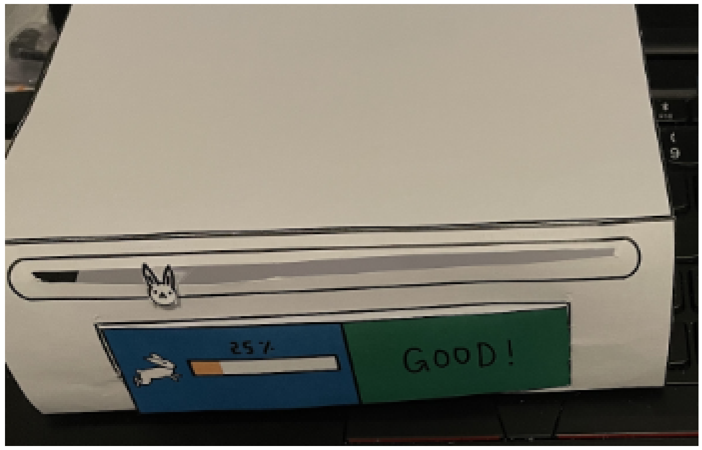


Figure 30. Picture from the lo-fi prototype for the understanding of explaining the function of the sub-system

Before explaining the function of this sub-system, **Figure 30** can be seen for easier understanding of the function of the sub-system. The wide screen on the top is the progress screen to display the race progress in real-time. As can be seen in **Figure 30** (although it is a lo-fi prototype), the animal will be moved based on real-time progress. This can be regarded as a race accomplishment, but this only displays how far the animal runs in real-time without any indication. The screen placed on the bottom left is the race accomplishment screen to display the race accomplishment every 5 minutes. As mentioned above, the race accomplishment will be calculated every 5 minutes as the percentage. Based on the lo-fi evaluation, this race accomplishment will be displayed on the screen as the percentage and the bar graph of this percentage (like in **Figure 30**). The screen placed on the bottom right is the scale screen to display the predicted scale of the student's concentration level every 5 minutes. There are three colors of the background of this screen and the color will be assigned based on the predicted scale (green: scale 4 - 7, yellow: scale 2 - 3, red: scale 1). The predicted scale will be displayed as the digit from 1 - 7, not the text seen in **Figure 30**. These three displays will be the outputs of the function of the sub-system [display & feedback]. These outputs will be sent to the Hardware, the displays connected to the Arduino.

Chapter 6 - Realization

In this chapter, the realization phase of the project will be explained. Based on the general system architecture (chapter 5.4.2), the key 5 functionalities are face detection, analysis, prediction, gamification to animal race, displays, and feedback. Displays, face detection, and feedback should be performed by physical electric elements, but other functionalities can be programmed with the software.

6.1 Hardware

Hardware is an essential component of the system because the prediction of the concentration level is based on the monitoring data from a webcam, and because the feedback and stimulation should be delivered and displayed. For the realization of these all essential functions, it needs to prepare electric components, a webcam, a wooden box, and a laptop.

6.1.1 Electric Components

Electric components including a microcontroller and three display screens are required for the prototype, in order to send the data to a microcontroller and display the feedback about the concentration levels on the screens with the alertness stimulation.

6.1.1.1 Microcontroller

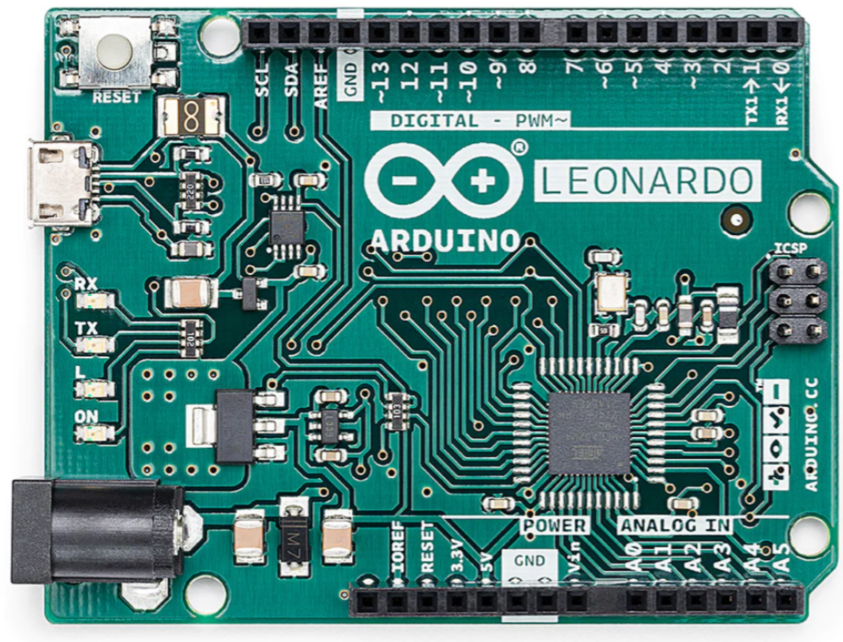


Figure 32. Arduino Leonardo

The Arduino Leonardo in Figure 32 will be used to connect to the screens displaying the data from the main system. In the initial phase of the project, all required functions were planned to manage by Raspberry Pi 4 so that it does not need to connect to the laptop and the Raspberry Pi can be the main system including all the sub-systems. However, because of a short supply from Covid-19, most stores did not have any stock and even one store was able to deliver Raspberry Pi 4 on June 30th, which is nearly the last phase of the project. Thus, the Arduino Leonardo was selected as a microcontroller, regarding the personal familiarity and much knowledge from the modules of Creative Technology.

The Arduino Leonardo has 14 digital pins for digital input and 6 analog pins for analog input. In the realization phase of this project, only digital pins will be used based on the datasheet of the screens about the connection schematics.

6.1.1.2 Display Screen

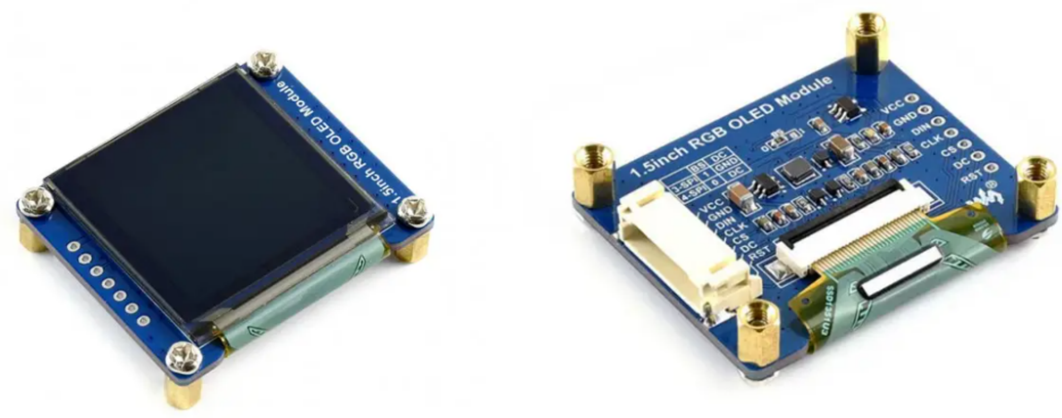


Figure 33. RGB OLED Module *Display for the race accomplishment and the scale of the concentration level*

For the displays of the concentration level and race accomplishment, two RGB OLED Modules with a 1.5-inch diagonal will be used (**Figure 33**). This will be connected to the Arduino Uno, and display the concentration level and the race accomplishment after it receives that data from the sub-systems through the Serial communication between the laptop and Arduino.

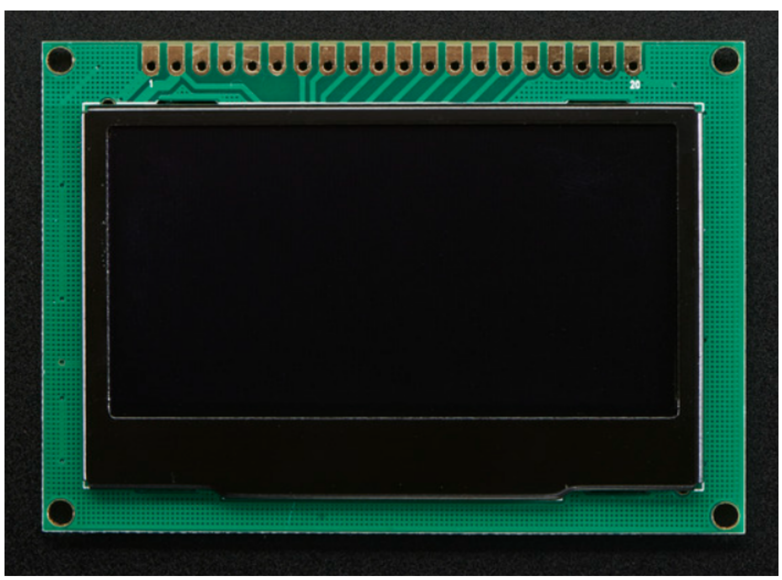


Figure 34. Display screen for the race progress in real-time

For the race progress, an OLED Module with a 2.42-inch diagonal (**Figure 34**). Compared with the other two screens, this screen does not provide the RGB color and only provides white and black colors. Based on the lo-fi evaluation, the screen for the race progress will not be able to attract students too much to wonder about the real-time progress, by displaying the race progress in monochrome.

6.1.2 Webcam

Figure 35. Logitech C270 HD Webcam

For face detection, Logitech C270 HD Webcam in Figure 35 will be used. This webcam is rather cheap but provides crisp, nice HD 720p / 30 fps video with a diagonal 55-degree field of view.

6.1.3 Wooden Box

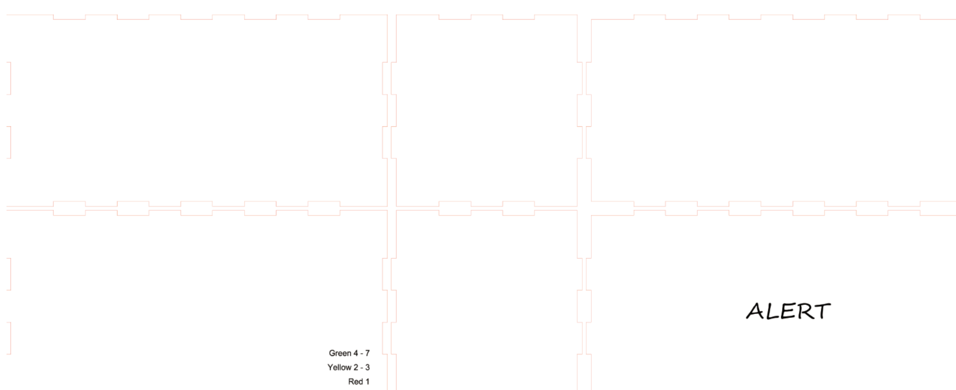


Figure 36. Design the blueprint of a wooden box for the laser cutting

To realize the wooden box, the blueprint of a wooden box was designed first in **Figure 36**. Based on the color mapping for the laser cutting, the red lines are for cutting, and the black texts are for engraving. This blueprint was built by laser cutting, with the help of Alfred, a technician of the SmartXp.

Figure 37. The result of the laser cutting

Figure 37 is the result of the laser cutting of the blueprint **Figure 36**. For the size of this box, the width is 30cm, the depth is 15cm, and the height is 15cm. Considering the evaluation of the lo-fi testing, this size was considered important by measuring the student's desk and thinking of the proper size.

6.1.4 Laptop

Figure 38. Laptop 'ThinkPad P1 Gen 2'

To operate the software and process the displays, the laptop is used in **Figure 38**. This 'ThinkPad P1 Gen 2' laptop has the appropriate performance to process all the required software, whilst monitoring and analyzing the video from the webcam.

6.2 System Overview

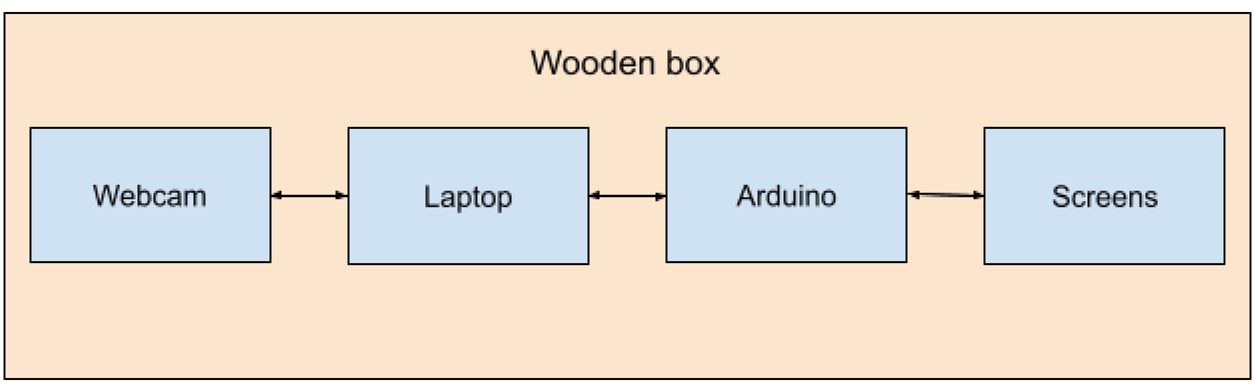


Figure 39. The connection scheme of the hardware

The connection of the hardware is shown in **Figure 39**. All hardware components are included inside the wooden box. The three screens are connected to the Arduino Uno, and Arduino exchanges the data (race accomplishment & the scale of the concentration level) with the Laptop through Serial communication. The webcam is connected to the laptop with the USB cable, to provide real-time video.

Below, **Figure 40** shows the wiring schematic of the screens and the Arduino Leonardo. Because of no schematic icon in the application of schematic drawing, the Arduino Leonardo should connect to the laptop through a cable of USB to USB Micro B, and the webcam should connect to the laptop through a cable of a webcam to USB. **Figure 41** shows the detailed wiring diagram of the screens and the Arduino Leonardo.

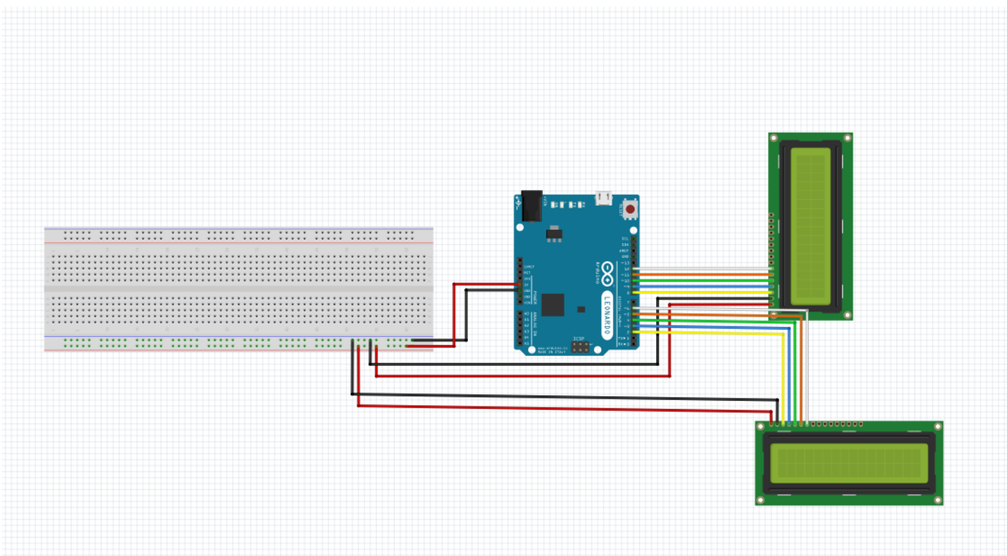


Figure 40. The wiring schematic of the hardware components

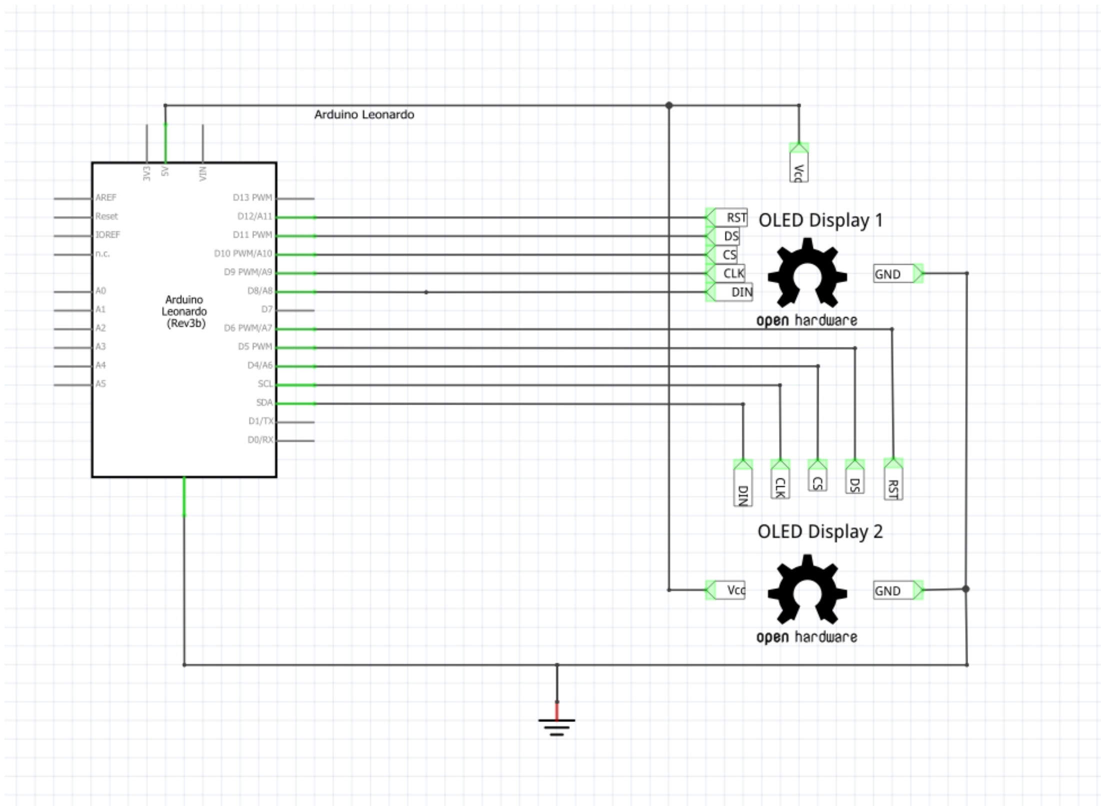


Figure 41. The detailed wiring diagram of the screens and the Arduino Leonardo

6.3 Software

6.3.1 Arduino IDE

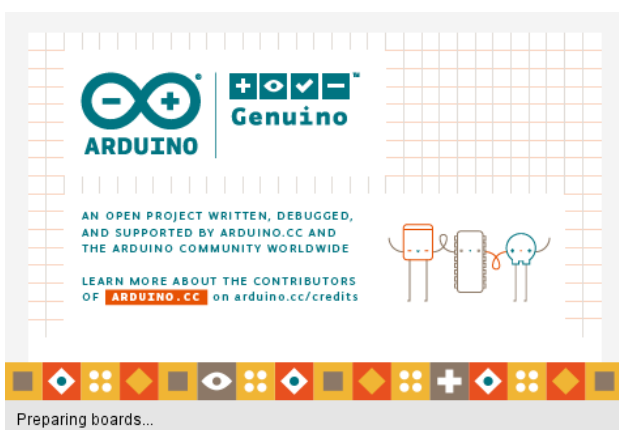


Figure 42. Arduino IDE

All the screens connected to the Arduino Uno are controlled by the software, Arduino IDE (Figure 42). This software is open-source with a simplified version of C++. The Arduino software performs the function of exchanging data with Python and displaying the data with the design for the screen. Based on the system architecture in Chapter 5.4, this performs the sub-system [display & feedback]. The written code in Arduino IDE can be seen in **Appendix 3**.

6.3.2 Python

Figure 43. Python and OpenCV

Except for the sub-system [display & feedback], all the other sub-systems will be managed in Python (**Figure 43**). For face detection, OpenCV is used. The written code in Python is included in **Appendix 4**.

6.4 Hi-fi Prototype

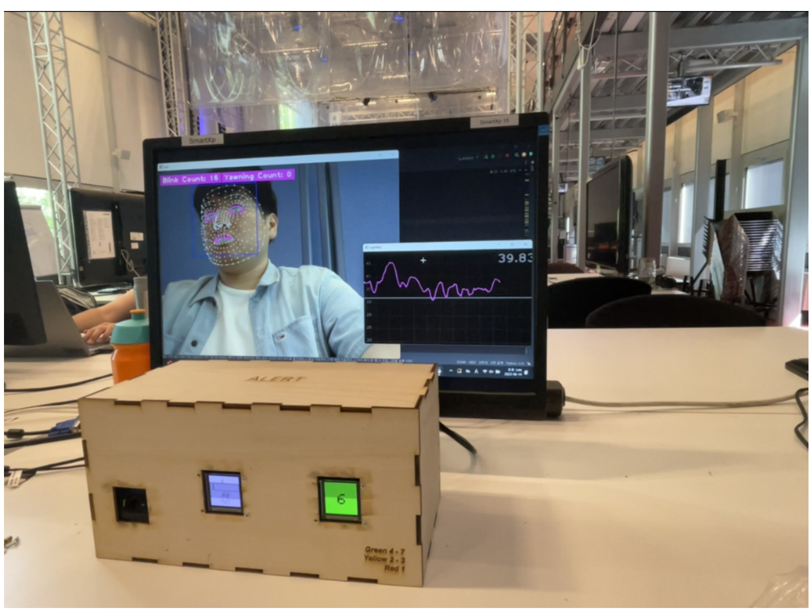


Figure 44. Result of the hi-fi prototype

Figure 44 shows the overall look of the final prototype. The webcam and the Arduino Leonardo connect to the laptop. Face detection and the analysis of the eye blinking are shown in **Figure 44**.

Figure 45. The wooden box including the webcam and two screens

Figure 45 shows the wooden box including a webcam and two screens. A webcam and two screens are visible. By engraving the text on the front side of the wooden box about the scale and the color, the introduction was provided for understanding the relation between color and the scale of concentration levels. On the top side of the box, the name of this system was engraved.

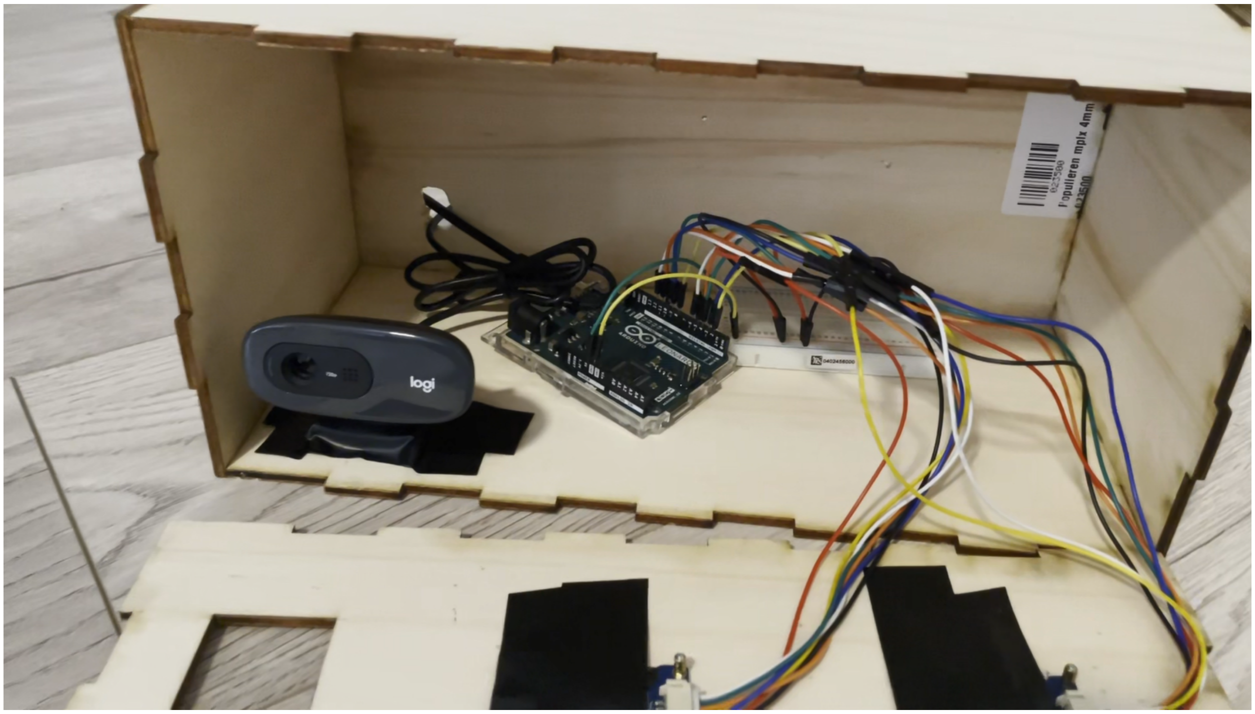


Figure 46. Inside of the wooden box

Figure 46 shows the inside of the wooden box. As designed, this wooden box consists of a webcam, the Arduino Leonardo, and two screens fixed by bolts and nuts.

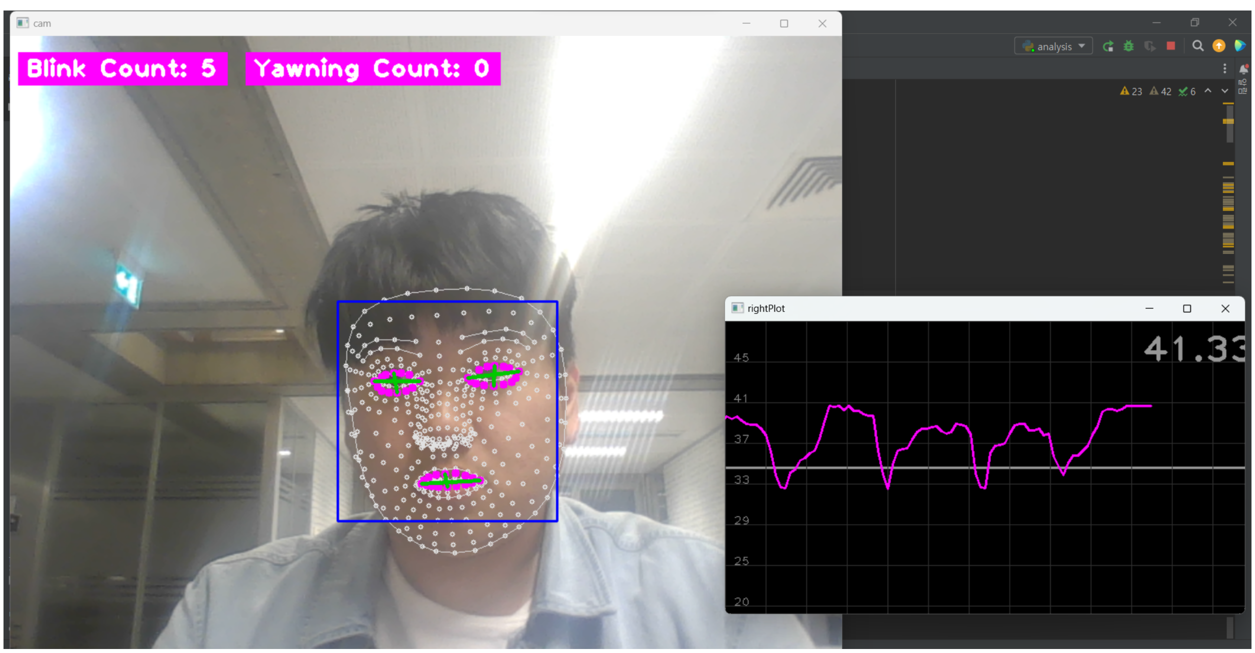


Figure 47. The result of the Face Detection and monitoring

Figure 47 shows the results of face detection and monitoring. A webcam and two screens are visible. By engraving the text on the front side of the wooden box about the scale and the color, the introduction was provided for understanding the relation between color and the scale of concentration levels. On the top side of the box, the name of this system was engraved.

Practical Problems

Because of performing face detection and communication to Arduino at the same time, there was a problem with the face detection declining the frame of the video. This led to the problem that face detection cannot sometimes detect blinks, especially fast blinks. To address this problem, the Python and Arduino code should be arranged to reduce the excessive work of the RAM and CPU. Using Arduino Mega can be one of the solutions because it has a better and faster processing speed. Also, the webcam which records the video with greater flames would help to solve this problem.

6.5 Performance

The performance of the system was identified through several pilot tests. It will be described first based on the sub-system introduced in **Chapter 5.4**. Then, the overall performance will be explained lastly, discussing whether the system complies with the functional requirements introduced in **Section 5.3.2**.

6.5.1 Face Detection & Monitoring

The performance of the face detection system will be described in different situations.

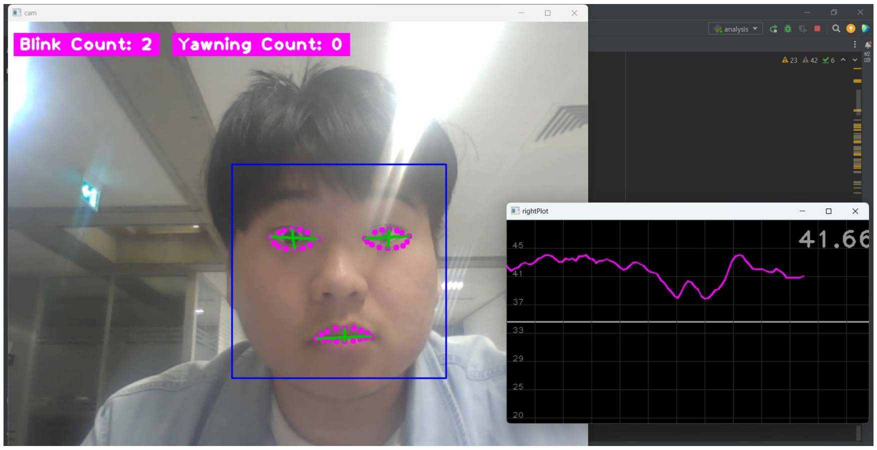


Figure 48. Face detection for eyes wide open

Figure 48 shows the face detection for eyes wide open and monitoring the EAR (eye aspect ratio) of both eyes with the analysis of the graph. The system detects EAR following the analysis designed in **Chapter 5.4.2.1**. As the example of the developer myself, it shows around 41% for the eyes wide open.

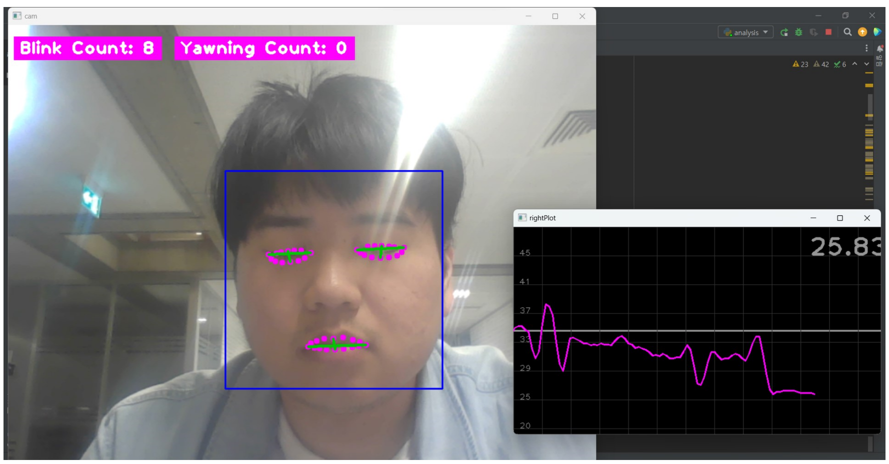


Figure 49. Face detection for eyes close

Figure 49 shows the face detection for eyes close and monitoring the EAR (eye aspect ratio) of both eyes with the analysis of the graph. The system detects EAR following the analysis designed in **Chapter 5.4.2.1**. As the example of the developer myself, it shows around 26% for the eyes close.

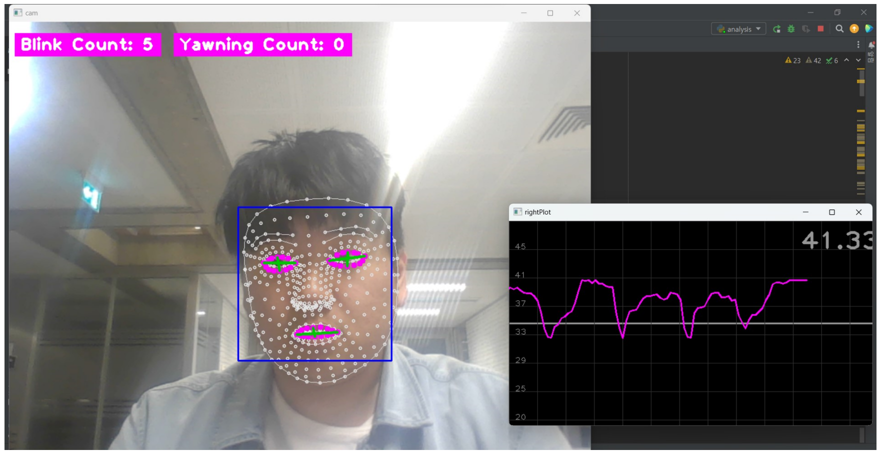


Figure 50. Face detection for eye blinking

Figure 50 shows the face detection for eyes blinking and blinking duration, and monitoring the EAR (eye aspect ratio) of both eyes with the analysis of the graph. The system detects eye blinking and calculates the blinking duration, following the analysis designed in **Chapter 5.4.2.2**. As can be seen in the graph of **Figure 50**, there is the graph going up and down. The gray line is the value of the EAR for detecting blinking. It shows 35% for this value. Based on this value, the system detects the blinks. When the EAR is going down to this value, it regards one blink. Eye durations cannot be identified in Figure 50, but if EAR stays under the average of over ⅓ seconds (as designed in Chapter 5.4.2.2), then it regards the blinks with a long duration.

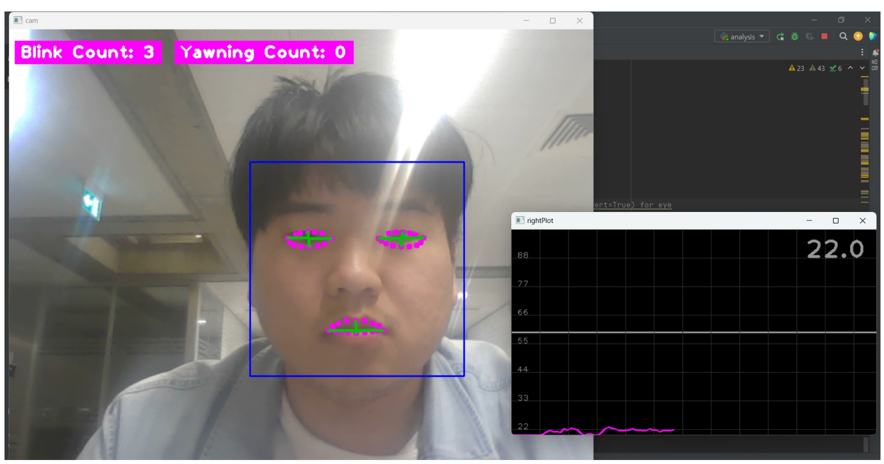


Figure 51. Face detection for mouth close

Figure 51 shows the face detection for mouth close and monitoring the MAR (mouth aspect ratio) with the analysis of the graph. The system detects MAR following the analysis designed in **Chapter 5.4.2.1**. It shows around 22% for the mouth close.

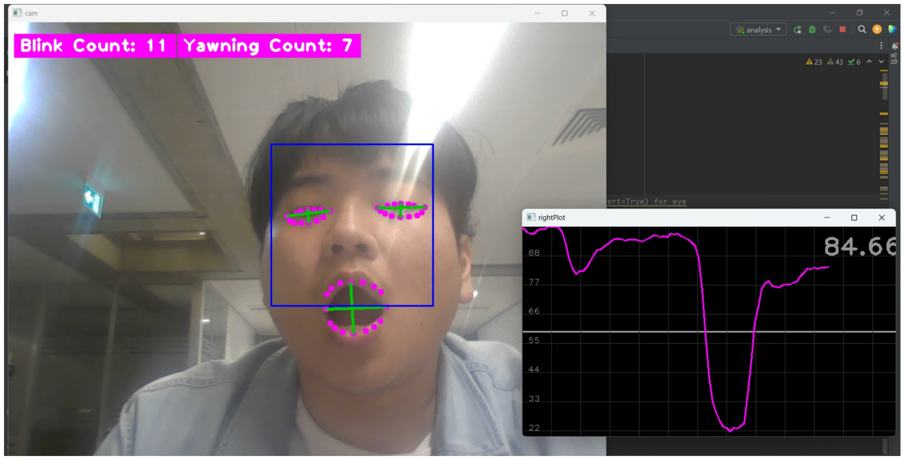


Figure 52. Face detection for mouth wide open

Figure 52 shows the face detection for mouth wide open and monitoring the MAR (mouth aspect ratio) with the analysis of the graph. The system detects MAR following the analysis designed in **Chapter 5.4.2.1**. As the example of the developer myself, it shows around 85% for mouth wide open.

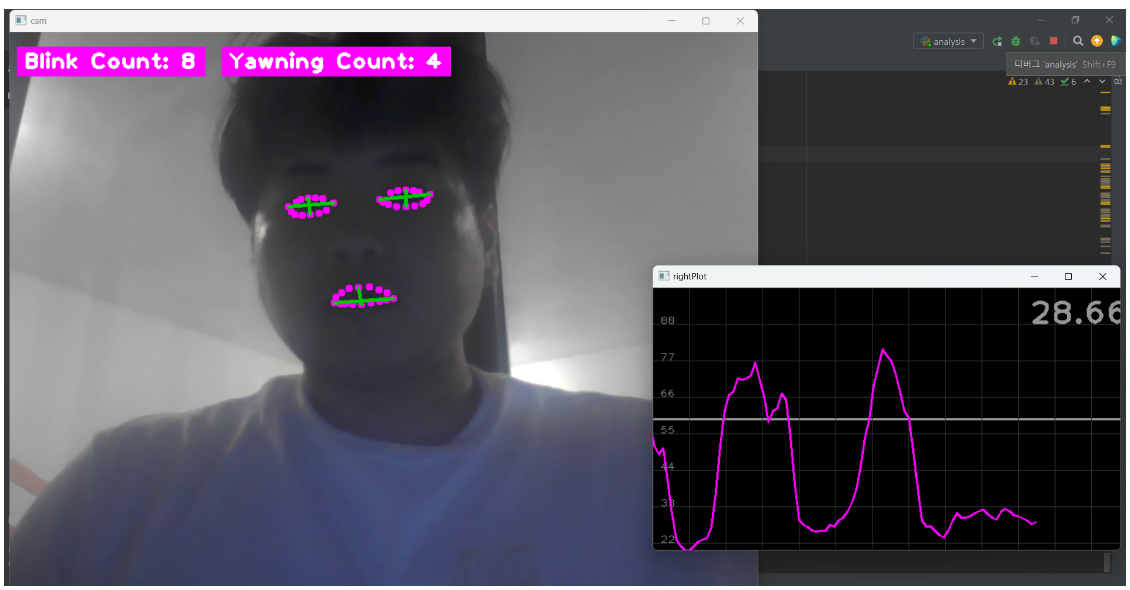


Figure 53. Face detection for mouth close

Figure 53 shows the face detection for yawning and monitoring the MAR (mouth aspect ratio) with the analysis of the graph. The system detects MAR following the analysis designed in **Chapter 5.4.2.1**. The system detects and counts yawning, following the analysis designed in **Chapter 5.4.2.2**. As can be seen in the graph of **Figure 53**, there is the graph going up and down. The gray line is the value of the MAR for detecting yawns. As the example of the developer myself, it shows 60% for the average MAR. Based on this value, the system detects the yawns. When the MAR is going down to the value, it regards one yawn.

6.5.2 Display & Feedback

Figure 54. Displays for the scale of the concentration level and different colors for alertness stimulation

Figure 54 shows the displays for the scale of the concentration level with different colors for the alertness stimulation. As designed in the specification phase, the scale displays on the background of different colors. This scale and the color are updated every 5 minutes.

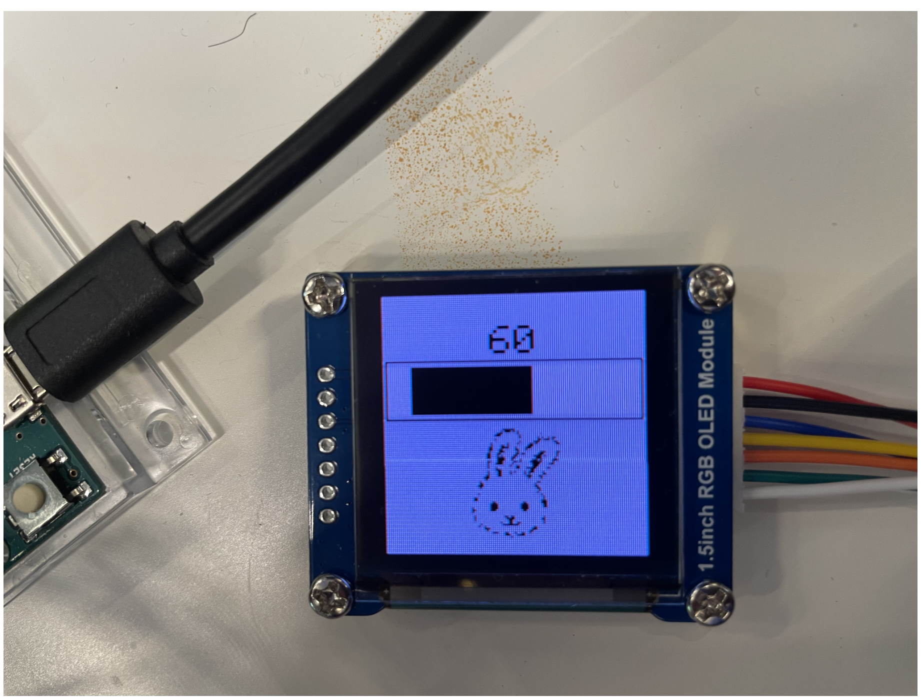


Figure 55. Display the race accomplishment

Figure 55 shows the displays for the race accomplishment. As designed in the specification phase, this screen displays the race accomplishment and the icon of the animal randomly assigned to a student. In this case, the rabbit is assigned. **Figure 55** is the results of short self-testing for the race accomplishment with a scale of 6 until accomplishing 60. As designed in **Chapter 5.4.2.3**, it supposes to take 10 minutes because the scale is equal to the animal's speed per minute. There is a little difference of 2.61 seconds less than expected. This is because of not considering the Delay statement in the Arduino code and the processing time of the laptop. Considering that people normally blink 10 times per minute [60], this difference is expected not to largely influence the user experience.

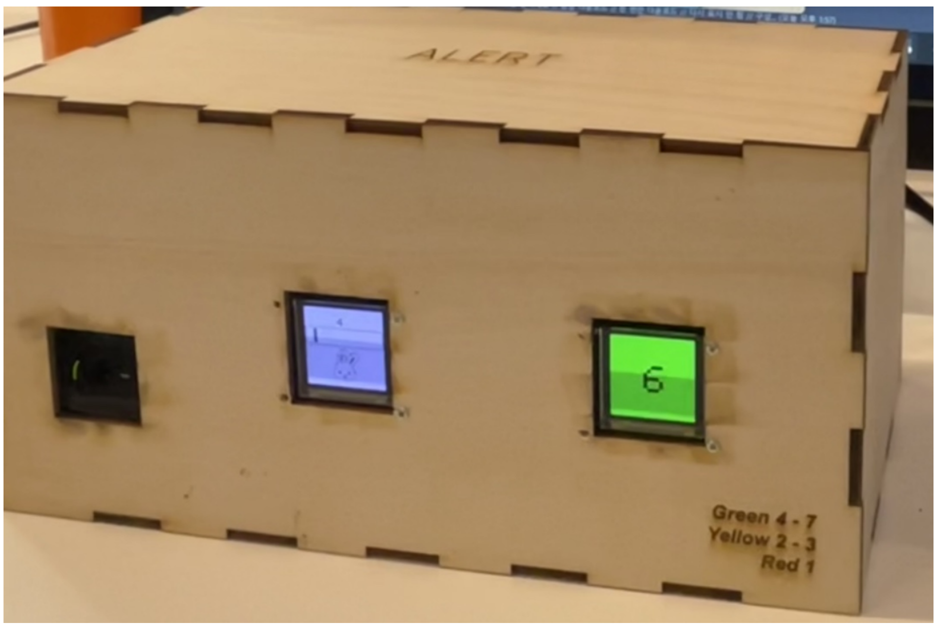


Figure 56. The overall look of displays

Figure 56 shows the overall look of displays fixed to the wooden box. **Figure 56** is the results of a pilot test for the prototype. In the first 5 minutes of the pilot test, the system detects yawning so the total score is 0 + 0 + 1 = 1 (blinking score + duration score + yawning score). As designed in **Chapter 5.4.2.2**, the total score of 1 is regarded as the prediction of the scale of 6 for the concentration level.

6.5.5 Overall Performance

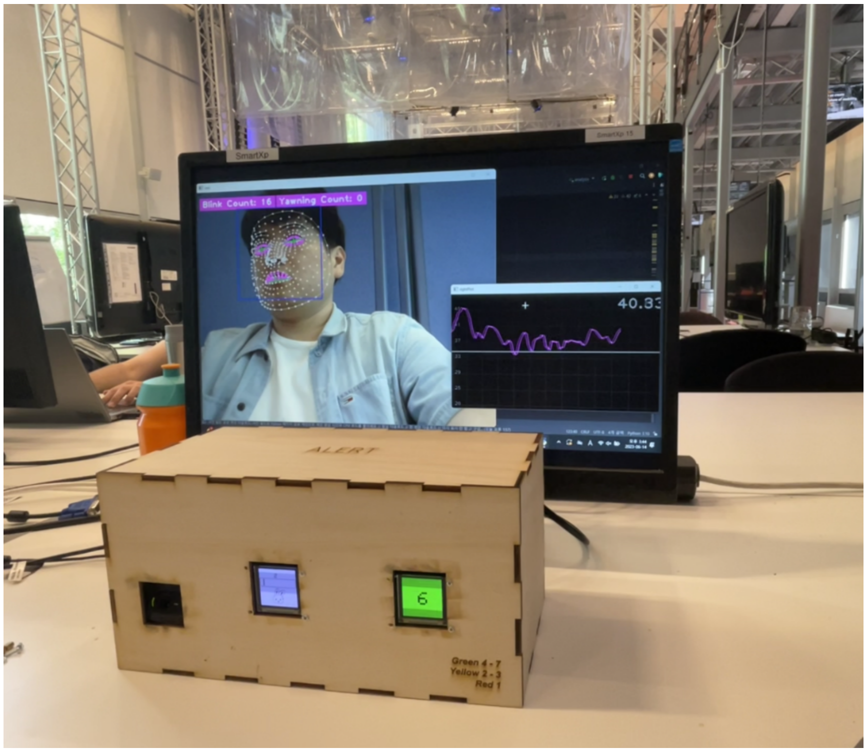


Figure 57. A picture of the second 5 minutes while a pilot testing

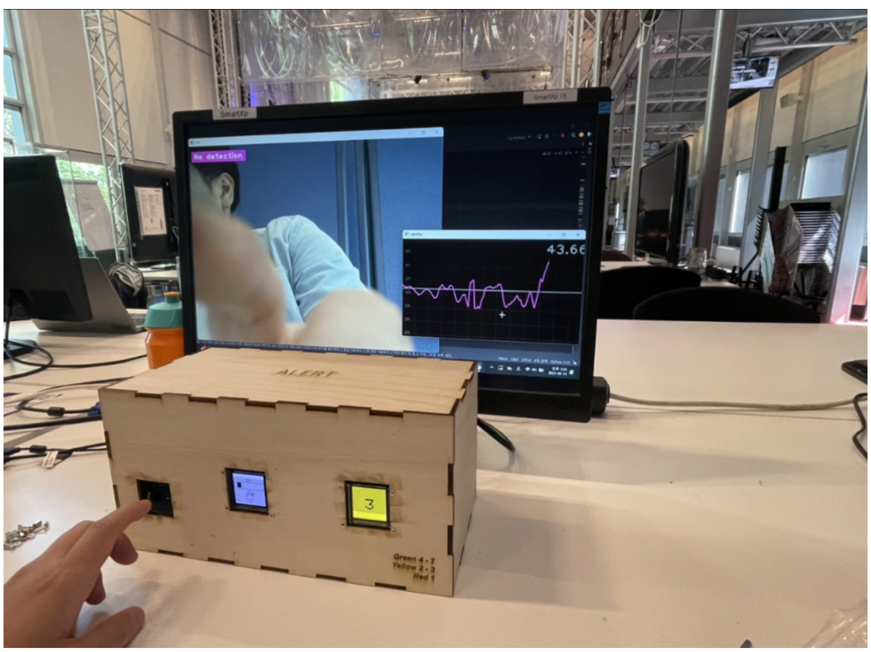


Figure 58. A picture of the situation of no face detection while pilot testing.

Figure 57 and **Figure 58** are the situations during pilot testing. **Figure 57** shows the overall performance of the hi-fi prototype. It was the second 5 minutes of pilot testing. As mentioned above, in the first 5 minutes, there is one yawn and the prototype detects this. Then, in the second 5 minutes, the prototype updates the scale 6 and displays this scale with green background and the race accomplishment calculated from the first 5 minutes. **Figure 58** shows the performance of the hi-fi prototype in a situation where there is no face detection. As designed in **Chapter 5.4.2.3**, it updates that the scale is displayed as '**?**' at that moment of no face detection. When the system detects the face again, then the predicted scale in the previous 5 minutes will be displayed again.

Category	Functional Requirement	Results
Must	The race must start when the technology starts to operate.	△
	The camera must capture and analyze the student's **eye movements** (blink duration and frequency, and eye direction) and **head movements** (head nod, doze off) in real-time.	**O**
	The analysis must predict the student concentration level by monitoring and collecting data **every 5 minutes in real-time**.	**O**
	The right screen must display the scale of the student concentration level from **1 to 7**. (1 for low level, 7 for high level).	**O**
	The left screen must display the student's **accomplishment of the race** in real-time.	**O**
	The background of the right screen should be turned based on the scale of the concentration levels. ● Green for the scale of 4 - 7 ● Yellow for the scale of 2 - 3 ● Red for the scale 1	**O**
Should	The **animal speed** should be in proportion to the **scale** of the student's concentration level.	**O**
	The **color change** should be adjusted to not be a too sudden and dramatic change.	**O**
	The animal species should be displayed **simply and intuitively**, and the animal race should be displayed intuitively.	**O**
	The **size of the technology** should be considered important.	**O**
Could	The **vibration** could be delivered when the student shows the **lowest scale** of concentration level.	**X**
	The **vibration** could be subtle enough to deliver **subtle and haptic vibration** to the student's desk.	**X**

Won't	The feedback about students' concentration levels won't send to a teacher so that it won't be distracting and demotivating.	**O**
	The light on the screen will not be turned suddenly and dramatically.	**O**

Table 10. Functional Requirements

Table 10 shows the self-reflection of whether the system matches the functional requirements defined in **Chapter 5.3.2**. **O** holds that requirements are fully satisfied in the prototype, △ means that requirements are partially met, and **X** means that requirements are not satisfied in the prototype.

Chapter 7 - Evaluation

In this chapter, the evaluation of this project will be presented. The goal of the evaluation is to answer the newly formulated research questions, mainly investigating whether this prototype is able to help students to concentrate on the lecture in a non-distracting and non-demotivating way.

7.1 Plan and Setup for User Testing

7.1.1 Purpose of User Testing

The main purpose should be discussed to evaluate the prototype of the system through user testing. Considering the main goal of this project and the design choice of the prototype, the following evaluation questions (**EQs**) in this phase can be considered:

EQ1*: Does the prototype help students to notice their concentration and to maintain concentration on the lecture?*
EQ2*: Does the prototype give the proper stimulation when they start to lose concentration?*
EQ3*: Does not the prototype distract or demotivate students from the lecture whilst operating?*

The first **EQ** is related to the goal of this project and the problem dealt with in this project. To remind, the problem identified from the students and teachers is that students have been familiar with losing concentration and it is difficult to notice that they are losing concentration. The first **EQ** aims to identify whether the prototype interacts with users through the designed purpose. The designed purpose is for the system to monitor students' concentration levels in real-time and give feedback to the students.

The second **EQ** is related to one of the main goals of this project. As introduced in **Chapter 1.1**, the main goals are two: 1) provide feedback to the students by monitoring their concentration levels in real-time in a non-distracting and non-demotivating way and 2) stimulate the students' alertness during the lecture based on the feedback given by the technology. The second **EQ** has the purpose to investigate the first of the main goals.

The third **EQ** is related to the first main goals of this project - non-distracting and non-demotivating. To answer this **EQ**, the observation is necessary because this will be answered based on the participants' memory and this can lead to the problem of recall [65]. This will be explained in **section 7.1.2.2.4**.

Overall, these three **EQs** will identify whether the prototype matches the goals and requirements built since the phases have been through in this project. This will lead to the evaluation of the hi-fi prototype.

7.1.2 Plan and Setup for user testing

In this section, the overall plan for the evaluation will be described. Then, the setup for the usability testing will be discussed. Lastly, the procedure of testing will be delivered.

7.1.2.1 Plan for the Evaluation of Hi-fi Prototype

The evaluation will be conducted on the results of the usability test from the primary user group. This system aims to be used in face-to-face lectures. However, there are some difficulties to test the hi-fi prototype in the actual face-to-face lectures. First of all, the system is now the prototype, so there could be unexpected challenges from the integration with the lecture room, and distracting the participant, other students, and the teacher. Furthermore, regarding the evaluation phase expected to conduct in the 4th week of June, many students and professors will be busy with the exam and the project in the last quarter of this academic year. Therefore, the usability test will be carried out in a similar environment and setup with the face-to-face lecture.

To do this, it is necessary to prepare the thing that can replace the face-to-face lecture and test it out in a similar environment and venue. First, a small lecture will be prepared to replace the face-to-face lecture. This will be around 8 - 10 minutes and the content will be about the rules of basketball. Considering the face-to-face teaching method, online lectures or videos will not be used, and instead this lecture will be made by the researcher and the researcher will teach the participant about the basketball rule. The slides from this lecture are included in **Appendix 1**. Regarding the lecture time, the detecting time of the prototype will be adjusted to detect every 2 minutes. The observation will be carried out, in order to investigate how the users interact with this system. However, because the researcher does not have any experience in teaching, it will be difficult to conduct the observation whilst teaching. For this problem, the testing will be recorded and the observation will be conducted by watching these records again. To do this, the participants must consent to recording the usability test.

Second, the environment and venue of the lecture room will be replaced by a similar environment and venue, and the project room in Vrijhof seems one of the best locations. This is because there are student desks and a TV for display and this can be regarded as the small size of the lecture room.

After the usability testing, 4 open questions will be asked. These questions were designed based on the newly formulated research question in **section 7.1.1**. The participants' answers will be great feedback to not only answer the RQs but also give insight into how this system can be improved and should be revised.

7.1.2.2 Setup for User Testing

7.1.2.2.1 Samples and Recruitment

The primary users of this project were identified as UT students. Although, in Chapter 4.1, it was mentioned that the user group is both students and teachers, the primary users were the UT students through evaluation of the lo-fi testing, because the system does not provide any feedback or technical support to the teachers. Still, regarding the authority of this system by the teachers (mainly) and students, both are the main stakeholders. In this regard, the recruitment of the user testing for the hi-fi prototype will be carried out with the aim of 8 participants. These all participants will take the prepared lecture while the prototype is operating in front of them.

7.1.2.2.2 Environment and Venue

As mentioned above, the venue of the usability test is the project room in Vrijhof. **Figure 59** is a picture of one of the project rooms in Vrijhof and **Figure 60** shows a simple diagram of the environment of the usability test. Participants will be asked to sit where they can see the lecture and the researcher face-to-face because face detection is based on the frontal face. The hi-fi prototype will be placed in front of them from the appropriate distance where they can retain enough space regarding the results of the lo-fi prototype (the system occupying a large space can be distracting). The TV furnished in the project room will be used to display the prepared slides for the small lecture about basketball rules. The researcher's smartphone will be placed near the participant, where it can record the participant's interaction with the prototype.

Figure 59. The picture of one of the project rooms in Vrijhof

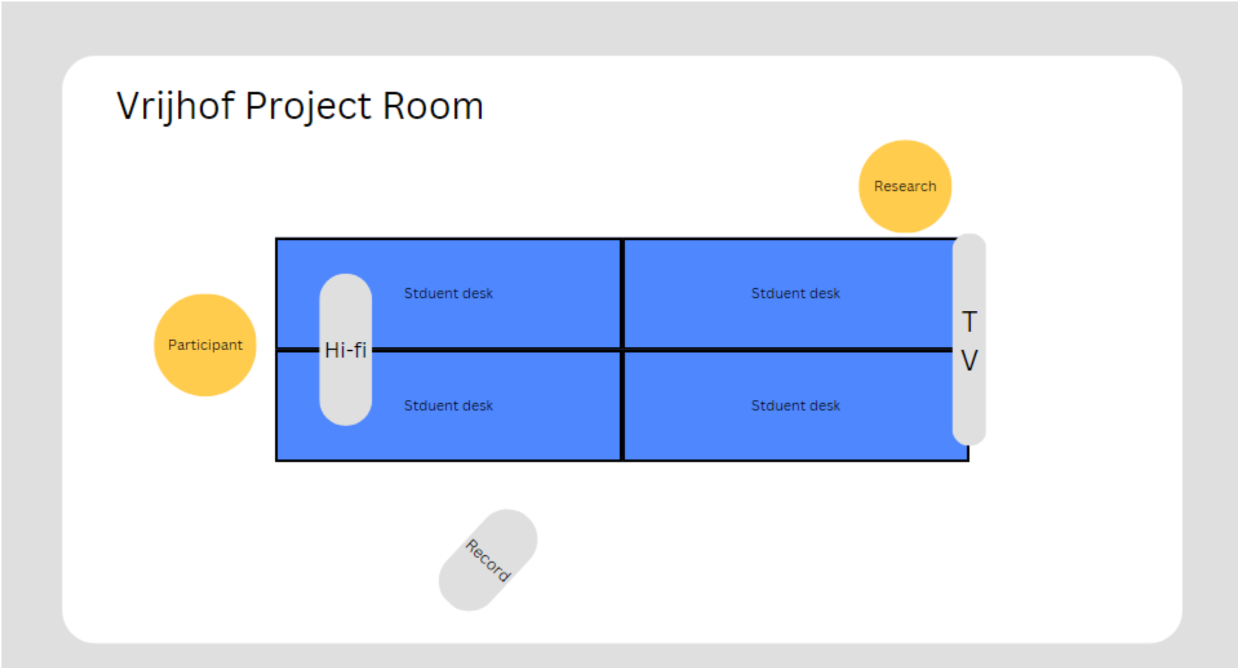


Figure 60. Simple diagram of the testing environment

7.1.2.2.3 Task

The task which will be asked of participants during testing is taking the small lecture with as full concentration as possible, imagining that they are taking the actual face-to-face lecture. To draw the concentration from the participants, a small quiz will be provided related to the basketball rule in different situations. The quiz will be asked the following: 1) Showing the prepared short video (such as **Figure 61**) of the one situation during the basketball match 2) Asking what is illegal and legal 3) Comparing the participant's answers with the quiz answers 4) Score the correct answer in one situation 5) Showing the other 4 videos of the different 4 situations 6) Record the total score. The quiz will be asked after asking interview questions. After testing, the tasks for the participants are to answer the three open questions and to solve the prepared 5 quizzes. At the end of the usability test, the participant will be able to be aware of how many of the answers are correct.

Figure 61. An example of the short video which will be played to the participant for the quiz.

7.1.2.2.4 Questions

Three open questions for the short interview after testing were designed. The reason for preparing the open questions is to gain as much feedback from the primary users as possible and to answer the research questions from various perspectives of the participants. To ask these open questions, this short interview will follow the semi-structured interview. With the focus on the prepared questions, the participants will be able to freely answer these questions. Based on the participants' answers, some follow-up questions will be asked, for example, when they give interesting answers (derive more for interesting aspects) or the answer does not include what the researcher wants to know in the question (guide the interview). The questions are the following:

Q1*: How much do you think you concentrate? And How long do you think you maintain your concentration during this 8 - 10 lecture?*
Q2*: How does the prototype affect your concentration level?*
Q3*: How does the alertness stimulation from the prototype affect your alertness level?*
Q4*: What from the prototype makes it difficult to maintain concentration in the lecture?*

Question 1 aims to compare the answers with the observation of the usability test. There are two objectives here: 1) investigate the approximate accuracy of monitoring sleepiness and fatigue, and prediction of concentration level 2) identify the thing which is difficult to be identified through this interview and questions. For example in the second objective, the participants can answer that they think they showed full concentration on the lecture, but through the observation, it can be identified that the participant keeps glancing at the prototype and this means that the participant is distracted unconsciously. Lazar [65] states that participants can suffer from problems of recall because interviews involve data collection that is separated from the task and context under consideration. He emphasizes that participants can answer what they remember as participants report on their perceptions of needs or experiences. In this case, The other three questions basically ask about the interaction between participants and the prototype based on what participants remember. This will lead to the problem of recall. Therefore, **Question 1** will be asked in order to avoid this problem.

The other questions aim to gain the answer to the research questions. Furthermore, they have the purpose to receive the users' feedback about how this system can be improved and should be revised. Because the interviews are semi-structured, various answers in different aspects can be drawn. These answers will enable the researcher to evaluate the prototype in different aspects.

7.1.3 Procedure

The usability test for the evaluation of the hi-fi prototype will comply with the following procedure.

1. Provide the consent form and the information letter to potential participants
2. Explain the context of the project, the purpose of the usability test, and the hi-fi prototype
3. Setup and Ask the informal question about the overall look and feel of the hi-fi prototype
4. Prepare the small lecture and recording
5. Notice to the participant that there will be a quiz about lecture
6. Testing
7. Stop recording and prepare the interview
8. Ask prepared 4 open questions and follow-up questions if needed
9. Prepare the quiz and conduct
10. Calculate the total score and tell this score to a participant
11. Provide the email and phone number if participants are interested in the result of the usability tests and this project or if participants wonder where the data collected from the usability tests will be used and comply with privacy prevention (Debriefing).

12. De-setup, organize and transcribe the results

7.2 Result

7.2.1 Observation

Participants	Prototype	Participant and Interaction
Participant #1	- For the first 4 - 5 minutes of the lecture, the prototype keeps sending feedback on a scale of 1 or no detection ‘**?**’. So, the detecting value for the EAR was adjusted to be lower. Also, the webcam angle was adjusted to the sitting pose of Participant #1. Then, the lecture was restarted after obtaining consent from Participant #1. - It was observed that Participant #1 has a habit of supporting the face with the hands or gathering them in front of the mouth. The prototype cannot sometimes detect the face and so it kept sending the feedback of ‘?’ meaning no detection. -	- Participant #1 shows the concentration in a lecture. It can be proven from the participant memorized most of the lecture content when the participant solved quizzes. - Participant #1 did not care much about the prototype. However, when the background color is changed to yellow or red, then the participant was observed glancing at the scale screen.
Participant #2	- At the beginning of the lecture, the system displayed ‘?’ or red again. But in this test, Participant #2 fixed the sitting posture. Then, the system detected well. - The feedback about the scale became higher when closer to the end.	- Participant #2 was observed that the participant kept fixing the sitting posture. But, Participant #2 said that it was a habit when the participant concentrated on something. - Participant #2 showed a high concentration level. It can be proven from the participant memorized most of the lecture content. And the participant remembered the content not included in the slides. - Participant #2 concentrated well but the participant kept glancing at the prototype at every updating time (2 minutes).
Participant #3	- Participant #3 is the case of a well-detected prototype. - Participant #3 showed the scale assigned to the green. And only two	- Participant #3 showed rather a good concentration level. - The participant did not care much about the prototype. Only two short

	times of detection show the scale 3. - The rabbit went the furthest because the prototype showed the best detecting performance.	glances. - The participant seemed to feel proud when the lecture finished and the participant compared the accomplishment with other participants.
Participant #4	- Participant #4 is relatively tall so it is quite difficult to adjust the angle of the prototype and the webcam detection. - So, mostly the prototype showed no detection '?'. One for green and two times for 3 and yellow.	- The participant concentrated well in the beginning, but the participant was observed to lose concentration because of the prototype performance. - Keep glancing at the prototype at every updating time (2 minutes). The participant seemed to care about this but it was not distracting because the participant concentrated on the lecture immediately. - The participant kept fixing the sitting posture because of the detecting problem.
Participant #5	- The prototype mostly displayed scale 3 and yellow. And two times of scale 1 and red. - The prototype sometimes did not detect awnings because the participant has a habit of supporting the face with the hands or gathering them in front of the mouth.	- The participant did the basketball training in the association before this testing. - Participant #5 mentioned that the participant was really tired and fatigued before testing. - It was observed that the participant cannot concentrate well on the lecture. - The participant did not care much about the prototype but when it changed to red and scale 1, then the participant had a look at the prototype.
Participant #6	- The prototype displayed mostly scale 5 or 6 and green. - No displaying '?' and every feedback was green and only one time for yellow.	- It was observed that Participant #6 cannot concentrate at all, but the participant showed interest in the prototype. It can be proven that the participant got only one correct out of six quizzes. - The participant had a look at the prototype at every updating time. The participant looked at the scale and accomplishment.

Table 11. The result of the observation

7.2.2 Interview

***Q1**: How much do you think you concentrate? And How long do you think you maintain your concentration during this 8 - 10 lecture?*
***Q2**: How does the prototype affect your concentration level?*
***Q3**: How does the alertness stimulation from the prototype affect your alertness level?*
***Q4**: What from the prototype makes it difficult to maintain concentration in the lecture?*

	Q1.	Q2	Q3	Q4
Participant #1	I stayed up all night so I have a little sleepiness and fatigue. But, I think I quite concentrated on the lecture. I think I can maintain concentration for around 2-3 minutes.	When the scale and the color were changed to low, then I tried to concentrate more. If the scale is detected as low, then it makes me have a desire for getting a higher scale.	When the screen background was changed to red, then it led to self-motivation so I tried to concentrate more by myself. And so the scale became higher as 3. But still tried to concentrate more to get the green and a higher scale.	No.
Participant #2	I think I concentrated 100%. Because it was interesting content. I think I maintained concentration until the end.	At the beginning of the lecture, the prototype displayed scale 2. It made me care about it a little. But it was not distracting. Even, It made me try to concentrate more. At becoming closer to the end, I think I fully concentrated so I did not care about it at all.	When the system display the red and scale 1, it aroused my attention. It is quite conspicuous, The color change is conspicuous and intuitive. I care more about scale than race accomplishment during the test. But when i get feedback on a scale 5, the rabbit ran rather far so it made me proud and motivated.	No. At the beginning of the lecture, the system seems to detect well so I change my sitting pose because I want to receive clearer feedback. But it was not distracting a lot. As I said, I concentrate more when closer to the end, so I did not care much about it.
Participant #3	I think I concentrated 7 out of 10. I think I did not lose and I maintained my concentration,	I think it was really effective for self-motivation. I can notice my concentration level in real-time. I identified that I showed mostly	I didn't care much about it but when the color changed from green to yellow, I noticed that from the glance and I tried to concentrate more.	No, but the color changed from green to yellow was quite conspicuous and obvious. This might be distracting. But in my case, it was not.

		green and it motivated me to keep receiving this high scale.		I like this simple interface.
Participant #4	Actually, the lecture was really fun and interesting, but I think I lost from the middle because the system kept displaying '**?**'.	Although It mostly said ?, it helped to notice my concentration level in real time. When the system display green, it made me proud that I was concentrating well. When the color changed from green to yellow, it led to motivation.	I think it was really effective to regain concentration. It truly alerted me when I lost concentration in the middle of the lecture.	No.
Participant #5	Honestly no. Today's training was really hard so I was too fatigued. But, the content was interesting and my favorite so I can concentrate a little bit.	I realized that I was losing concentration in real time. It motivated me to concentrate more but I think my fatigue was more than the motivation.	I think the color was really effective to stimulate. It was conspicuous and obvious. In my case, most feedback was yellow and I think I can maintain not to completely lose concentration because of this stimulation.	No, but I am just worried that a student can cheat this system to get a higher scale. I know there are not any benefits from cheating, but what if friends will have the competition for fun?
Participant #6	Yes. I think. I concentrated but I did not have any interest in the sports and basketball also. But, this made me feel like an actual lecture. Basically, the lecture content did not attract interest.	The green color made me proud. So, I motivated myself to get the green and a high scale until the end.	The rabbit and race accomplishment was interesting. I saw the rabbit went further when I received a higher scale. This led to motivation to move this rabbit much further and closer to the end of the race path.	No

Table 12. The result of the Interviews

7.3 Evaluation

The evaluation will be discussed based on the evaluation questions defined in **Chapter 7.1.1**. The evaluation questions (EQs) are the following:

EQ1*: Does the prototype help students to notice their concentration and to maintain concentration on the lecture?*
EQ2*: Does the prototype give the proper stimulation when they start to lose concentration?*
EQ3*: Does not the prototype distract or demotivate students from the lecture whilst operating?*

For the first and the second **EQ**, the prototype did help students to notice their concentration in real-time and to regain and maintain concentration during the lecture. The prototype provided effective alertness stimulation by changing the color of the screen background. According to the answers of the interview from the participants, this stimulation is conspicuous and obvious so that it can stimulate alertness leading to regaining concentration. Also, it motivated the students to want to receive feedback about better concentration and a higher scale. However, the race accomplishment still needs further research to figure out whether it can lead to the motivation to change the mindset towards the lecture. Because this was not able to be observed and answered by the participants by conducting only these user tests. Most participants did not care much about this feature and it was expected that there was no following lecture after these tests. For the last **EQ**, there are no other things observed that can distract or demotivates students from the lecture. However, one participant wondered what if a student cheats the detection to receive a high scale and then if this student uses this scale for the competition with friends for fun. A student can cheat the detection for a higher scale of concentration, but there are no benefits from here because race accomplishment is designed for individuals themselves. It can be used for competition with friends for fun, but it can also lead to the motivation for the following lecture on the next day from one who loses the competition. For this reason, this project does not take into account this problem.

Based on the results and the evaluation, the non-functional requirements will be assessed whether the prototype met these requirements.

Category	User Requirement	Results
Must	The technology must be easy to use and interact with.	**O**
	The monitoring must be done in a **non-distracting** way.	**O**
	Two screens must display the race accomplishment and the scale of concentration levels in a non-distracting way.	**O**
	The feedback must be delivered to the students in a **non-distracting** and **non-demotivating** way.	**O**
Should	The system should provide the appropriate **alertness stimulation** to help them to regain concentration.	**O**
	The feedback about the student's concentration level should provide **a little accuracy** to the actual student's concentration level so that it is not demotivating students.	△
	● The technology should provide enough space for the desk to students. ● The technology should not be too high or too wide to be visible and distracting.	**O**
Could	The system could lead to self-motivation to try to regain concentration and to change the mindset towards the lecture.	△

Table 13. Non-functional requirements evaluation

Table 13 shows the self-reflection of whether the system matches the non-functional requirements defined in **Chapter 5.3.2**. **O** holds that requirements are fully satisfied in the prototype, △ means that requirements are partially met, and **X** means that requirements are not satisfied in the prototype.

Chapter 8 - Discussion & Future Work

8.1 Hi-fi prototype performance

As the client, the Data Management & Biometrics (DMB) faculty expects a technology that can provide feedback to the students and the teacher about the concentration levels of the students and can stimulate the student's alertness, in non-distracting and non-demotivating ways. The results from the evaluation phase can derive that the prototype provides real-time feedback to the students about their concentration levels and can stimulate the students' alertness. The prototype will bring a positive influence on not only the university students but also on the broader educational field. The prototype can make students notice their concentration levels in real-time and stimulate their alertness and this can lead to the improvement of the learning quality and productivity. Additionally, in respect of the 'Smart Lecture Room', the prototype can help to come up with many integrations with other technology included in the Smart Lecture Room.

8.2 Limitation

The evaluation of the prototype still remains the limitation of this project, the prototype, and the evaluation. First, the adjustment of the detecting variables is the limitation of the prototype. Especially in the university, there are many students of various nationalities and they all have different eye sizes and other physical features. Adjusting the EAR, MAR, and blink duration needs the data from the quantitative tests to find the well-balanced variables. In addition, the webcam detecting angle should be varied based on, for example, the student's height and the place where students sit in the lecture room. The second limitation is the accuracy of the prediction from the analysis of sleepiness and fatigue. In the evaluation phase, the prototype was observed that it predict the scale lower than a student's actual concentration level. This is expected to be solved by further research on the specific scale of the indicator of the concentration for this project or more fractionalizing the analysis for the prediction. Lastly, there are limitations from the evaluation setup. For example, a sample size of 6 can be regarded as a small sample size. However, considering the evaluation setup, the lecture including the quiz should be conducted 1 by 1 and so the time consuming of the user testing can lead to this limitation.

8.3 Future Work

For future work, this project needs further research on the webcam angle, distance, and detecting variables, by conducting the quantitative tests. Quantitative testing will help to find the proper variables and angles and to avoid discriminatory technology. Considering more aspects to analyze for the prediction can be one of the future works. Because all aspects to analyze for the prediction are included on the face and head. For example from the evaluation phase, if the student has a habit of supporting the face with the hands or gathering them in front of the mouth, then the system may not be able to provide an accurate analysis and prediction of the concentration levels. The consideration of other aspects measuring sleepiness and fatigue can be a solution. For example from the background research, HRV can be one of the examples.

Considering the evaluation phase, several tests should be conducted in the future in the real face-to-face lecture. This will help to improve and evaluate the prototype in three aspects: 1) to evaluate the prototype in the actual lecture room, 2) to investigate the availability in the lecture room, and 3) to evaluate one non-functional requirement which cannot be evaluated from the evaluation phase of this project. To remind, this requirement is that '*the race accomplishment could lead to self-motivation to try to regain concentration and to change the mindset towards the lecture.*'

Chapter 9 - Conclusion

This project presents the development of the technology monitoring students' concentration and stimulating their alertness. The problem observed by the primary users of this technology is that it is difficult for teachers to notice that their students are losing concentration during the lecture and that it is difficult also for students to regain and be alerted again during the lecture. To address this project, the main **RQ** is '*How can monitoring technology identify students' concentration and stimulate alertness during face-to-face lectures, by giving feedback to students and teachers in a non-distracting and non-demotivating way?*'.

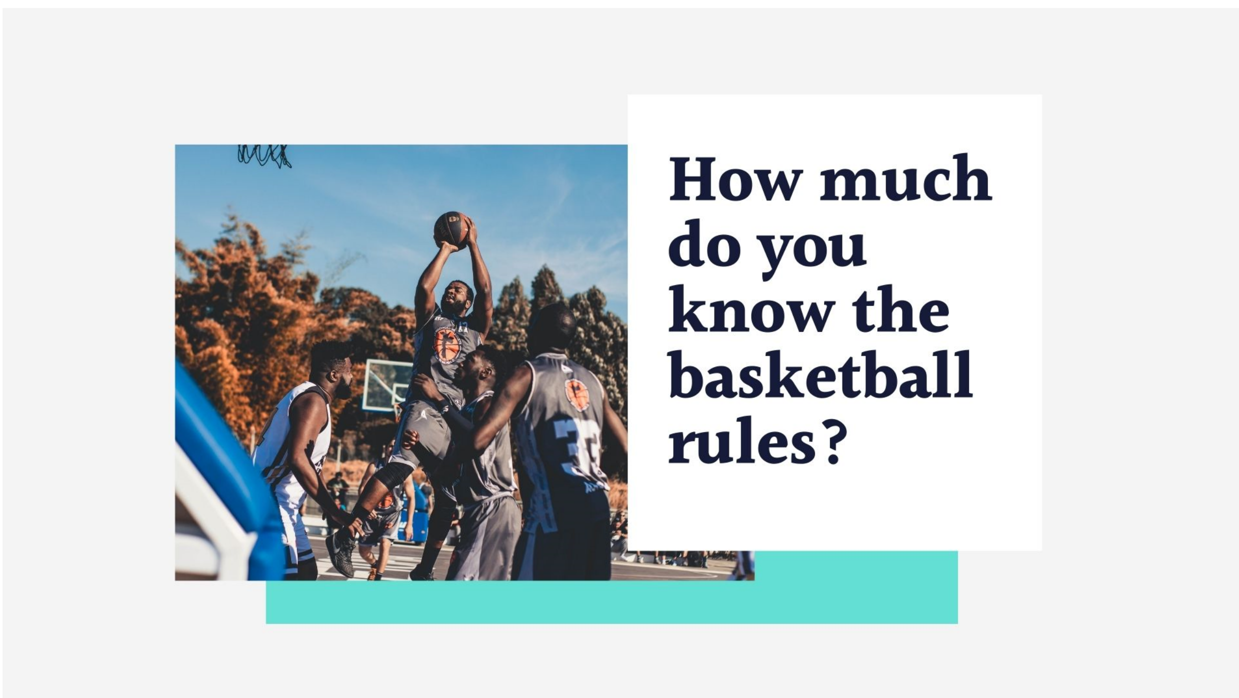
Because of the limitation to directly measuring the concentration levels by the brain data, this project dealt with sleepiness and fatigue as an indicator of the concentration levels. To achieve the main **RQ**, the system named "ALERT" was developed. The "ALERT" includes a webcam and two screens. A webcam detects a student's face to collect data on eye blinking, blink duration, yawning, and head direction for 5 minutes. These collected data will be analyzed in the main system and the concentration levels will be predicted on a scale from 1 to 7. This scale will be displayed on one of the screens with the different assigned colors - red, yellow, and green. This will stimulate the student's alertness and furthermore it is expected to lead to self-motivation to regain and maintain concentration on the lecture. Another screen is for gamification. When the lecture starts, the students will be randomly assigned to different animals. Animals will run the race at a speed that is equal to the scale of concentration levels. The screen will display the race accomplishment of the animals and this feature is expected to be used for the self-motivation not only to regain and maintain concentration but also to change the mindsets towards the lecture.

The result of the evaluation of the prototype shows that the prototype helps students to notice their real-time concentration levels during the lecture, and to stimulate alertness. Additionally, the prototype helps students to regain and maintain concentration, and to have self-motivation. However, the evaluation remains some further research but the possibility of the prototype was observed by the participants of the evaluation testing.

This prototype shows the positive potential of not only the university students but also the broader educational field. Also, the prototype will remain the possibility of future work on the integration with other technologies of the Smart Lecture Room.

Appendix

Appendix 1. Lecture slides for the user test in the evaluation phase.



CONTENTs

Basic rule 1

Travelling

A player only can advance the ball by dribbling. If they run while holding the ball, they are traveling.

Double Dribble

If a player stops dribbling, they may not resume; instead, they must pass the ball or shoot it.

Shot Clock

Teams have limited time to shoot the ball during 24 seconds of possession. If the shot clock elapses, it's a 'shot clock violation'.

Basic rule 2

Travelling 2

A player who gathers the ball while dribbling may take two steps in coming to a stop, passing, or shooting the ball.

Out of Bounds

The ball and players in possession of the ball must always remain within the boundaries of the court.

Kicking the ball

Kicking the ball with any part of the leg is a violation when it is an intentional act. The ball accidentally striking the foot, it is not a violation.

Defensive foul

Holding foul

A player shall not hold the progress of an opponent by extending a hand, arm, leg or knee or by bending the body into a position that is not normal.

Pushing foul

A player shall not push the progress of an opponent by any parts of the body.

Blocking foul

Illegal body contact to impede the the routing of an opponent.

Illegal use of hands

Normally called 'shooting foul' in the street.

Illegal use of hands to attempt to deter an opponent's progress.

Offensive foul

Charging foul

A player shall not charge into an opponent who has established a legal guarding position.

Agressive use of elbow

A deliberately-thrown elbow or any unnatural physical act towards an opponent with no contact involved

Illegal screen foul

Normally called 'moving screen'.

move laterally or toward an opponent being screened, after having assumed a legal position.

Illegal use of off-arm

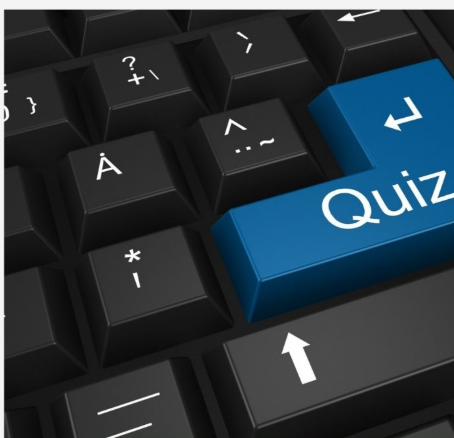
Using the off-arm with lifting the armpit is illegal.

Travel and gather step

Gather step & Travel

1) No matter how many steps a player takes, it doesn't count while dribbling.
   - only consider 'carrying the ball' and 'double dribble'.

2) Still doesn't count the step when dribbling ended.
3) Start to count when the player cannot take more dribbling. (so when the player grabs the ball and the next step)
4) Over 2 steps, it's a travel.



Quiz

ROUND 1 — EASY

Q1. #3 Jordan Poole violated one of the basic rules, but the referee can't see and didn't call the violation.

What is the violated rule?

ROUND 1 — EASY

Double Dribble

If a player stops dribbling, they may not resume; instead, they must pass the ball or shoot it.

He stops dribbling and was trying to catch the ball to shoot or pass. But the opponent expected and defended well. Then, he wanted to keep dribbling and he moved the ball from right to left without dribble. He violated the rule of 'Double Dribble'.

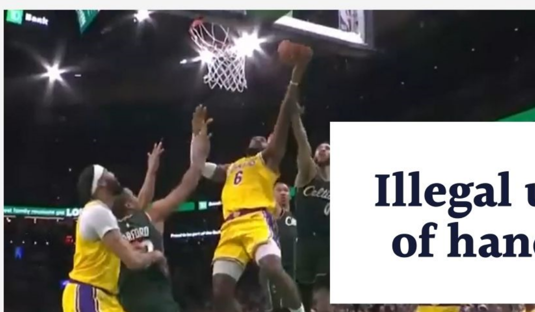
ROUND 2 — EASY

Q2. #6 Lebron James got the defensive foul by #0 Jayson Tatum, but the referee can't see and didn't call the foul.

What is the violated rule?

ROUND 2 — EASY

ROUND 2 — EASY



Illegal use of hands

Illegal use of hands to attempt to deter an opponent's progress.

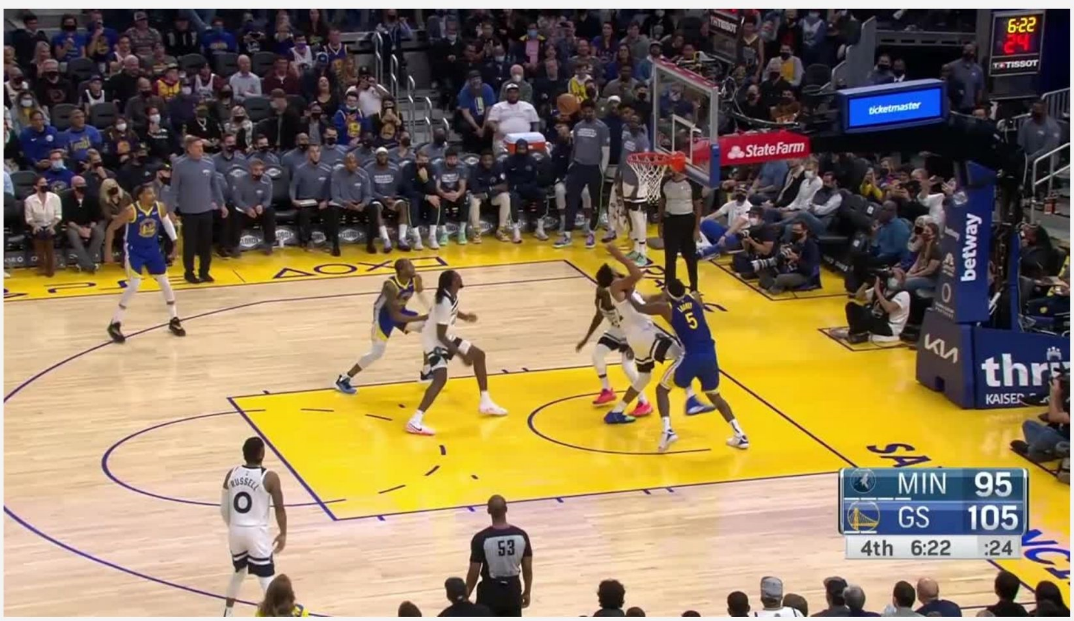
Lebron tried to do the lay-up. Tatum used his hands to deter the progress of Lebron's left hand for the lay-up.

ROUND 3 — MODERATE

Q3. #22 Patrick Beverley violated the defensive foul and #9 Andre Iguodala violated the offensive foul at the same time. So the referee called the 'double foul' and declare the Jump ball.

What are the violated rules?

ROUND 3 — MODERATE



ROUND 3 — MODERATE

Pushing foul & Aggressive use of elbow

A player shall not push the progress of an opponent by any parts of the body.

A deliberately-thrown elbow or any unnatural physical act towards an opponent with no contact involved

Beverley had unnecessary body contact with little extending arms. Then, he violated the pushing foul.

Iguodala tried to pass the ball at the corner, but he extended his arms too much. So, his elbow hit Berverley face and he violated the aggressive use of elbow.

ROUND 4 — HARD

Q4. Travel or Gather ?

ROUND 3 — MODERATE

Q4. Travel or Gather ?

ROUND 3 — MODERATE

Gather

ROUND 5 — HARD

Q5. Travel or Gather ?

ROUND 5 — HARD

Q5. Travel or Gather ?

ROUND 5 — HARD

Gather

ROUND 6 — HARD

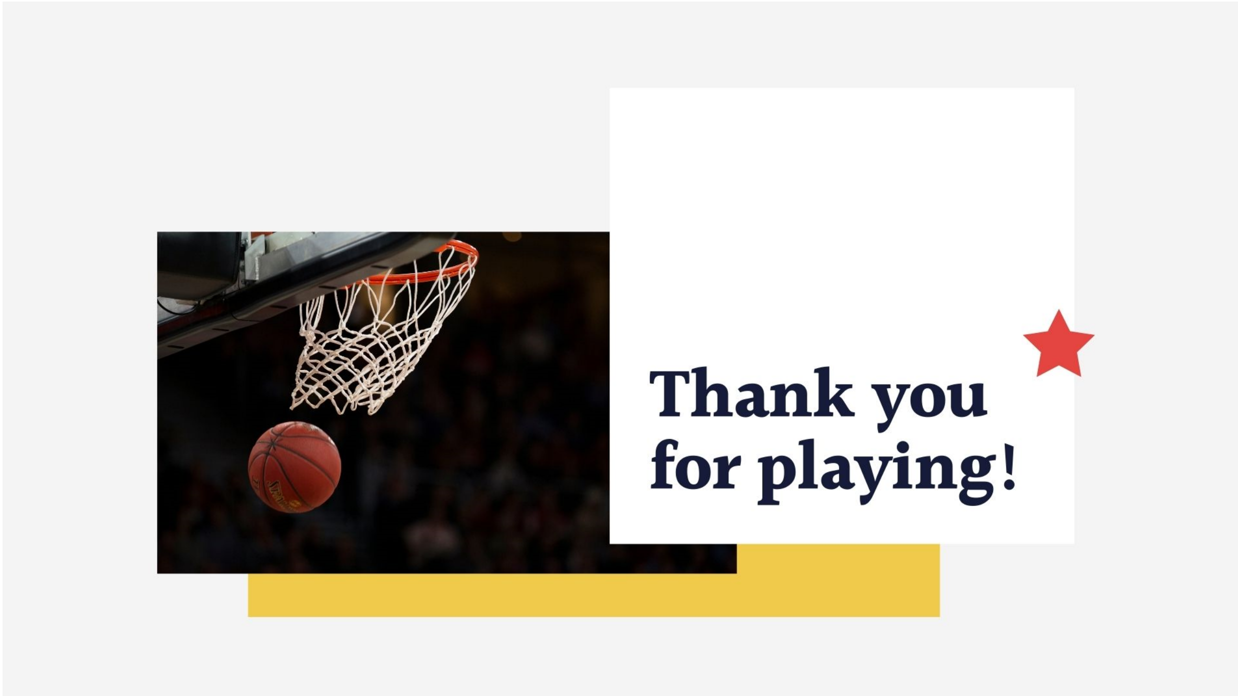
Q6. Travel or Gather ?

ROUND 6 — HARD

Q6. Travel or Gather ?

ROUND 6 — HARD

Gather



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