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E-learning System focusing on Emotional Aspect using Biological signals

-Boredom detection by eye tracking-

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E-learning System focusing on Emotional Aspect using Biological signals

-Boredom detection by eye tracking-

by

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Declaration of Authorship

I, Saromporn CHAROENPIT, declare that this thesis titled, E-learning System focusing on Emotional Aspect using Biological Signals and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at Shibaura Institute of Technology.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at Shibaura Institute of Technology or any other institution, this has been clearly stated.
- Where I have consulted the published work of other, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with other, I have made clear exactly what was done by others and what I have contributed myself.

Signed: _____
(Saromporn CHAROENPIT)

Certified by: _____
(Prof. Dr. Michiko OHKURA)

Date: _____

Abstract

E-learning is a computer-based content and instructional methods designed to build knowledge and skills for individuals and organization. The disadvantages of e-learning include lack of immediate feedback in asynchronous e-learning and potentially more such negative emotions as frustration, anxiety, and confusion. When learners have negative emotions, they usually do not learn well. Therefore, to cope with those is considered to be a key issue. Therefore, I proposed and designed a new e-learning system with real-time feedback focusing on the learners' emotions. To realize the e-learning system, biological sensors and analyze of learners' emotions were added into the system.

At first, the study is proposed the design of a new e-learning system focusing on emotional aspects. The feature of this system is to give feedback from emotional aspect.

Second, the study focused on estimation of various emotions to confirm importance of their detection using questionnaire. The experimental results suggest that emotional aspects should be taken into account to design interfaces or contents of an e-learning system at least for the difficult contents.

Third, the study focused on estimation of learners' emotions by eye tracking. The fixation duration ratio, number of fixation ratio and pupil diameter ratio were useful to analyze learners' negative and positive emotions. The experimental results suggest that the eye metric results are considered more reliable than the questionnaire results.

Finally, the thesis implemented a prototype of the e-learning system with real-time feedback to help learners escape from boredom. To provide appropriate feedback to the learner, a caution module was added into the prototype employing fixation duration and pupil diameter as metrics for boredom detection. The experimental results indicated that this e-learning system with real-time feedback focusing on escaping boredom has potential to be applicable for helping learners to continue learning.

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Abbreviations

AOI	=	Areas of interest
BMP	=	Beats per minute
BVP	=	Blood Volume Pulse
CES	=	Courseware evaluation survey
CMS	=	Course Management System
ECG	=	Electrocardiography
EDA	=	Electro dermal activity
EEG	=	Electroencephalogy
EMG	=	Electromyography
EQ	=	Emotional quotient
EREC	=	Emotion recognition sensor system
IQ	=	Intelligence quotient
LA	=	Learning area
LMS	=	Learning Management System
Moodle	=	Modular Object Oriented Dynamic Learning Environment
OLA	=	Out of learning area
PHP	=	PHP hypertext preprocessor
PPG	=	Photoplethysmography
PPT	=	Power point
SD	=	Standard Deviation
SCL	=	Skin conductance level
SCR	=	Skin conductance response
SKT	=	Skin temperature
SQL	=	Structured query language
VLE	=	virtual learning environment

Chapter 1

Introduction

This chapter provides an introduction to the research work presented in this thesis. It describes the motivation of this research, problem statement, research goals, and finally the structure of the thesis is introduced.

1.1 Motivation

The traditional context of learning is experiencing a radical change. Teaching and learning are no longer restricted to traditional classrooms [1]. E-learning is content and instructional methods delivered on a computer and designed to build knowledge and skills related to individual or organizational goals [2]. Convenience is one of the major advantages of e-learning [3]. It allows learners to work and learn at their own pace without the unyielding time restrictions of traditional learning. Since e-learning provides access to learning materials at any time, learners have flexibility to schedule around families, jobs and other activities [4, 5]. Another major benefit of e-learning is

accessibility it provides. Learners can learn from wherever they are on the condition that the internet is accessible [6]. E-learning allows learners to select learning materials that meet their level of knowledge, interest and what they need to know to perform more effectively in an activity. E-learning actively focuses on the learners and it is more interesting for them because it provides all information that they want to learn [7]. E-learning is flexible and can be customized to meet the individual needs of the learners [8].

Figure 1.1: E-learning (left) and traditional classroom learning (right) [9]

The disadvantages of e-learning include lack of immediate feedback in asynchronous e-learning, increased preparation time for the instructor, unease to some people, and potentially more frustration, anxiety, and confusion [6, 10]. Many learners have experienced some negative emotions, always feeling sleepy or bored, in their learning. When the learners have these negative emotions, they usually do not learn well [8]. Moreover, a common problem of e-learning is that the learners could easily get bored because of the environment might not fully support e-learning system [11]. To cope with these negative emotions (e.g. frustration, anxiety, confusion, boredom, sleepiness) is considered to be a key issue. Therefore, to persuade the learners to continue learning when they get negative emotions, an appropriate tool should be initiated in order to effectively avoid causing negative emotions to the learners [11].

Certainly, emotions can affect learning, in both a positive and negative ways [12].

Kort et al. [13] confirmed this in the following quote: “When a learner experiences positive emotions, the learning process can be enhanced. When a learner experiences negative emotions, the learning process can be disabled.” Goleman [14] is of similar opinion as the following quote: “Learners who are anxious, angry, or depressed do not learn; people who are caught in these states do not take in information efficiently or deal with it well [13, 15].

Recent studies have acknowledged how negative emotions (e.g., anger, frustration, confusion, and boredom) and positive emotions (e.g., engagement, excitement) experienced by online learners inhibit or support the process of learning [16]. Russell and Kort’s models share a common axis: the emotional state. If, during learning, emotion is found to change in a consistent manner then this would provide a means to study how learning behaviors relate to emotions [17]. At first, learners might be curious and fascinated about a new topic of interest or they might be puzzled and motivated to reduce confusion. Some discrepancies between the information and the learner’s knowledge are arising. Puzzling in studied materials has negative effects and learners feel the state of confusion. As learners try and fail to solve the educational tasks they might experience some undesirable emotions like frustration. When misconceptions are cleared-up, learners might obtain hopefulness by acquiring new insights and searching for new ideas [18, 19].

Emotions are reliable indicators of what is really going on inside of us [20]. There have been many efforts to recognize emotions [21, 22] such as questionnaire, biological signals measured by different sensors, e.g. electroencephalograph sensor measuring EEG activity from the brain, skin conductance sensor, and photoplethysmyograph measuring blood volume pressure. As the other beneficial information for emotion recognition includes face and voice recognition, body movements (e.g. the way person is sitting on a chair) and learners’ surroundings [23].

Many researches employed questionnaires while other researches employed biological signals to analyze and evaluate the learners’ emotion. Using only the questionnaires to evaluate the learners’ emotion might not be good enough to analyze their real emotions during learning because the emotion evaluation proceeded after learning. Therefore, measuring learners’ biological signals during learning is considered a

way to improve the precision for analyzing the learners' emotions because the human's emotions can be investigated through biological signals right at the time they are engaged to a certain activity.

Regarding to the motivation, there are many ideas for the development of the e-learning system in the future. One idea is to improve e-learning system to be interactive with learners based on learners' emotional states. For example, the system can recognize the learners' emotions and provide an appropriate respond. Moreover, the e-learning system can reduce negative emotions and motivate the learners to carry on learning. To adapt this idea to current e-learning system, I found there are several issues to be solved. I will describe each issue and how to solve it in the problem statement section.

1.2 Problem statement

E-learning should be designed to motivate learners so that they can enjoy their learning experience on the web and complete their assignments on time [24]. These days, there are no e-learning systems that provide any ability to focus on emotional aspects in real-time. Therefore, this thesis discussed the problems ~~s~~and proposed the solution. The details are shown as follows:

1.2.1 How to design e-learning system focusing on emotional aspects

At present, the existing e-learning systems mostly focus on the improvement of study materials such as the content of lessons, assignments, tests, etc. However, we have found out that one of the obstacles that causes~~s~~ ineffective learning is the learners' emotions which make them unable to learn continuously. It is difficult that the learners can continuously concentrate on the lesson for a long period because they are able to learn independently and control the learning process according to their preferences. Since emotions are considered to be very important to effective learning, an appropriate e-learning system is needed to be investigated so that the learners can concentrate on the lesson throughout the learning period. Due to the fact that the existing e-learning systems have no ability to recognize the learners' emotions and respond to them accordingly. This

research focuses on a design of e-learning system that can detect learners' emotions so that they can learn continuously.

1.2.2 How to clarify the learners' emotions

Since people have different ability, emotion, interest, former knowledge, and experience regarding the lesson, they have unequal ability to learn. During each learning period, the learners may have various emotions, e.g., interested, bored, sleepy, anxious, enjoyable, satisfied. Therefore, it is important to investigate on how to evaluate the learners' emotions during a learning session. However, the method to recognize actual emotions of the learners is complexes. Questionnaire is considered an effective tool to evaluate the learners' opinions and sentiment in various aspects including emotions. Therefore, it is chosen as a tool to evaluate and analyze the learners' emotions in an initial phase of the research.

1.2.3 How to estimate learners' emotions by eye tracking

Even though questionnaire-based evaluation is considered to be somewhat effective for gathering the learners' opinion about their emotion during a learning period, it still has some limitations. Using only questionnaires is impossible to know if a respondent gives a true answer or not. In addition, the answer is not responded in real-time. Thus, a more effective tool to detect the learners' emotions should be used, especially the biological sensors, because people's emotions are expressed through biological signals in a similar way. Even if one can hide their emotions to make others unable to notice from the outer appearance, they cannot hide their emotions from biological sensors.

1.2.4 How to integrate the e-learning system with real-time feedback

To create the most effective e-learning system, only detecting learners' emotions is not sufficient. Appropriate feedback from the system during a learning period is necessary since it can give an instant response to the learners. With the feedback, the learners can be encouraged to learn continuously. The most common emotional state in learning is

boredom. Therefore, the research focuses on a design and development of the system that can detect the boredom of the learners and give appropriate feedback to decrease that emotion. This study showed examples of feedbacks for the learners to avoid getting bored and carry on the lessons.

1.3 Research Goal

Currently the existing e-learning systems cannot recognize learners' emotions to provide an appropriate feedback. Therefore, the overall objective of this research is to design and construct an e-learning system which focuses on the learners' emotion using biological signals. In order to achieve the overall goal of this research, there are several contributions as described as below:

1. Proposing the design of a new e-learning system focusing on emotional aspects
2. Evaluation of various emotions to confirm importance of their detection
3. Estimation of learners' emotions by eye tracking
4. The integration of new e-learning system with real-time feedback by eye tracking

1.4 Summary

Since the learners' emotions have a great affect on learning process meanwhile the current e-learning systems fail to detect the learners' emotional states, it is difficult for the learners to continuously concentrate on the lesson for a long period as long as they are not independent and cannot control the learning according to their preferences. In this thesis, I addressed the solutions to the problems including how to design e-learning system focusing on emotional aspects, how to clarify learners' emotion, how to estimate of learners' emotion by biological signals, how to integrate e-learning with real-time feedback by emotion detection. The goals of this research address the design of an effective e-learning system that focuses on the learners' emotions using biological signals.

1.5 Organization of Thesis

This thesis consists of other seven chapters, which are organized as follows:

Chapter 2: Literature Review. This chapter presents the literatures related to this research. Three main topics for this research are reviewed including e-learning system, learners' emotions, and biological signals.

Chapter 3: Design of a New E-learning System Focusing on Emotional Aspects. This chapter presents the structure of the proposed system. This proposed new e-learning system is used to build a prototype of the e-learning system in the experiments in Chapters 4, 5, and 6.

Chapter 4: Confirmation of the Importance of Emotion Detection. This chapter describes a study of new e-learning system focusing on emotional aspects by using questionnaires as a tool for emotion detection. The main finding of this chapter is to confirm that emotional aspects should be taken into account.

Chapter 5: Emotion Estimation in E-learning System using Eye Tracking. This chapter describes a study of the proposed e-learning system focusing on the usage of biological signals, i.e., eye tracking indexes. The main finding of this chapter is to find the eye tracking indexes that can effectively estimate the two types of emotions: interest and boredom.

Chapter 6: Proposed E-learning System with Real-time Feedback from Eye Tracking. This chapter presents a study of the new e-learning system with the real-time feedback from eye tracking. The experimental results of the previous chapter were used to build the feedback algorithm.

Chapter 7: Discussion. This chapter offers a discussion of this thesis as well as a summary of the method to achieve the overall research goal and solve the stated problems.

Chapter 8: Conclusion. This chapter summarizes this research. Finally, the latter part of this chapter presents the future work and approaches for further development of the proposed e-learning system.

Chapter 2

Literature Review

In this section, I reviewed the literatures related to my research and presented an overview of e-learning system, learners' emotions, and biological signals.

2.1 E-learning system

Khan developed a framework for e-learning that contained the following eight dimensions [25]:

- E-learning's pedagogical dimension, which refers to teaching and learning, addresses issues concerning content, audience, goal, and media analyses, design approach, organization and methods, and strategies of e-learning environments.
- The technological dimension of the e-learning framework examines the technology infrastructure issue in e-learning environments. This includes infrastructure planning, hardware and software.

- The interface design refers to the overall look and feel of the e-learning programs. This dimension encompasses the page and site designs, the content design, navigation, and usability testing.
- E-learning evaluation assesses both learners and the instruction and learning environments.
- E-learning management maintains the learning environment and distributes information.
- The resource support dimension of the e-learning framework examines the online support and resources required to foster meaningful learning environments.
- E-learning's ethical considerations are related to social and political influence, bias, cultural, geographical, and learner diversity, information accessibility, etiquette, and legal issues.
- The institutional dimension is concerned with issues of administrative affairs, academic affairs, and student services related to e-learning.

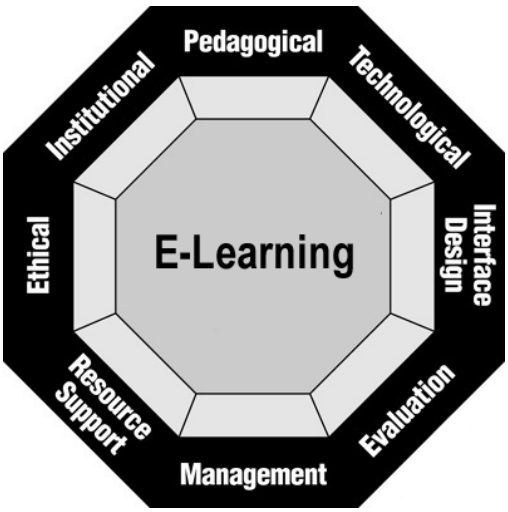


Figure 2.1: Badrul Khan's E-learning framework [25]

I employed this framework for the new e-learning system. These factors can encompass various online learning issues, including: pedagogical, technological, interface design, evaluation, management, resource support, ethical and institutional. Various factors discussed in the eight dimensions of the framework can provide a guidance in the design, development, delivery and evaluation of flexibility.

As identified by different researches, Kittanakere et al. summarized the main goals of e-learning systems as follows [26]:

- Focus on active learning.
- Accommodate various learning styles.
- Explicitly place the responsibility for learning on the students themselves.
- Develop written and oral communication skills.
- Clarify the teacher's role as facilitator and mentor.
- Provide better coverage of class material.
- Develop a sense of self-confidence and independence in students.
- Encourage peer review.
- Develop interpersonal communication skills when students are geographically distant.
- Support the entire educational process when students are separated both geographically and temporally.
- Teach time management, especially meeting deadlines

Many of the above goals reflect the advantages of e-learning systems over traditional learning approaches. Another advantage is that they are scalable. The number of learners that an e-learning system can handle with individual attention is much more than that can be accommodated in a classroom setting [26].

Hu also integrated an e-learning performance evaluation system [27], which included two technology platforms for blog and online testing systems. The blog system evaluates learning processes to motivate learning awareness and provides real-time feedback of evaluation information. The online testing system evaluates the learning result of a certain period to help students summarize what they have learned and experienced in the learning process.

Joanne et al. formally evaluated the module's phase using the outcome levels of Kirkpatrick's framework [28] as follows:

- Level one: assessment of learner satisfaction with educational intervention. This involves a courseware evaluation survey (CES) developed to evaluate participant satisfaction based on five variables.
- Level two: students' learning. This involves a multicenter randomized controlled study using pre and post-test knowledge before and after residents used the module.
- Level three: assessment of training transfer. This involves a retrospective pre and post questionnaires, which are commonly used for quantitative analysis in medical education research.
- Level four: outcomes, which examined the effects on the environment resulting from the application of training.

I employed Kirkpatrick's framework to analyze the effectiveness of e-learning system.

Wang et al. also designed two kinds of humorous performances that were learning-relevant to help students remember [29]. One appeared at the end of every learning video, and the other appeared when the students expressed emotions. They used paper-and-pencil materials that consisted of a pre-test, a post-test, and a questionnaire. The computerized materials consisted of a multimedia computer program for teaching Chinese history.

2.2 Learners' emotion

Russell developed this circumplex model to describe a user's emotion space [30]. The basic set includes the most important and frequently occurring emotions during learning: interest, engagement, confusion, frustration, boredom, hopefulness, satisfaction, and disappointment as shown in Figure 2.2. I used this model to analyze learners' emotions.

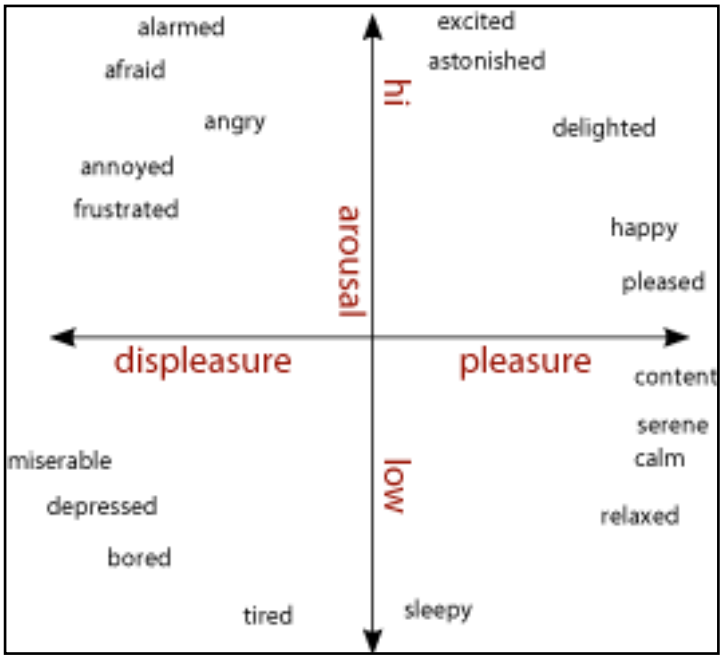


Figure 2.2: Russell's circumplex model [30]

Kittanakere et al. introduced the design of an emotion sensitive e-learning system that gives emphasis on the complete learning process and is very cost effective. The system categorizes a learner's emotional state as follows: happy, neutral, and sad. This motivates thinking about incorporating emotional aspects of teaching in e-learning systems to make them more intelligent. An intelligent e-learning system should be able to adapt to the knowledge, learning abilities, and needs of each learner [26]. This would give them the feel of individual care, which would assist in the learning process.

Goleman, the author of Emotional Intelligence, argued that the emotional quotient (EQ) is more important than the intelligence quotient (IQ) [14]. The issue is for e-learning to recommend ways in which to keep e-learning from being boring. I recognized that e-learning is different from face-to-face instruction lacking a trainer to address the emotional component and I provided some very sensible advice on how to keep e-learning relevant.

Wu et al. defined three basic learning emotions: absorbed, neuter and fatigue, and discussed the features of every defined learning emotion by face detection system using AdaBoost algorithm based on skin color [31]. The facial expression characteristics of absorbed expression and fatigue expression are more obvious than neuter expression, so it can be found that the recognition rate of absorbed expression and fatigue expression is higher than neuter expression.

Dirkx called for the recognition of the positive emotions engendered by learning. Furthermore, he suggested that critical theory failed to "adequately account for the emotional and spiritual dimensions of learning [32]. At about the same time, Gardner [33], Goleman [14], and LeDoux [34] rethought the significance of emotion. Concurrently, Damasio [35, 36] conducted experiments that indicated that emotion and cognition are innately intertwined. Although other researchers are beginning to build on the work of Damasio and his team, "inquiry has been slow to advance our understanding of emotions in education". Learning processes are the currency of exchange in education, and emotional experiences are a "neglected dynamic" [37] in complex social environments where learning takes place. This is particularly so in online learning. According to O'Regan [21], the transition to online teaching and learning provides the opportunity to test the assumptions about emotion embedded in our practice, building on the strands of research developed regarding emotion and the human experience, emotion and cognition, and, more recently, emotion and learning.

Zembylas applied qualitative methodology to investigate emotional presence, using learners' monthly emotion journals and interview strategy. The analysis resulted in two broad themes: positive and negative emotions related to learning. Positive emotions included joy, enthusiasm, and excitement for the flexibility of online learning, which were higher in intensity and frequency in earlier months; pride and contentment for fulfilling the course requirements; and surprise and excitement for the emotional nature of online communication. Negative emotions included fear and anxiety for the unknown mode of online learning and its demands (technology, time management, structure); alienation and the need for connectedness, which emerged during the first weeks of the course and when the students struggled to find satisfying ways of communicating with

their classmates and their instructor; and stress and guilt for the inability to balance multiple roles and responsibilities, the most serious obstacle that the students faced. They struggled to combine their occupation, family, and social life, which made it hard to cope with the numerous demands of the program [38].

2.3 Emotion recognition using biological signals

Emotion recognition using physiological signals has increasingly become a hotspot and developed trend in the fields of affective computing and human-computer interface.

Kaiser and Oertel also developed an emotion recognition sensor system; an e-learning system was enhanced with affective abilities [23]. The system providing a catalogue of affective measures describes actions to support the user in handling negative emotions. To ensure the initiation of a correct measure, a user is to be asked to verify the emotion recognition. The emotion recognition sensor system (EREC), developed at the IGD-R, consists of a sensor glove, a chest belt and a data collection unit.

Khalifa et al. argued that the data collected from eye tracking devices indicate the person's interest level and the focus of his attention [39]. From eye position tracking and such indirect measures as fixation numbers and duration, gaze position, and blink rate, information about the user's level of attention, stress, relaxation, problem solving, learning success, and fatigue can be drawn.

Ismail and Mohamed integrated eye tracking technology to track and analyze a learner's behaviors on an e-learning platform [40]. They focused on the interesting areas of courses that reflect a user's emotions, attention, stress, relaxation, problem solving, and fatigue.

Areej et al. measured and recorded the eye gaze of participants as they interacted with an e-learning module and examined their comprehension and their individual learning styles [41]. They derived four scales from significant bodies of knowledge: active/reflective, sensing/intuitive, visual/verbal, and sequential/global. According to their results, visual learners exhibited increased visual attention on multimedia elements, while higher verbal learners exhibited more attention on textual content.

Marco et al. addressed the problems of students on eye tracker's screens and their eye data while solving problems that were recorded under such real-time conditions as gaze coordinates, fixation durations, and pupil diameters, from which they subsequently obtained indirect but important measures, such as saccadic velocities and blink rates [42]. If a learner decreases the number of blinks, the increase of the fixation or pupil size is related to learners with high working levels or without understanding of the content.

Mealha et al. summarized data representation and information visualization techniques for data analysis within different contexts (advertising, websites, television news, and video games) [43]. They used common eye tracking related data representation techniques that offer valuable input about user interaction and eye gaze behavior by measuring fixations and saccades.

Liu recognized emotions of joy and sadness based on ECG signal. The process of emotion recognition based on ECG signal has the following four main steps: 1), affective data acquisition; 2), affective feature extraction; 3), affective feature subset selection; and 4), classifier design. The changes of emotions may be reflected by the changes of P-QRS-T wave, if emotions influence ECG signal. Therefore, feature extraction is based on precise location of P-QRS-T wave [44].

Jang et.al. improved the limitation that it is result in specific context; they used 10 different emotional stimuli sets to induce seven emotions, i.e., happiness, sadness, anger, fear, disgust, surprise and stress under the same conditions. They identified the difference among emotions using physiological responses induced by these emotional stimuli and the most optimal algorithm for emotion recognition. For this, they selected physiological signals of electrodermal activity (EDA), electrocardiogram (ECG), photoplethysmography (PPG), and skin temperature (SKT), because the signals reflect the activity of the autonomic nervous system, which plays a major role in maintaining the internal equilibrium of the body. The result can help emotion recognition studies lead to better chance to recognize not only basic emotion but also a user's various emotions, e.g., boredom, frustration, love, pain, etc., by using physiological signals. Also, it is able to be applied on many human-computer interaction devices for emotion detection [45].

Filipe C., Ana F., Hugo S., Hugo G., and Andre L. presented and set up and

methodology for multimodal biosignal data handling, targeting emotion recognition. Relevant physiological patterns were observed for different emotions. The most promising ones include: smile pattern in the EMG and the EDA signal; different characteristics for the BVP signal for distinct emotions such as anger and disgust; high arousal (high SCL and large amplitude of the SCRs) associated with anger and disgust; low arousal associated with fear and sadness; large SCR associated with surprise [46].

Yisi L., Olga S., and Minh K.N. concentrated on recognition of “inner” emotions from electroencephalogram (EEG) signals as humans could control their facial expressions or vocal intonation. The need and importance of the automatic emotion recognition from EEG signals have grown with increasing role of brain computer interface applications and development of new forms of human-centric and human-driven interaction with digital media. They proposed fractal dimension based algorithm of quantification of basic emotions and described its implementation as a feedback in 3D virtual environments. The user emotions are recognized and visualized in real-time on his/her avatar adding one more so-called “emotion dimension” to human computer interfaces [47].

2.4 Conclusion

In conclusion, although some researches proposed biological signals such as ECG, EEG, SKT, and eye tracking to recognize emotions, only a few of them applied biological signals to recognize learners’ emotions. Many researches measured and analyzed learners’ emotion such as happy, neutral, sad, attentive, stressful, and relaxed, but did not focus on various learners’ emotions during the learning sessions. Various emotions considerably causes a lack of concentration and motivation to learn. In the other words, there are insufficient researches that have focused on users’ emotions and biological signals to recognize learners’ emotions in e-learning system. However, those researches suggest that they are helpful for learners to deal with negative emotions such as boredom, anxiety, or anger as well as to keep their attention and they can enhance their learning motivation, interest, and performance.

Therefore, this research proposes new method for e-learning system. The focus is on the employment of biological signal which will be used to recognize various emotions in real-time. This system aims to find various learners' emotion in learning and enhance the learning efficiency.

Chapter 3

Design of a New E-learning System Focusing on Emotional Aspects

Referring to the literature review, I summarized the e-learning system that focuses on emotional aspects using biological signals. I performed a survey on learners' emotions, which are important while learners use e-learning system. The standardized and generalized technologies are considered to be applied in this research. This chapter discusses the overall design of the new e-learning system.

3.1 E-learning system design

The current e-learning systems is difficult for the learners to continuously concentrate on the lesson for a long period. In this thesis, the goal is to design and construct an e-learning system which focuses on the learners' emotions using biological signals. Therefore, I proposed a new design of an e-learning system using biological signals including

electroencephalograph (EEG), electrocardiogram (ECG), and eye tracking to detect and symptoms of learners' emotions.

This chapter described the overall design of the new e-learning system as shown in Figure 3.1. This system uses a web server that users can easily access by web browser on a personal computer. During the learning sessions, biological signals including electrocardiogram (ECG), electroencephalograph (EEG), and eye tracking were used to detect and symptoms of learners' emotions which have significant influence on learning through the system.

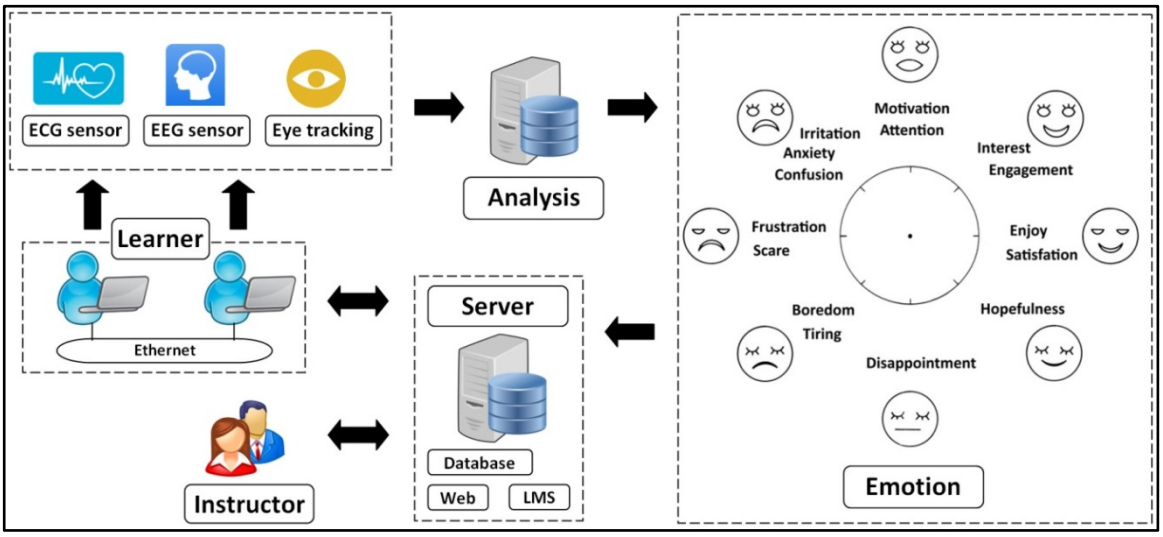


Figure 3.1: The proposed new e-learning system

The design of the new e-learning system consists of five modules: learners, instructors, servers, biological signals, and analysis of the learners' emotions [48]. The details are described below:

1. **Learners:** individuals who register to take e-learning courses provided by the Learning Management System (LMS).
2. **Instructors**: a critical element of this system. They create and design courses, contents, tests, quizzes, and evaluations in LMS.
3. **Servers:** web, LMS, and database. The details are described below:

a) Web server dispenses web pages as requested by the LMS.
b) Database server provides database services to the LMS.
c) The LMS is a web-based technology that plans, implements, and assesses a specific learning process. Typically, it provides an instructor with a way to create and deliver content, to monitor learners' participation, and to assess their performance. The LMS consists of the following five parts:
    - Course management which helps store, organize, and communicate a course's information. It consists of two user groups, learners and instructors, who can access the system anytime and anywhere.
    - Content management which includes tools for creating and supporting the content.
    - The test and evaluation system which manages exams, interactive quizzes, and integrated tests into the database system to evaluate the learners.
    - Course tools which are used to help and guide each user.
    - The data management system which manages the files and folders of each user.

4. Biological signals: electrocardiography (ECG), electroencephalography (EEG) and eye tracking for measurement of emotion of learners. The details are as follows:
    a) An EEG sensor measures the voltage fluctuations of the electric ions within the brain's neurons as shown in Figure 3.2 [49]. EEGs are classified into the following four types:
        - Beta waves: 14-30 Hz, under normal conditions or with some anxiety
        - Alpha waves: 8-13 Hz, during meditation or in a relaxed state
        - Theta waves: 4-7 Hz, during slumber
        - Delta waves: 0.5-3 Hz, while falling into a deep sleep

Ohkura et al. analyzed users' emotions by brain waves. When a person is relaxed, the proportion of the alpha waves among the brain waves becomes high. I applied this analysis method [50, 51].

Figure 3.2: EEG sensors [51]

b) An ECG sensor measures the electrical activity of the heart over a specific period of time. ECG signals can be interpreted as the heart rate in beats per minute (BMP) as shown in Figure 3.3 [53]. Ohkura et al. used ECGs to estimate users' emotions by the following indexes [50, 51].

- R-R interval: time interval between the two R waves of the ECG or the inverse of the heart rate
- Heart rate: number of heart-beats per minute
- LF/HF: HF/LF ratio
  - LF: lower frequency of component: 0.04-0.15 Hz
  - HF: higher frequency of component: 0.15-0.4 Hz

I defined the average heart rate and its variance as the average number of heart-beats a minute and its variance, respectively and the average R-R interval and its variance as the average interval time between the R-waves of the ECG and its variance, respectively. These are known indexes for stress, uneasiness, or relaxation and are used to measure dynamic feelings.

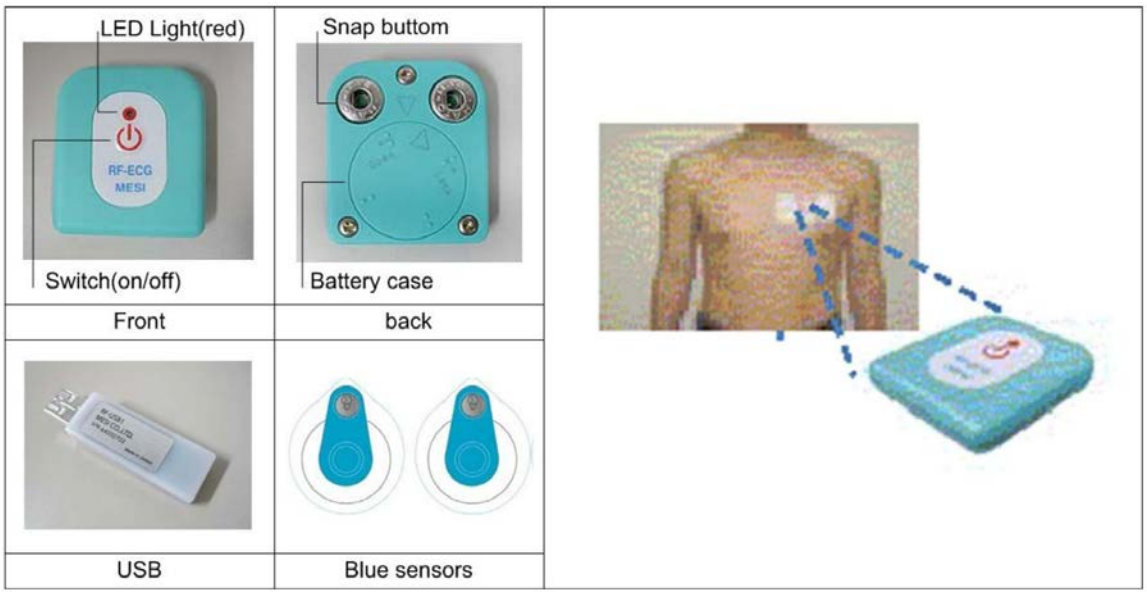


Figure 3.3: Wireless Bio Sensors RF-EEC [52]

c) An eye tracking method measures a person's point of gaze, which focuses on what a person is looking at and locates the eye spot as shown in Figure 3.4. Porta et al. and Al-Wabil et al. related pupil size, fixation length, blink rate, and saccadic speed to estimate users' emotions [53, 54]. For example, pupil size is related to actions and thinking. However, it can also depend on other factors than processing load: aural stimuli, light variations, or emotions unrelated to the task being performed. Fixation duration and blink rate that identify specific patterns can provide information about user emotional states.

5. Analysis of learners' emotions: I devised this system to understand how the learners' emotions evolve during the learning process to develop learning systems that recognize and respond appropriately to their emotional changes. I used a questionnaire design and Russell's circumplex model to describe the learners' emotion space [30].

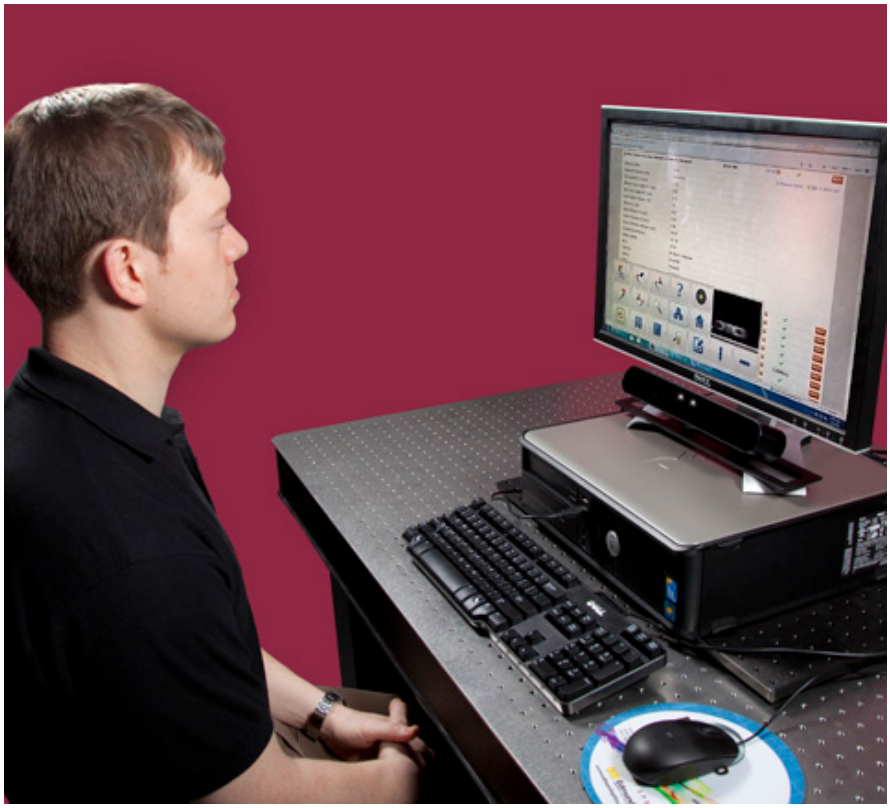


Figure 3.4: Eye tracking [55]

3.2 E-learning system framework

I used an e-learning framework [25] that contains eight dimensions encompassing the following online learning issues: pedagogical, technological, interface design, evaluation, management, resource support, ethical, and institutional issues. Each factor has several sub-factors, and each sub-factor consists of issues related to a specific aspect of an e-learning environment. These issues generate many questions that course designers ask themselves when planning or designing an e-learning system framework.

E-learning system framework using biological signals consists of five modules: learner, instructor, server, biological sensors and analyze emotion of learner as shown in Figure 3.5.

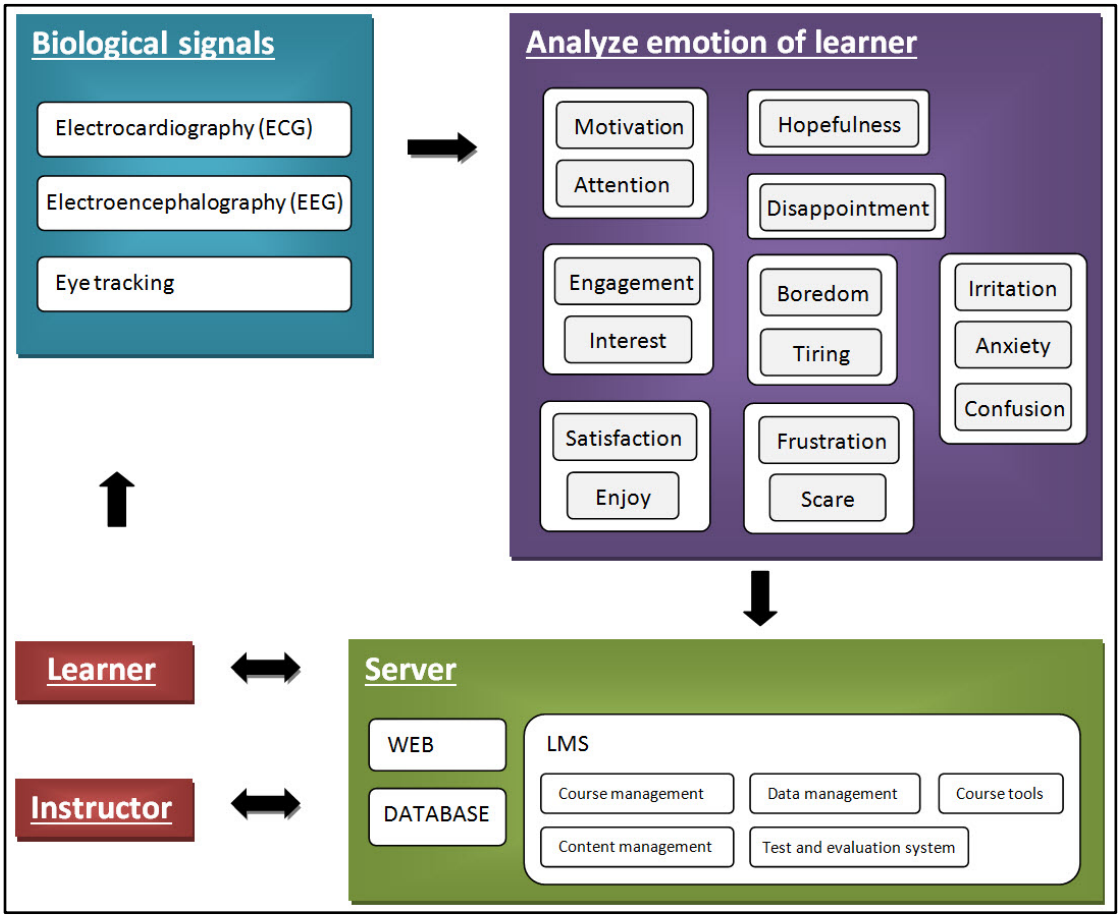


Figure 3.5: Framework design

3.3 Modular Object Oriented Dynamic Learning Environment (Moodle)

Moodle is an Open Source Course Management System (CMS), also known as an LMS or a Virtual Learning Environment (VLE) [56].

Moodle is license free Open Source software. It lets instructors, trainers and administrators manage online learning and online training. The LMS can be used to conduct courses online or to support face-to-face teaching and learning. It can also be extended with modules for assignments, quizzes, grading, certification, social and collaborative learning in an engaging manner [57].

Moodle has several features considered typical of an e-learning platform, plus some original innovations [58] as shown in Figure 3.7. Some typical features of Moodle are

- Assignment submission
- Discussion forum
- Files download
- Grading
- Moodle instant messages
- Online calendar
- Online news and announcement (College and course level)
- Online quiz
- Wiki

Developers can extend Moodle's modular construction by creating plug-ins for specific new functionality. Moodle's infrastructure supports many types of plug-ins:

- activities (including word and math games)
- resource types
- question types (multiple choice, true and false, fill in the blank, etc)
- data field types (for the database activity)
- graphical themes
- authentication methods (can require username and password accessibility)
- enrollment methods
- content filters

Moodle can be integrated with online content resource repositories, enterprise solutions for managing course registration, payment and enrolment, course schedules, allocation of training resources, compliance management, and learners' records. Moodle can be installed on any computer that can run PHP, and can support an SQL type database. It can be run on Windows, Mac operating systems, and Linux [58].

Due to the effectiveness of Moodle system as discussed above, I employed Moodle to create course, content, pre-test and post-test, and questionnaires in e-learning system.

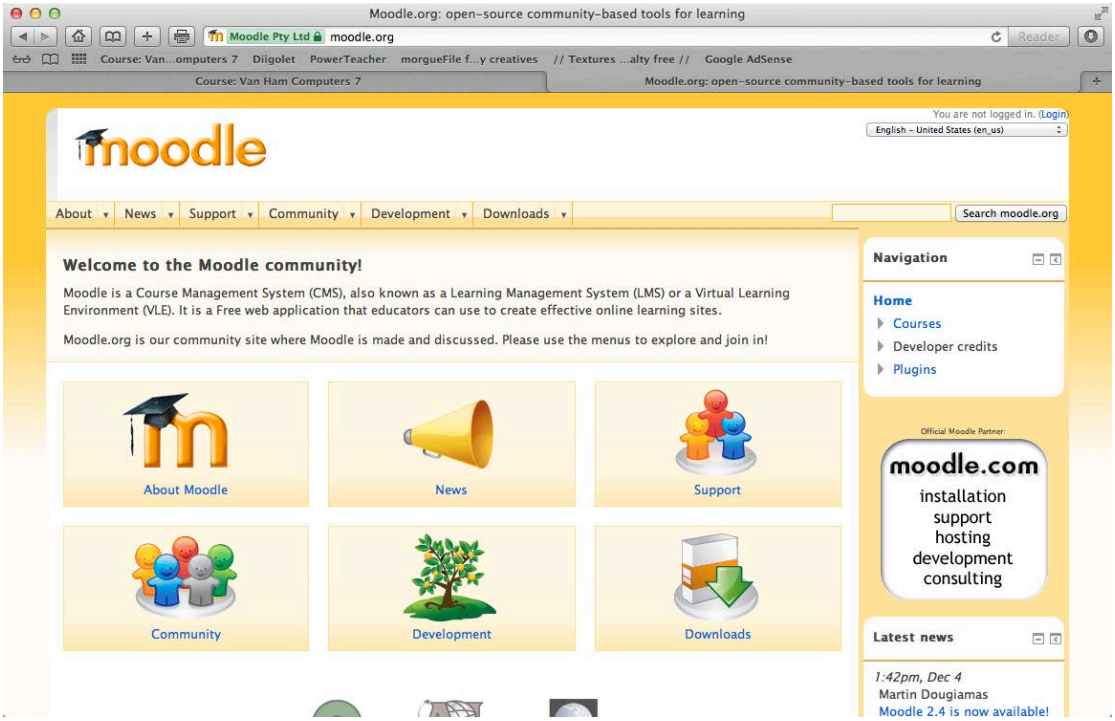


Figure 3.6: Moodle interface [58]

3.4 Discussion

The current e-learning systems is difficult for the learners to continuously concentrate on the lesson for a long period. I reviewed the existing researches in e-learning fields. I found that the existing e-learning systems are not intelligent enough because they have no ability to recognize learners' emotions and cannot support them accordingly. Thus, I proposed a new design of an e-learning system using biological signals including electroencephalograph (EEG), electrocardiogram (ECG), and eye tracking to detect and symptoms of learners' emotions. It consists of five modules: learners, instructors, servers, biological signals, and especially an analysis of learners' emotions. It analyzes learners' emotions based on Russell's 'circumplex model' which describes the human's basic emotion space. This new e-learning system was used as a core prototype in the experiments which focused on the evaluation of emotions using biological signals.

3.5 Conclusion

This chapter describes in details of the design for a new e-learning system. I designed to use biological signals to measure, detect, and analyze learners' emotional state. The system analyzed learners' emotions based on Russell's 'circumplex model' to describe the users' emotion space. The e-learning system used LMS, namely Moodle, as a core for course, content, data, and evaluation managements. The proposed new e-learning system as described in this chapter was used as a core prototype in the experiments as explained in Chapter 4, Chapter 5, and Chapter 6 which focuses on the evaluation of emotions, biological signals using eye tracking, and real-time feedback from eye tracking respectively.

Chapter 4

Confirmation of the Importance of Emotion Detection

In e-learning systems, even though few researches on such systems have investigated learners' emotions, they have proposed systems that provide functions tools to analyze certain learners' emotions such as boredom, interest, and sadness. Unlike previous work, in this chapter, I proposed a new e-learning system that considers attention, motivation, satisfaction, enjoyment, interest, anxiety, frustration, scare and tiring. I designed, implemented a prototype experimentally evaluated it, and confirmed that emotional aspects are important in e-learning.

4.1 Prototype Implementation of System

4.1.1 Prototype description

This chapter describes a study of a new e-learning system focusing on emotional aspects by using a questionnaire as a tool for emotion detection of emotional states. The main finding of this chapter confirms that the questionnaire is effective in detecting the emotions of learners. I built a prototype of the proposed e-learning system and experimentally evaluated it by pre and post-test scores and questionnaires about learners' emotions based on the system design that consists of four modules: learners, instructors, servers, and an analysis of learners' emotions as shown in Figures 4.1 and 4.2. The details are described below:

1. Learners**.**
2. Instructors**.**
3. Servers
4. Analysis of learner's emotion

In this research, I used questionnaire design [59] and employed several emotions based on Russell's 'circumplex model' [30] to describe the learners' emotion space as following:

1. Group 1: Motivation and Attention
2. Group 2: Interest and Engagement
3. Group 3: Enjoy and Satisfaction
4. Group 4: Hopefulness
5. Group 5: Disappointment
6. Group 6: Boredom and Tiring
7. Group 7: Frustration and Scare
8. Group 8: Irritation, Anxiety, and Confusion

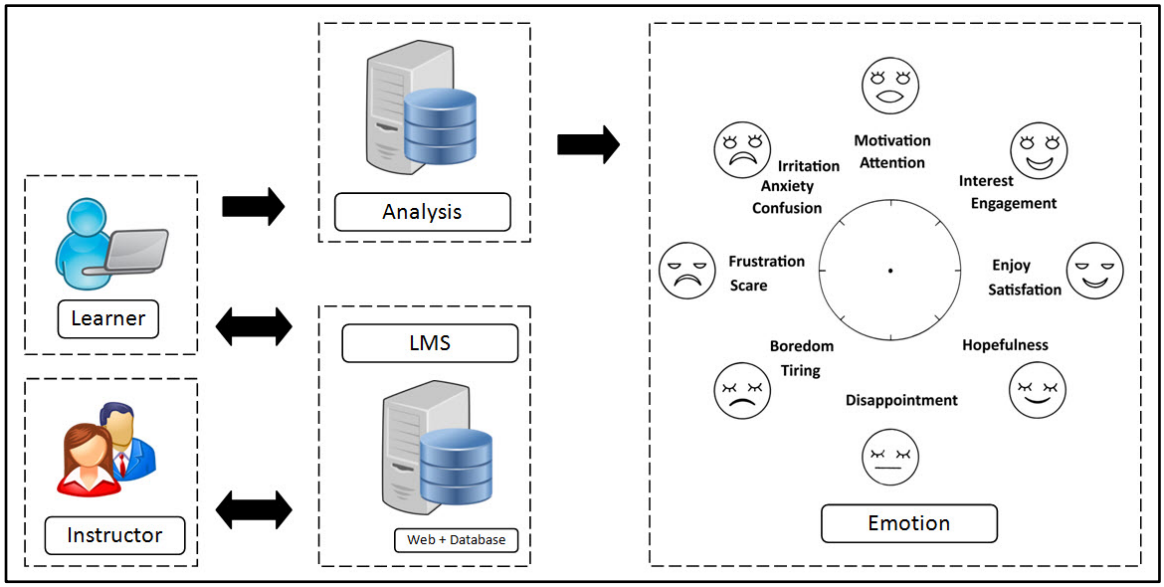


Figure 4.1: Proposed e-learning system

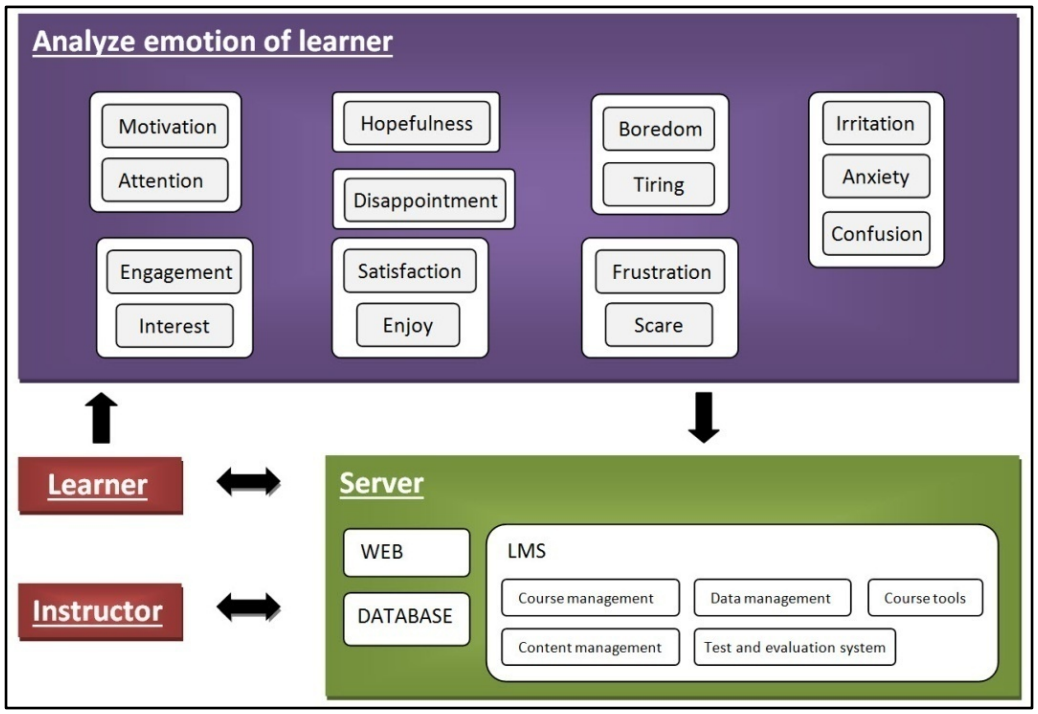


Figure 4.2: Framework design

4.1.2 Tools and Materials

The prototype of the e-learning tasks consists of a series of lessons, pre-tests, post-tests, and questionnaires for teaching C programming for control.

C programming for control is divided into two lessons.

1. Lesson 1 is the introduces of C programming for control covering the following two topics:
    - Introduction of C programming for control
    - Programming style
2. Lesson 2 is basic of C programming for control covering the following three topics:
    - Structure of a C program
    - Development of a small program in C
    - Data inputs and printing of the results obtained from a C program for control.

The content of lesson 2 is more difficult than lesson 1.

I designed two kinds of contents presented by power point (PPT) and video as shown in Table 4.1 and described below:

- The PPT design includes text and cartoon. Learners can control the content flow by pushing the enter button.
- The video design runs automatically and includes text, cartoon, and voice.

Table 4.1: Detailed design of PPT and video

Design / Detail	PPT	Video
Cartoon	Static	With movement
Voice	None	Yes
Control	Push enter button	Automatic

The pre-test and post-test are designed and used to evaluate the obtained knowledge based on C programming for control topic. Examples of pre and post-test questions for lesson 1 are shown in Tables 4.2 - 4.3. Since both consist of ten questions and each question has one point, the highest score is ten.

Table 4.2: Examples of pre-test questions for lesson 1 (in Thai).

Lesson 1 pre-test	
Q#	Content
1.	Which is a low-level language? a. Cobol b. Assembly c. Pascal d. Basic
2.	What language can computers understand? a. All languages b. High-level languages c. Machine languages d. Low-level languages
3.	What is the function of the Arithmetic and Logic Unit as part of the processor? a. Collection of various commands. b. Calculation and comparison. c. Results. d. Controls.
4.	What is a program command that compiles a high-level language into a machine language called? a. Object program b. Compiled program c. Source program d. Computer program
5.	What should be stored as a start command for a computer system in any part of the computer system? a. ALU b. CPU c. RAM d. ROM

Q# : Question number

Table 4.3: Examples of post-test questions for lesson 1 (in Thai).

Lesson 1 post-test	
1.	What is computer programming? a. Convincing your computer to never freeze b. Speeding up your computer c. Setting the alarm on a computer d. Telling your computer what to do through a special set of instructions
2.	Which of the following is NOT a software language? a. C b. C++ c. Visual Basic d. HTML
3.	If you were to look at a machine language program, you would see _____. a. Source code b. A stream of binary numbers c. English words d. Circuits
4.	Which of the following is NOT a web language a. C++ b. PHP c. Javascript d. HTML
5.	Every C program begins execution at function _____. a. main() b. #include c. Void d. Compiler

The questionnaires include 15 questions related to learner emotions in e-learning systems [59]. The 5- points Likert scale [60] was used to scale responses to the questionnaire items (Table 4.4).

I prepared two lesson patterns (Table 4.5). The process of each is shown in Figure 4.3, and the details are described below:

- Pattern I: the learners study C programming for control in lesson 1 by PPT and in lesson 2 by video.
- Pattern II: they learn C programming for control in lesson 1 by video and in lesson 2 by PPT.

Table 4.4: Questionnaire items on 5-point Likert scale (in Thai).

Q#	Content	Related emotion
1	The learning process increased my learning attention.	Attention
2	Putting a multimedia presentation into the learning system motivated me to use it.	Motivation
3	The learning system helped me learn better.	Satisfaction
4	I reduced my negative emotions after interacting with the learning system.	Negative emotion
5	Interacting with the learning system increased my positive emotions.	Positive emotion
6	E-learning made my course more enjoyable.	Enjoy
7	From time to time the courses were interesting.	Interest
8	E-learning is satisfying.	Satisfaction
9	Studying e-learning courses was often fun.	Enjoy
10	I felt proud after finishing an e-learning course.	Satisfaction
11	Some features of e-learning were stressful.	Anxiety
12	The e-learning courses were frustrating.	Frustration
13	Using the e-learning courses was irritating.	Irritation
14	Starting the e-learning course scared me.	Scare
15	Using the e-learning system was sometimes tiring.	Tiring

Q# : Question number

Table 4.5: Lesson patterns

Lesson	Pattern I	Pattern II
1	PPT	Video
2	Video	PPT

4.2 Evaluation Experiment

This experiment were performed with the cooperation of Thai Nichi Institute of Technology.

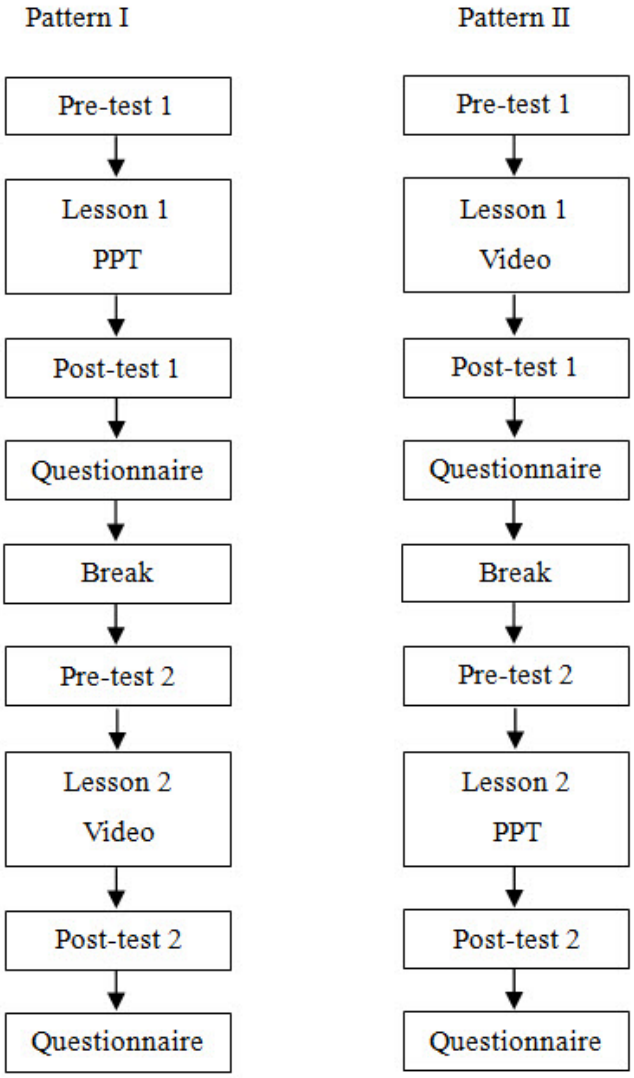


Figure 4.3: Process of our learning system

4.2.1 Participants

I conducted experiments by equally dividing 60 Thai-Nichi Institute of Technology students into two groups, and performed learning tasks using different learning methods. All subjects are in Thai. Conditions of participants are described as follows:

1. Participants never learn “C programming for control” before.
2. Participants are male and female Thai between 18-19 years old.

4.2.2 Expereiment Method

This system uses servers and is linked to the Internet by common web browsers such as Internet Explorer, Chrome, and Firefox [61]. Figure 4.4 shows a scene of the experiment. The procedures are described below (Figures 4.5 to 4.8):

1. Learners register when they first log onto the e-learning system. After logging in, personalized e-learning starts.
2. They take a pre-test within ten minutes before lesson 1 starts.
3. They learn lesson 1 of pattern I only one time. If they do not understand it, they can repeat lesson 1 to get additional explanation of the text content.
4. After finishing lesson 1, they take a post-test.
5. They answer a questionnaire.
6. They take a 10 minutes break.
7. They take a pre-test before lesson 2 starts.
8. They learn lesson 2 of pattern I only one time. If they do not understand, they can repeat lesson 2 to get additional explanation of the text content.
9. After finishing lesson 2, they take a post-test.
10. They answer a questionnaire.

Figure 4.4: Learners using the e-learning system

Figure 4.5: Example of the interface design for the first page

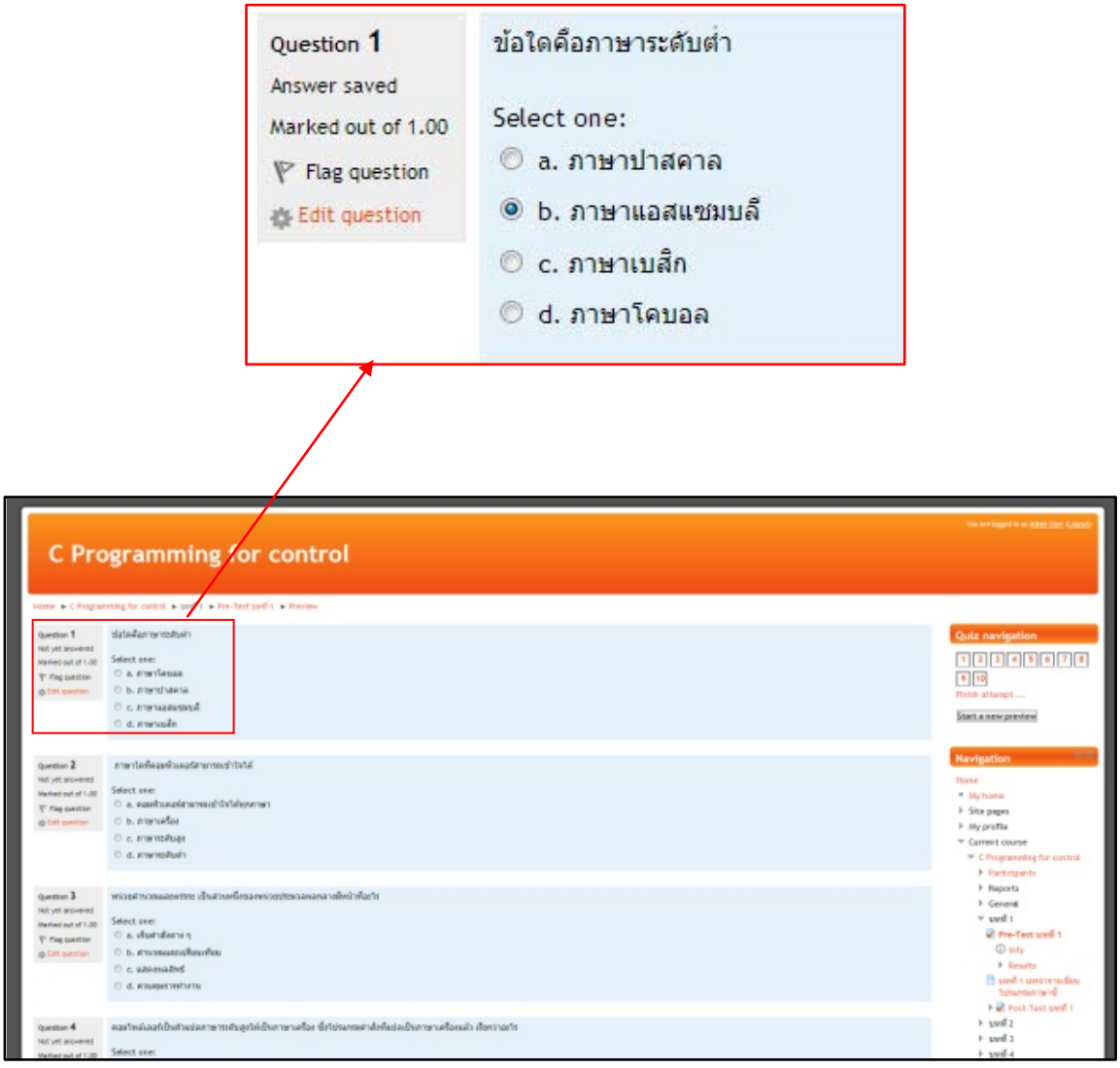


Figure 4.6: Example of the interface design for pre-tests, post-tests and questionnaires.

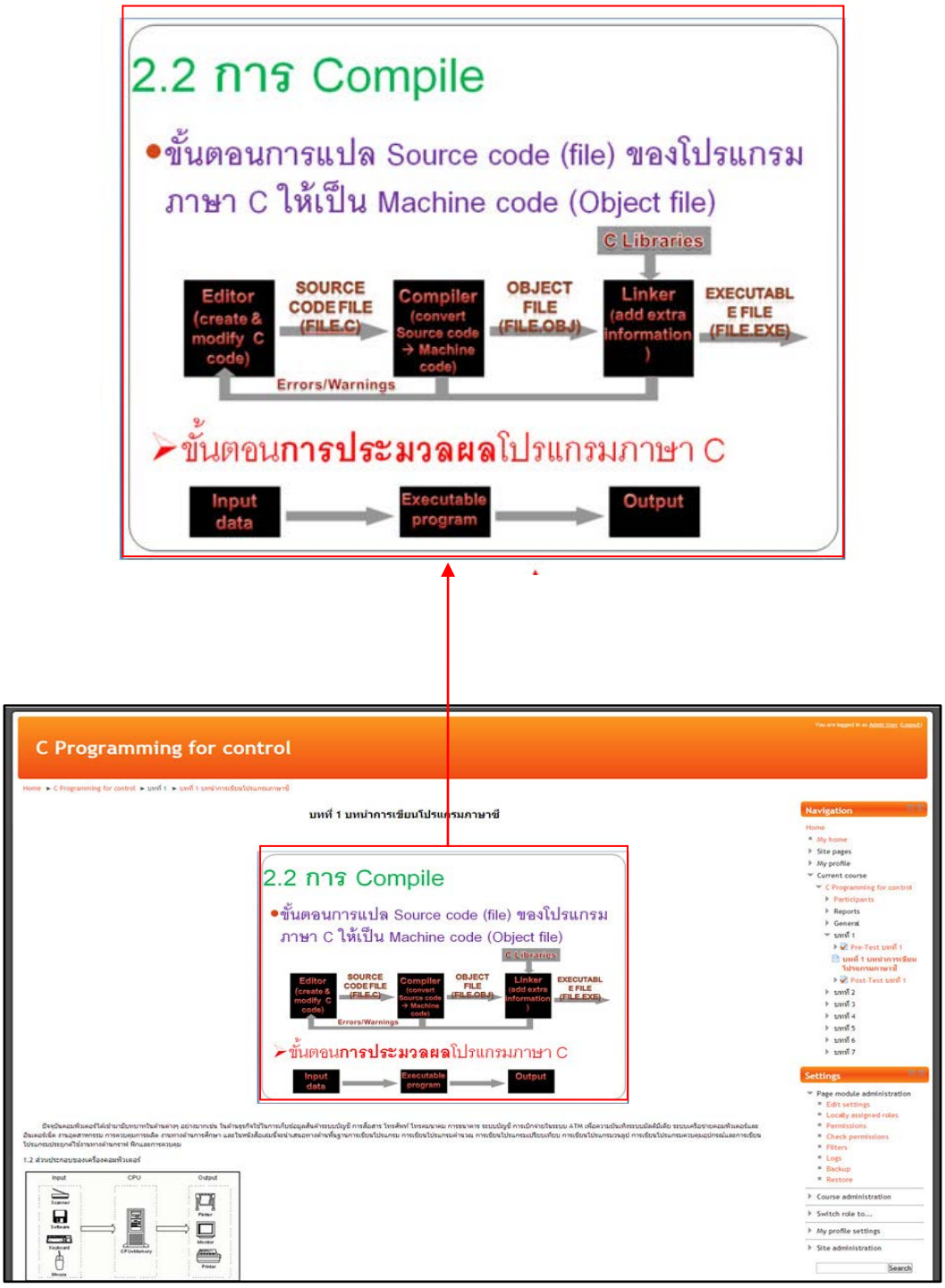


Figure 4.7: Example of the interface design for PPT

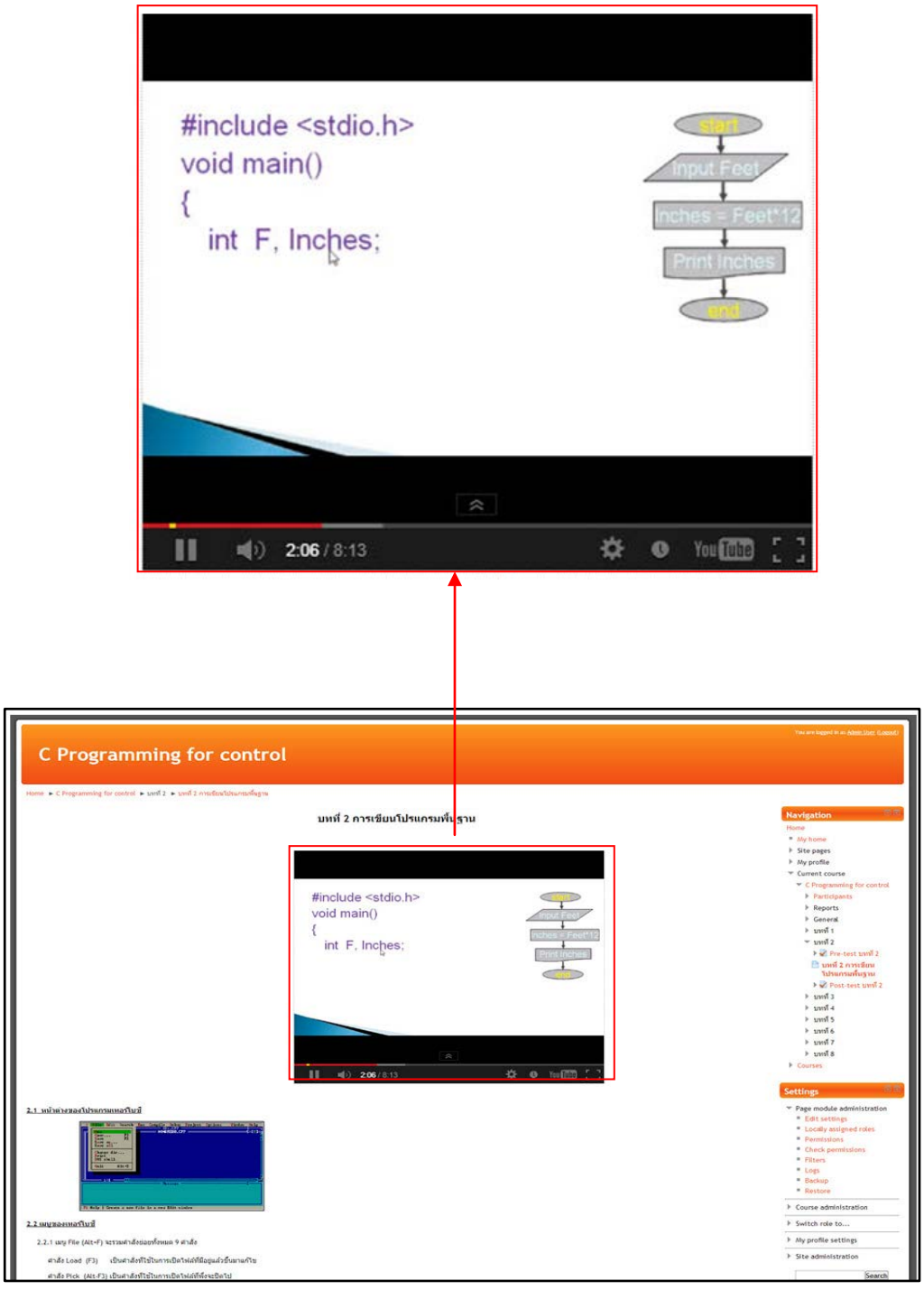


Figure 4.8: Example of the interface design for video

4.3 Experimental Results and Discussion

In this section, I obtained the following results by comparing the test scores and the questionnaire results.

4.3.1 Pre-test and post-test results

The results of the pre-test and post-test scores for learning lessons 1 and 2 are summarized in Table 4.6. According to the statistical analysis results, the mean difference between the post-test and pre-test results of lesson 1's PPT (2.90) is significantly higher than that of its video (2.63) ($p<.01$).

The mean difference between the post-test and pre-test results of lesson 2's video (3.37) is significantly higher than that of its PPT (3.17) ($p<.01$).

Table 4.6: Pre-test and post-test results.

Lesson	Design	Pre-test		Post-test		Differences between Post-Pre tests		t-test	
		Mean	SD.	Mean	SD.	Mean	SD.	t	P-Value
1	PPT	4.63	1.82	7.53	1.27	2.90	1.80	11.919	.000**
	Video	4.80	1.29	7.43	1.22	2.63	1.81		
2	PPT	4.83	1.68	8.00	1.36	3.17	1.80	38.980	.000**
	Video	4.27	1.23	7.63	1.52	3.37	1.81		

*+ p<0.1; * p<0.05; ** p<0.01*

4.3.2 Lesson 1 results

I conducted an independent-samples t-test to compare the results from learning lesson 1 between the pattern I using PPT and the pattern II using video for the questionnaires shown in Table 4.7. I found the following significant difference in the scores for questions 11 to 15 between the PPT and the video at 1% level:

- Q#11: E-learning with the PPT has features that caused more anxiety than e-learning with the video.
- Q#12: E-learning courses with the PPT caused more frustration than those with the video.
- Q#13: Using the e-learning with the PPT courses is more irritating than using ones with the video.
- Q#14: Learners were more scared when starting an e-learning course with the PPT than when starting one with the video.
- Q#15: Using the e-learning system with the PPT was at times more tiring than using one with the video.

On the other hand, I found no significant differences in the scores for questions 1 to 10.

Table 4.7: Learning lesson 1 results.

Q.#	PPT		Video		t	P-Value
	Mean	SD.	Mean	SD.		
1	3.67	.606	3.47	.776	1.112	.271
2	2.90	.548	3.20	.805	-1.687	.098
3	3.57	.504	3.50	.630	.453	.652
4	3.17	.913	3.37	.890	-.859	.394
5	3.30	.596	3.37	.669	-.408	.685
6	2.87	.730	2.97	.765	-.518	.606
7	2.93	.868	3.17	.950	-.993	.325
8	3.43	.568	3.37	.615	.436	.664
9	3.07	.583	3.20	.484	-.963	.339
10	3.97	.669	3.73	.740	1.282	.205
11	3.30	.988	2.07	1.143	4.472	.000**
12	2.63	.490	1.90	.885	3.971	.000**
13	2.40	.814	1.57	.774	4.065	.000**
14	3.83	.648	2.17	1.440	5.780	.000**
15	3.27	.907	1.93	1.230	4.779	.000**

*+ p<0.1; * p<0.05; ** p<0.01*

Q# : Question number

4.3.3 Lesson 2 results

I conducted an independent-samples t-test to compare the results from learning lesson 2

between the pattern I using video and the pattern II using PPT for the questionnaires shown in Table 4.8.

I found a significant difference in the scores for questions 1, 2, 4, 5, 7, 13, and 14 between PPT and video at a 1% level. In addition, I found a significant difference in the scores for question 15 between PPT and video at 5% level:

- Q#1: The learning process with the video increased the learning attention more than the process with the PPT.
- Q#2: Putting the multimedia performance on the video motivated learners to use the system more than learning through the system with the PPT only.
- Q#4 and #5: Video interaction in the learning system increased the learners' positive emotions and lowered their negative emotions more than when learning with the PPT.
- Q#7: Sometimes the course with the video was more interesting than with one with the PPT.
- Q#13: Using the e-learning course with the PPT was more irritating than using one with the video.
- Q#14: Learners are more scared when starting an e-learning course with the PPT than when starting one with the video.
- Q#15: Using the e-learning system with the video was at times more tiring than using ones with the PPT.

Table 4.8: Learning lesson 2 results.

Q.#	PPT		Video		t	P-Value
	Mean	SD.	Mean	SD.		
1	2.47	.571	3.97	.809	-8.297	.000**
2	2.63	.556	3.70	.837	-5.816	.000**
3	3.30	.915	3.17	.699	.634	.529
4	3.30	.596	3.77	.728	-2.717	.009**
5	2.83	.699	3.67	.802	-4.290	.000**
6	2.00	.743	2.40	1.070	-1.682	.099
7	1.50	.630	2.23	.817	-3.893	.000**
8	2.10	.803	1.87	.571	1.297	.200
9	2.60	1.248	2.20	.714	1.523	.135
10	1.93	.640	2.40	1.102	-2.006	.051
11	3.10	.923	3.50	.974	-1.633	.108
12	3.60	1.003	3.27	.521	1.615	.114
13	4.17	.747	3.13	.434	6.553	.000**
14	4.40	.770	3.57	.679	4.446	.000**
15	2.03	.765	2.50	.630	-2.580	.012*

*+ p<0.1; * p<0.05; ** p<0.01*

Q# : Question number

4.3.4 Comparison of lessons 1 and 2

According to the results in Tables 4.7 and 4.8, I obtained the followings:

- Q#1: The learning process with the video increased more learning attention than the other with the PPT in lesson 2. This may reflect that automatically playing the video in lesson 2 required learners to pay more attention than in lesson 1, because lesson 2' is more difficult than lesson 1, as I previously mentioned.
- Q#2: In lesson 2, Learners were more motivated by the multimedia presentation in the learning system than the PPT. Future work will investigate which attributes in Table 2 affect motivation.
- Q#4 and #5: Interaction with the learning system using the video increased learners' positive emotions and lowered their negative emotions better than with the PPT in lesson 2. Future work will investigate which attributes affect positive and negative emotions.
- Q#7: The course with the video was more interesting than that with the PPT in

lesson 2. Future work will investigate which attributes affect interest.

- Q#11 and #12: The PPT caused more anxiety and frustration than the video in lesson 1. Future work will investigate which attributes affect anxiety and frustration.
- Q#13 and #14: Using the e-learning course with the PPT was more irritating than the course with the video both in lessons 1 and 2. Starting the e-learning session with the PPT, learners were more likely to be scared than when staring one with the video both in lessons 1 and 2. Future work will investigate which attributes affect irritation and scare.
- Q#15: Using the e-learning system with the video was more tiring than using one with the PPT in lesson 2. Perhaps the automatically playing the video is more tiring than the PPT where the learners could proceed to the next slide themselves. Perhaps the cause is the fact that the content of lesson 2 was more difficult than that of the lesson 1 as I already addressed.

4.3.5 Relation between test and questionnaire results

According to the Tables 4.6, 4.7, and 4.8, I obtained the followings:

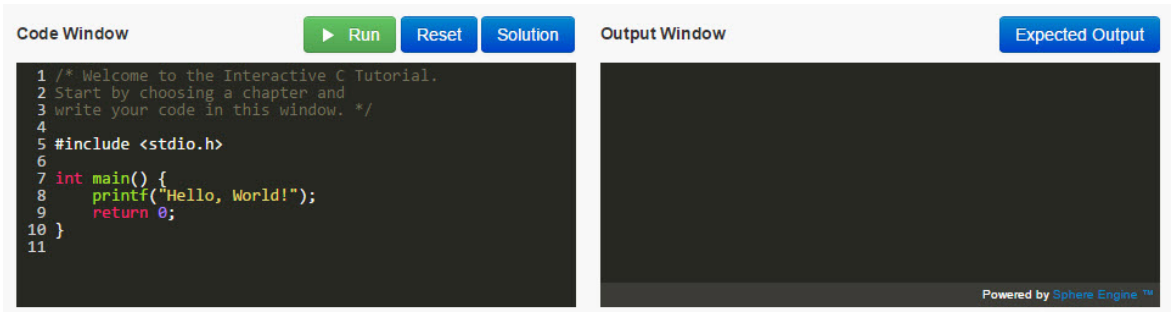
- Lesson 1: The mean test score of PPT is significantly higher than that of video, which shows that the PPT is more effective for lesson 1. On the other hand, the results of questionnaire for emotion show that the video is more effective for lesson 1. Therefore, the test scores and questionnaire results do not match.
- Lesson 2: The *mean* test score of video is significantly higher than that of PPT, which shows that the video is more effective for lesson 2. The results of questionnaire for emotion show that the video is more effective for lesson 2. Therefore, the test scores and questionnaire results match.

Since the content of lesson 1 was easier than of the lesson 2. The results of questionnaire for emotion might not reflect test scores when learner learning with video or PPT in lesson 1. On the other hand, the results of questionnaire for emotion were

directly reflected through the test scores in lesson 2. Therefore, those results show the importance of the emotional aspects in the e-learning systems at least for the difficult contents.

4.4 Discussion

In my system, PPT and video were employed. The reason is they are common to use. Learn-c.org and Khan Academy websites provided interactive computer programming tutorial by using two-window display as window to write code on the left and window to output on the right [62, 63] (Figure 4.9). Rossling et al developed system for algorithm animation such as animal that guides learners to learn the dynamics of program execution by visually demonstrating how the algorithms work [64]. They are more interactive than PPT or video but they are not common to use. These references indicate that there are many possible designs for e-learning tool. However, I think emotional aspect is also important and should be included in every designs of e-learning systems.



(a) code input (b) result

Figure 4.9: Example of the interface design of Interactive C Tutorial [62]

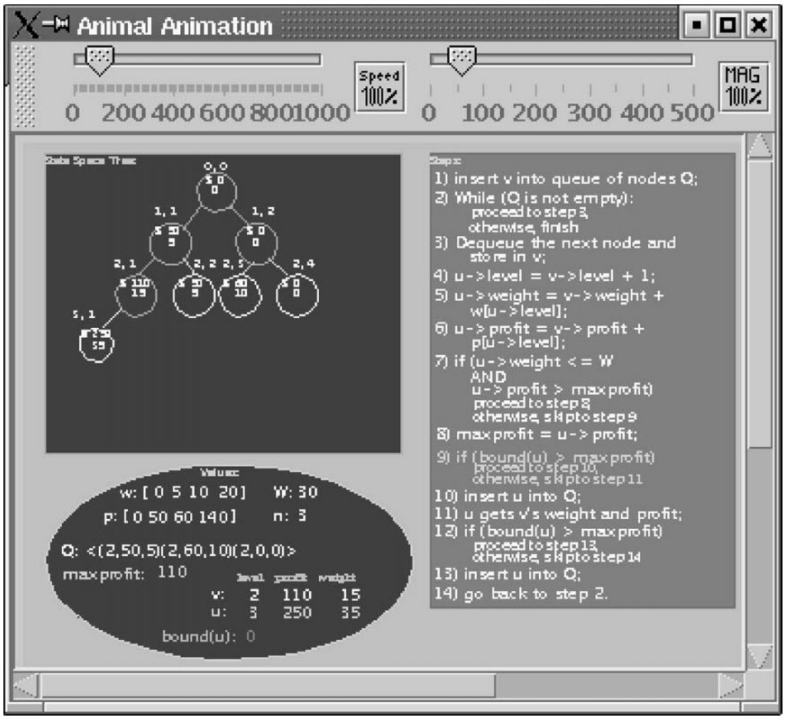


Figure 4.10: Example of the interface design of system for algorithm animation [64]

4.5 Conclusion

In this chapter, I applied the questionnaire to evaluate learners' emotion during learning using the system. The questionnaire is considered to be an effective tool used to gather opinion from learners. To detect emotions using the questionnaire, a set of question detected different various emotions during the period of learning including attention, motivation, satisfaction, enjoyment, interest, anxiety, frustration, scare, and tiring.

I built a prototype of e-learning system and performed the experiment. The evaluation was based on the scores of pre-test and post-test and the questionnaire about the learners' emotions.

According to the results from comparison between the mean test scores and results of the questionnaire for emotion, the experimental results suggest that emotional aspects should be taken into account to design interfaces or contents of an e-learning system at

least for the difficult contents.

The next chapter describes about this system which employed biological signals to measure and analyze learners' emotions.

Chapter 5

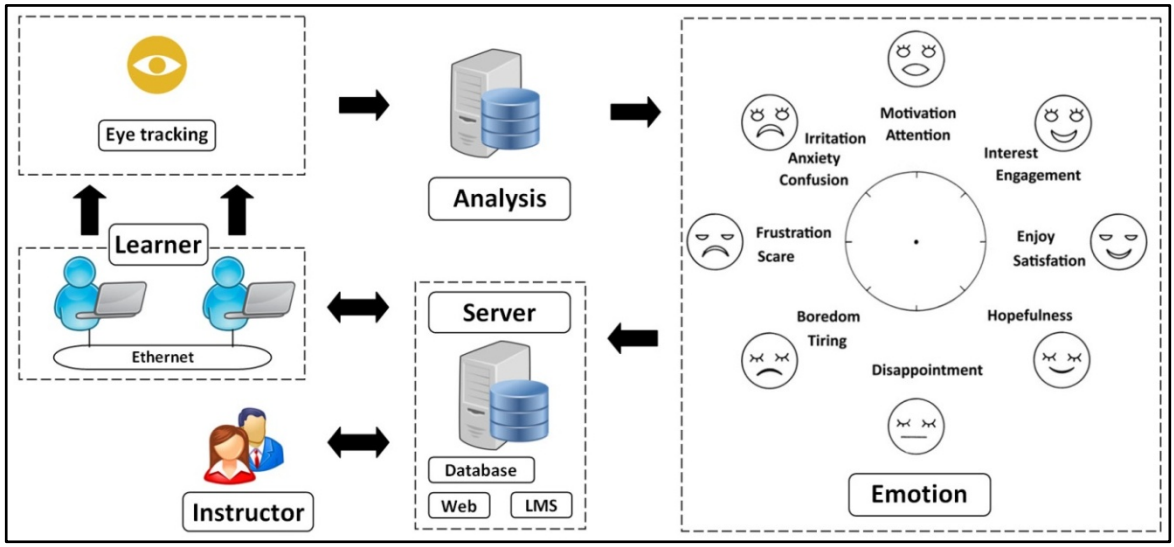
Emotion Estimation in E-learning System using Eye Tracking

Based on the previous experiment in chapter 4, I employed the questionnaire to screen out two emotion groups. Eye tracking can dynamically capture users' attention more directly than the other biological signals [65]. In this chapter, I employed eye tracking as a biological signal to detect the symptoms of learners' emotions. With an eye tracking equipment, I recorded the eye movements of learners and calculated their eye metric indexes, on which I focused to explore their relationship to two learners' emotions groups: interest and boredom groups. I designed and implemented a prototype and experimentally evaluated it.

5.1 Implementation of the System

5.1.1 Prototype description

The current system is based on the previously designed e-learning scheme in chapter 3 as shown in Figures 5.1. This experiment, I employed eye tracking to detect eye movements and explore learners' emotions. I focused on fixation indexes from eye tracking data. I analyzed fixation plots, heat map data to identify the specific targets of learners' visual attention to different parts of the interface, and the areas of interest (AOI) index related to learners' emotions.



Figures 5.1: Overall system designed

5.1.2 Tools and Materials

The contents, which are an introduction to C programming, consist of the following two parts:

1. Content 1: loops in C programming language
2. Content 2: decision making statements in C programming language

Content 2 is more difficult than content 1.

I designed contents 1 and 2 using power point (PPT). Each content consists of 17 pages. I prepared two styles shown below:

1. Style A: PPT slides using text only (Figure 5.2).
2. Style B: PPT slides using both text and pictures (Figure 5.3).

I prepared two patterns (Table 5.1). The process of each is shown in Figure 5.4 and the details are described below:

1. Pattern I: Learners studied content 1 in style A and content 2 in style B.
2. Pattern II: Learners studied content 1 in style B and content 2 in style A.

Table 5.1: Content patterns

Content	Pattern I	Pattern II
1.	Style A	Style B
2.	Style B	Style A

A pre-test is a set of questions given to learners before the learning began. After completing the content, they were given a post-test which is the same set of questions from the pre-test but different order of choices. Examples of the pre-test questions for content 1 are shown in Figure 5.5. Both tests consist of ten questions, each question is one point, and the highest score is ten.

The questionnaire asked nine questions related to learners' emotions in e-learning systems [59] (Table 5.2). Learners answered on a 5-point Likert scale [60] where five is the highest (strongly agree) and one is the lowest (strongly disagree).

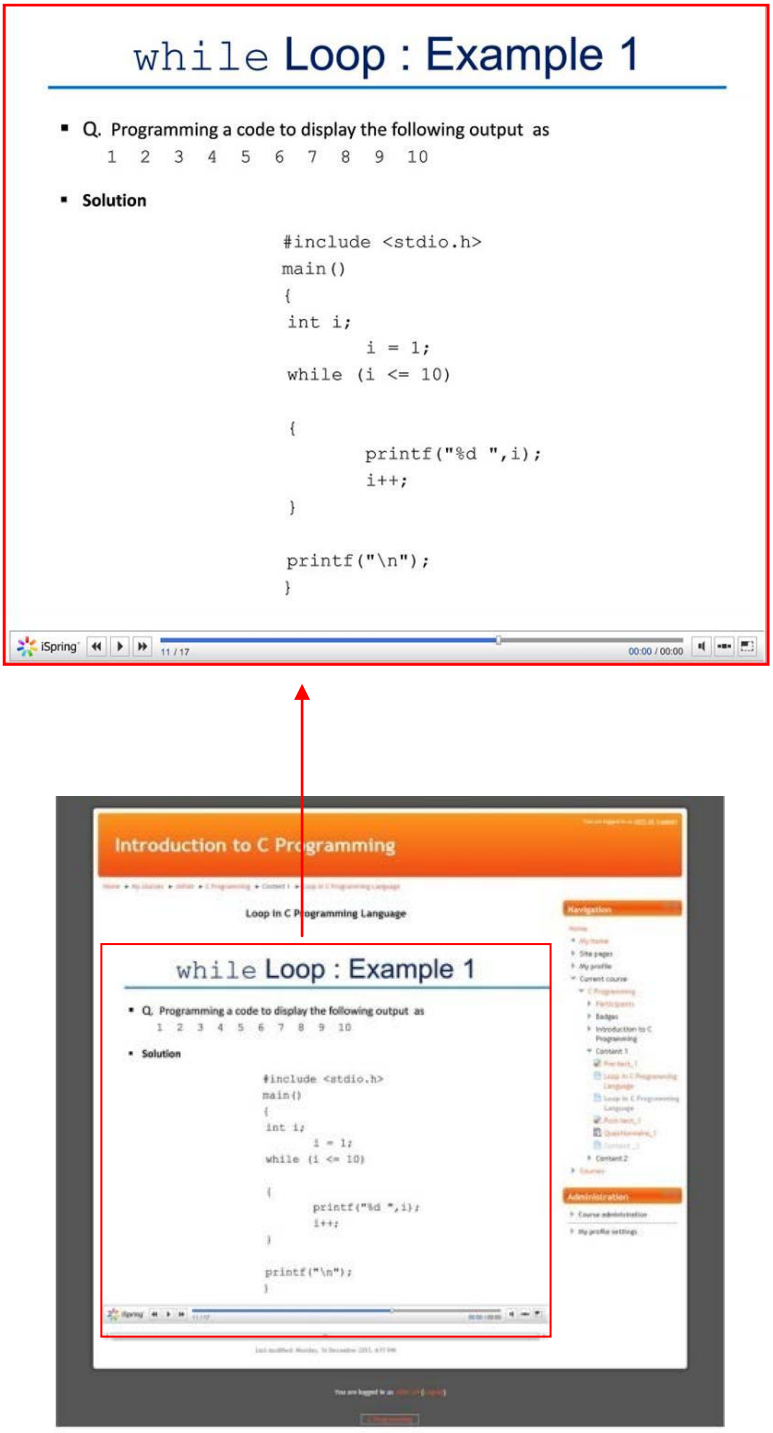


Figure 5.2: Interface design for style A

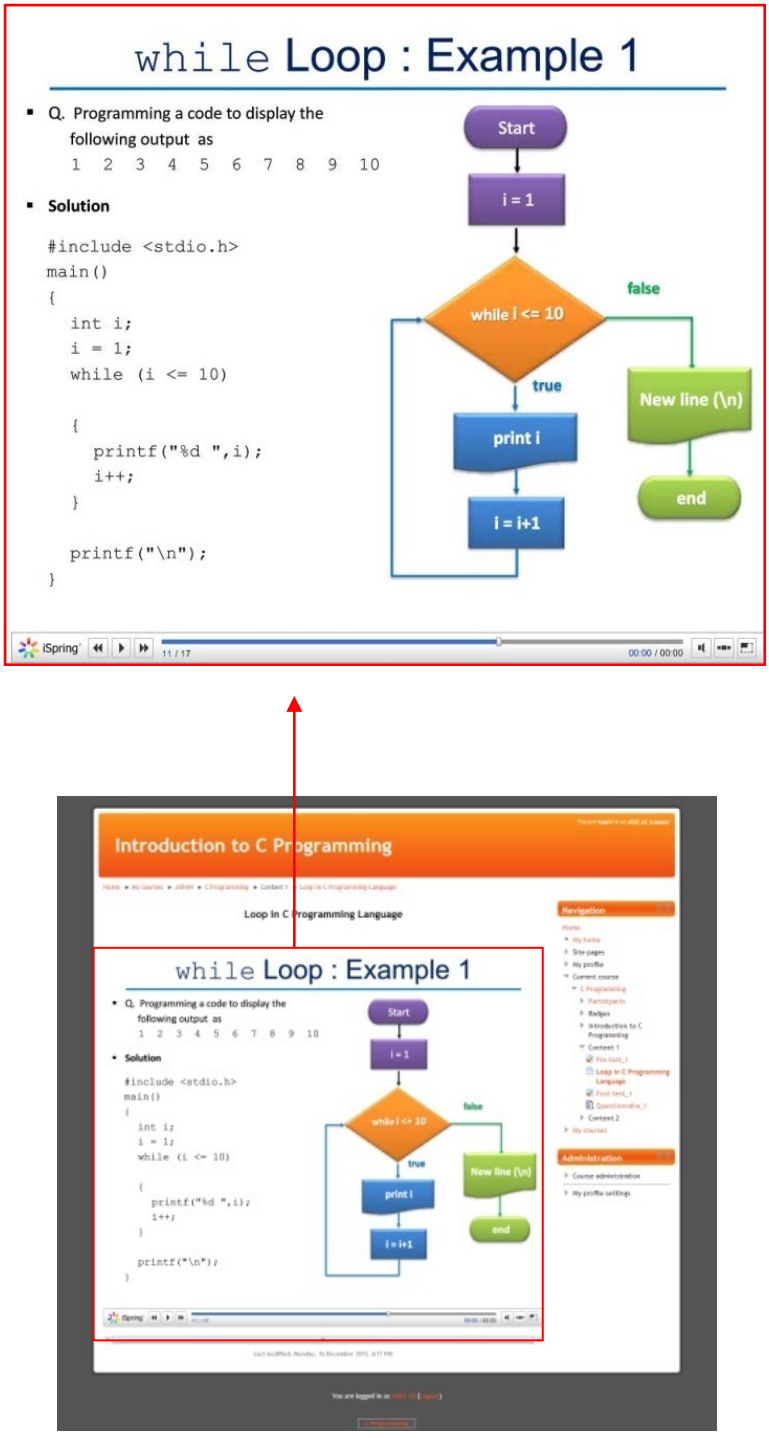


Figure 5.3: Interface design for style B

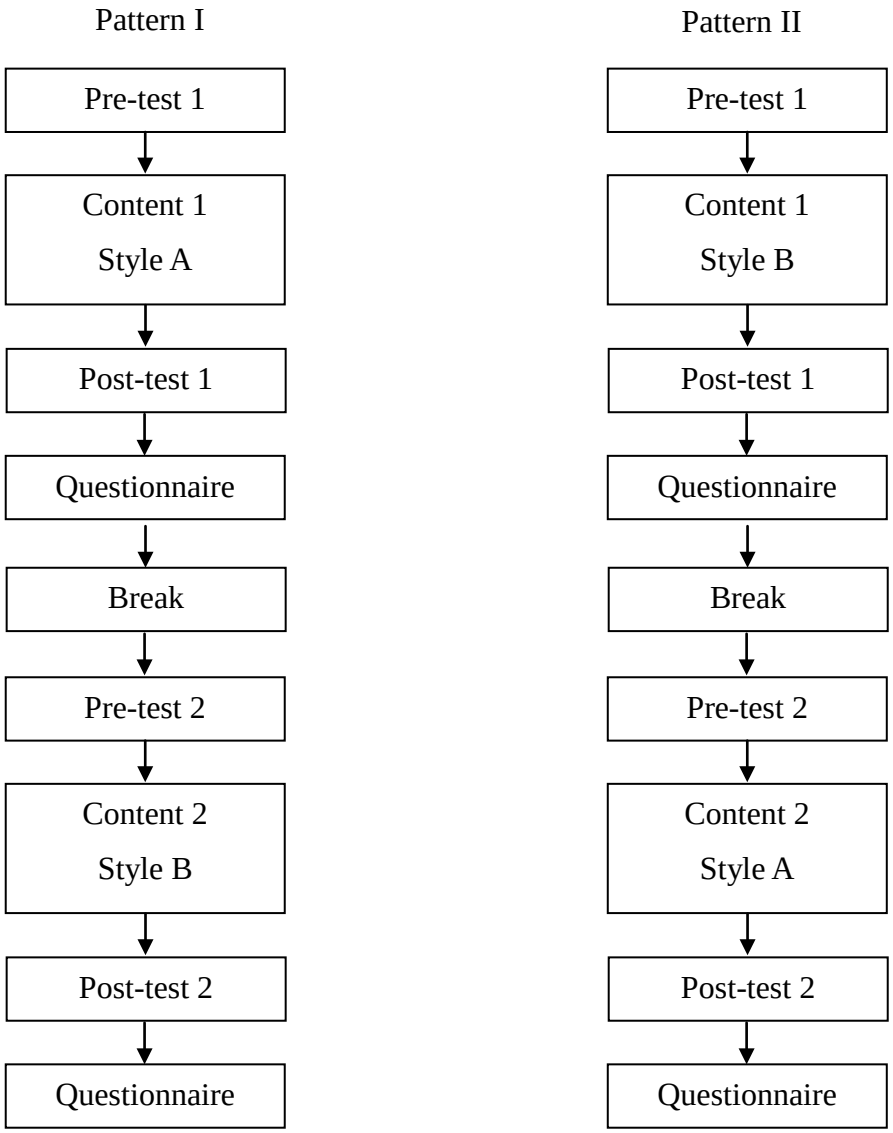


Figure 5.4: Process of the e-learning system

Q.#	Content
1.	What is the final value of x when the code is run? int x; for(x=0; x<10; x++) {}; a) 10 b) 9 c) 0 d) 1
2.	When is the code block following while(x<100) executed? a) When x is less than 100. b) When x is greater than 100. c) When x is equal to 100. d) While it wishes.
3.	Which is not a loop structure? a) For b) Do while c) While d) Repeat Until
4.	What is wrong? for (int k = 2, k <=12, k++) a) The increment should always be ++k. b) The variable must always be the letter i when using a for loop. c) There should be a semicolon at the end of the statement. d) The commas should be semicolons.
5.	If there is more than one statement in the block of a for loop, which of the following must be placed at the beginning and the end of the loop block? a) parentheses ( ) b) braces { } c) brackets [ ] There should be a semicolon at the end of the statement. d) arrows < >

Figure 5.5: Example of pre-test

Table 5.2: Questionnaire items on 5-point likert scale

No.	Questions	**Related emotion**
1.	The learning process increased my learning attention.	Interest
2.	Putting a picture and text into the learning system motivated me to use it.	Interest
3.	The system helped me learn better.	Interest
4.	Using the e-learning system was sometimes tiring.	Boredom
5.	E-learning has some features that cause anxiety	Boredom
6.	From time to time, the courses were interesting.	Interest
7.	The system did not interrupt me during the learning process.	Interest
8.	The e-learning courses were frustrating.	Boredom
9.	I felt satisfied after finishing an e-learning course.	Interest

I used EyeTech and Quick Glance hardware version 5.0 to record the eye movements of the participants. The device has a sampling rate of 50 Hz.

I applied the following eye metric indexes which are related to the learners' emotions. The following describes the eye metric indexes:

1. Number of fixations

   The number of fixations on a particular display element (of interest to the design team) should reflect its importance. More important display elements are fixated on more frequently [66].

2. Fixation duration

   Longer fixations (and perhaps longer gazes) are generally believed to indicate a participant's difficulty extracting information from a display [67].

3. Fixation point

   A fixation is defined as the point on the screen at which the participant is looking [68].

4. Fixation length

   The fixation length data are the time series data of the fixations, which are the main fixation points of the measured eye-tracking data [69].

5. Pupil diameter

   The eye's pupil allows light to enter the retina.

I analyzed fixation plots and heat map data to identify the specific targets of learners' visual attention to different parts of the interface, and the areas of interest (AOI) index related to learners' emotions. The fixation plot and heat map are described as follows:

1. Heat map

   Heat maps are the best-known visualization technique for eye tracking studies. In a heat map a screenshot is color-coded according to the amount of look each part attracts [70, 71]: The red areas are where users looked the most, the yellow areas indicate fewer fixation, and the green areas indicate

the least-viewed areas [72, 73]. If an area is white, it did not attract any fixations.

2. Fixation plots

   In a fixation plot, a single user's visit to page a depicted as a series of blue dots, each indicating on fixation. The size of each dot represents the duration of that fixation, with bigger dots indicating longer looks. The number of the dots shows the sequence of the fixation, and thin lines connecting the dots indicate the saccades as the eye moved from one location to the next [70, 71].

5.2 Evaluation Experiment

The research aims to find appropriate indexes from the biological signals to detect emotions of the learners. In this part, I analyzed the relations between learner emotions and eye tracking indexes. The target emotions are interest and boredom.

5.2.1 Participants

I conducted the experiments by equally dividing eight Brazilian students into two groups, and performed learning task using different learning methods. Conditions of participants are described as follows:

1. Three participants learned "C programming" before. However, another five participants never learned "C programming" before.
2. Participants are male Brazilian between 19-23 years old.

5.2.2 Expereiment Method

Figures 5.6 shows experiment scene. The procedures are described below:

1. I calibrate the learners' eye positions.

2. The learners register when they first log onto the e-learning to, start the personalized e-learning.
3. They take pre-test 1.
4. They learn content 1 in style A or B.
5. They take post-test 1.
6. They answer the first questionnaire.
7. They take a 5 minutes break.
8. They take pre-test 2.
9. They learn content 2 in style B or A.
10. They take post-test 2.
11. They answer the second questionnaire.

Figure 5.6: Experiment scene

5.3 Experimental Results and Discussion

In this section, I obtained the following results by comparing the test scores, the questionnaire results, and eye tracking results.

5.3.1 Test scores and questionnaires results

Table 5.3 contains both the test scores and the questionnaire results. The following are the details:

Table 5.3: Tests scores and questionnaire results

User	Content	Style	Test Scores			Questionnaire	
			Pre-test	Post-test	Scores diff.	Interest mean	Boredom mean
02	1	A	7	8	1	3.833	2.000
05	1	A	3	7	4	3.167	1.667
07	1	A	7	9	2	3.833	1.333
08	1	A	7	8	1	2.833	1.667
01	1	B	7	7	0	3.667	3.333
03	1	B	8	7	-1	3.667	2.333
04	1	B	5	10	5	3.833	3.333
06	1	B	10	10	0	3.500	2.000
01	2	A	6	7	1	2.667	3.333
03	2	A	6	8	2	3.667	2.667
04	2	A	7	6	-1	3.833	2.667
06	2	A	8	9	1	3.500	1.667
02	2	B	8	9	1	3.833	2.667
05	2	B	5	7	2	3.333	2.333
07	2	B	6	8	2	4.333	1.667
08	2	B	7	6	-1	2.667	2.667

1. The pre-test and post-test scores were calculated for ten questions. The difference of the scores are the differences the between the post- and pre-tests.
2. The questionnaire results of the mathematical means of interest and boredom were calculated from the questions shown in Table 5.2.

I found the following results from Table 5.3:

1. *Pre-test and post-test scores*

   In general, the post-test scores are higher than the pre-test scores. I focused on the following abnormal case where the post-test score is lower than the pre-test score: user 04 in content 2/style A.

2. *Questionnaire results*

   Mostly, the interest means are higher than the boredom means.

3. *Eye metric results*

   I applied the eye metric indexes which are related to the learners' emotions as previous explained in part 5.1.2 Tool and Materials.

5.3.2 Eye metric results

Table 5.4 shows the eye metrics in the two main areas of interest (AOI) in contents 1 and 2. The AOI screen was divided into two areas (Figure. 5.7): 1) learning area (LA) and 2) out of learning area (OLA), which consists of the following three eye metrics: 1) average number of fixations, 2) fixation durations (sec), and 3) pupil diameter (mm.).

1. "The number of fixation" ratio column was calculated by dividing the number of fixations in LA by the number of fixations in OLA. If number of fixation duration ratio is high, it indicates that learner is interested.
2. I calculated "the fixation duration ratio" column by dividing the fixation duration in LA by the fixation duration in OLA. If fixation duration ratio is high, it indicates that learner is interested.
3. "The pupil diameter ratio" column was calculated by dividing the pupil diameter in LA by the pupil diameter in OLA. If pupil diameter ratio is high, it indicates that learner is bored.

Table 5.4: Eye metric on AOI

User	Content	Style	Learning Area (LA)			Out Learning Area (OLA)			Number of fixation ratio	Fixation duration ratio	Pupil diameter ratio
			Number of fixation (mean)	*Fixation duration (sec)*	*Pupil diameter (mm)*	*Number of fixation (mean)*	*Fixation duration (sec)*	*Pupil diameter (mm)*			
02	1	A	33.882	8.780	3.160	0.941	0.267	3.168	22.680	20.681	0.997
05	1	A	36.412	9.280	3.074	1.059	0.239	3.209	14.925	17.075	0.958
07	1	A	23.000	8.772	2.786	1.235	0.301	2.835	15.480	25.114	0.983
08	1	A	32.647	8.543	2.954	2.529	0.752	3.141	10.960	9.851	0.941
01	1	B	26.647	6.972	4.103	0.765	0.186	4.280	20.182	22.110	0.959
03	1	B	27.118	8.496	3.776	0.294	0.078	3.854	19.696	28.269	0.980
04	1	B	29.706	9.157	4.021	0.353	0.119	4.149	16.033	21.231	0.969
06	1	B	61.059	18.812	3.124	1.882	0.619	3.133	20.400	20.639	0.997
01	2	A	19.765	5.632	3.931	0.882	0.208	4.163	17.526	21.164	0.944
03	2	A	21.706	6.939	3.769	0.294	0.131	3.767	13.960	14.082	1.001
04	2	A	43.235	12.716	3.721	3.059	0.715	3.936	7.744	9.305	0.945
06	2	A	81.176	22.472	2.851	1.471	0.379	2.954	31.674	36.273	0.965
02	2	B	75.563	18.907	3.080	3.000	0.705	3.177	16.289	16.876	0.968
05	2	B	53.750	13.223	2.997	0.750	0.189	2.982	44.300	49.463	1.003
07	2	B	77.438	25.772	2.866	0.688	0.130	2.809	92.143	157.282	1.020
08	2	B	80.875	26.785	3.287	1.500	0.414	3.308	44.167	49.980	0.994

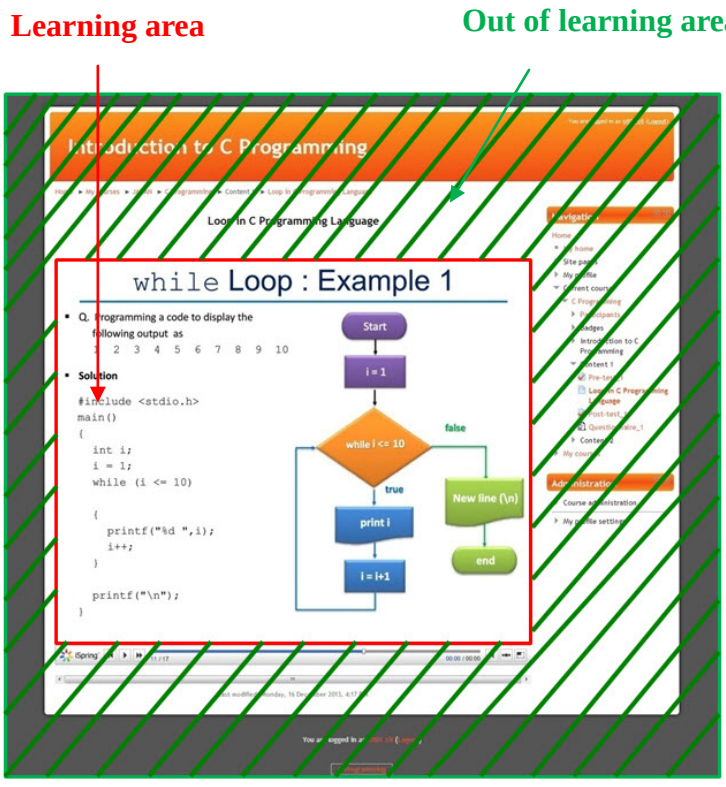


Figure 5.7: AOI of each area

I calculated the correlation coefficients between the eye metrics and the mean of interest in the questionnaires for both the contents and styles. Table 5.5 shows only significant correlation coefficient with interest and Table 5.6 shows only significant correlation coefficient with boredom results.

- Since the fixation duration ratio, the number of fixation ratio, and the pupil diameter ratio are positively correlated with interest (Table 5.5), they are candidates for indexes of interest. For example, Figure 5.8 showed correlation in content 1 between fixation duration ratio and interest from Table 5.5. This graph showed that correlation coefficient was positively correlated with interest in content 1 regardless of styles.
- The number of fixation in OLA is negatively correlated with interest (Table 5.5). Therefore, this is also candidates for indexes of interest. Since the fixation duration ratio, the number of fixation ratio, and the pupil diameter ratio are negatively correlated with boredom (Table 5.6), they are candidates for indexes of boredom.
- Since the fixation duration ratio, the number of fixation ratio, and the pupil diameter ratio were negatively correlated with boredom (Table 5.6), they are candidates for indexes of boredom. For example, Figure 5.9 showed correlation in style B between pupil diameter ratio and boredom from Table 5.6. This graph showed that correlation coefficient was negatively correlated with boredom in style B regardless of contents.

Table 5.5: Correlation between eye metrics and interest of questionnaires

Eye metric indexes	Content or style	Correlation coefficient with interest
Fixation duration ratio	Content 1	0.831**
Number of fixation OLA	Content 2	-0.778*
Number of fixation ratio	Content 1	0.673*
Pupil diameter ratio	Content 1	0.694**
Pupil diameter ratio	Style A	0. 665**

*+ p<0.1; * p<0.05; ** p<0.01*

Table 5.6: Correlation between eye metrics and boredom of questionnaires

Eye metric indexes	Content or style	Correlation coefficient with boredom
Fixation duration ratio	Content 2	-0.656**
Number of fixation ratio	Content 2	-0.690**
Pupil diameter ratio	Content 2	-0.790*
Pupil diameter ratio	Style B	-0.826*

*+ p<0.1; * p<0.05; ** p<0.01*

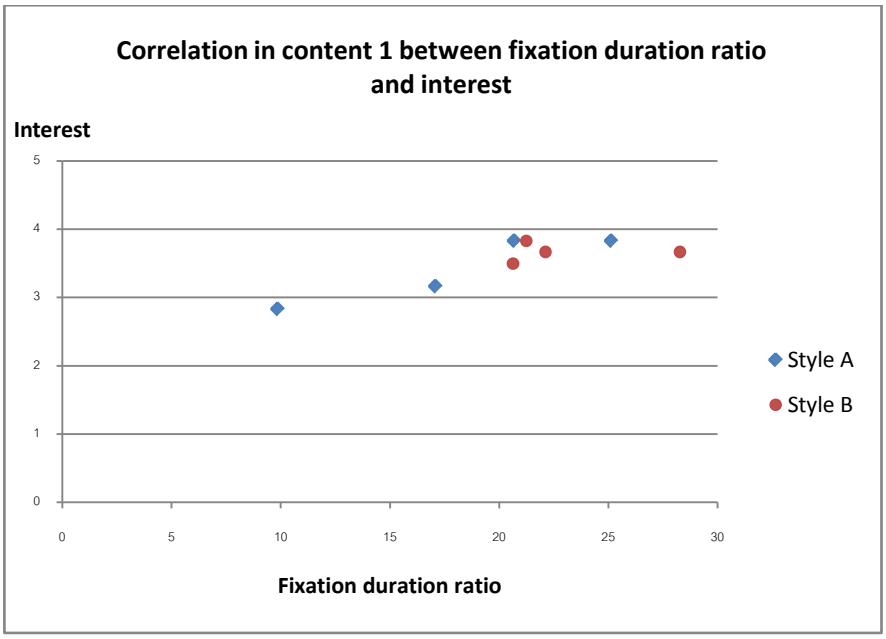


Figure 5.8: Correlation graph in content 1 between fixation duration ratio and interest

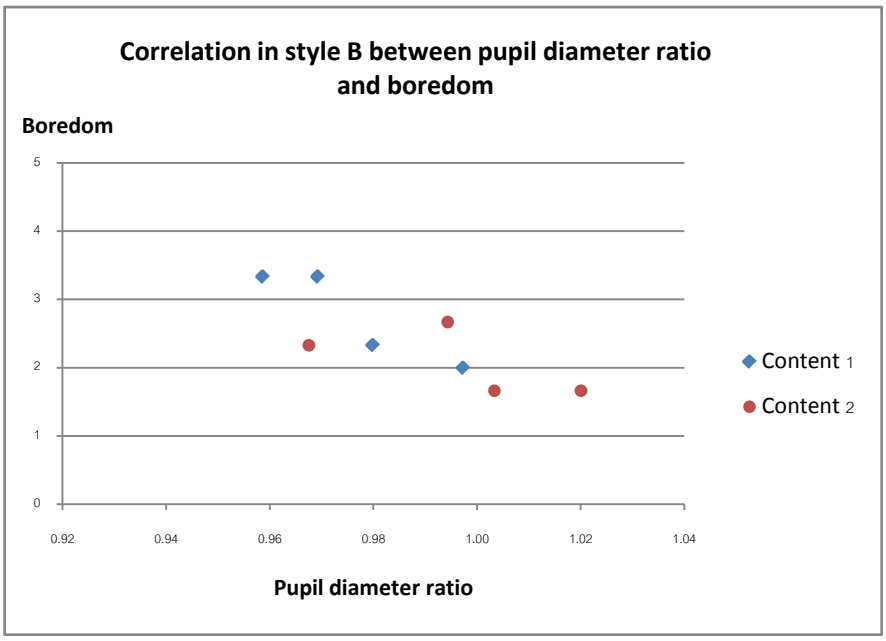


Figure 5.9: Correlation graph in style B between pupil diameter ratio and boredom

Therefore, correlation coefficient results of all users show candidate eye metric indexes of interest or boredom.

In addition, the questionnaire and fixation plot results of user 04 have mismatch because as following:

- Mean of interest group (3.833) is higher than mean of boredom group (2.667) of content 2 in questionnaire results (Table 5.3).
- Fixation plots show the evidence that he felt bored in content 2 (Figure 5.11).

Therefore, I focused on user 04.

Table 5.7 shows the independent-samples t-test comparisons of the eye metric indexes between contents 1 and 2 of user 04 in each area shown in Figure 5.8. I summarize them as follows:

- The number of fixation, fixation duration, fixation point, and fixation length

in OLA of content 2 are higher than content 1.

- I found no significant difference in the eye metric indexes between contents 1 and 2 in LA.

Table 5.7: T-test comparisons of eye metric indexes between contents 1 and 2 of user 04

Area	**Eye metric indexes**	**Mean and SD.**	***Content 1***	***Content 2***	**t**	**P-Value**
LA	Number of fixation	Mean	28.29	41.00	-1.640	0.057
		SD.	15.35	28.00		
	Fixation duration	Mean	8.85	12.12	-1.395	0.087
		SD.	5.07	8.22		
	Fixation point	Mean	0.30	0.28	1.300	0.101
		SD.	0.04	0.06		
	Fixation length	Mean	2.89	5.09	-2.371	0.014
		SD.	1.25	3.60		
OLA	Number of fixation	Mean	1.76	5.29	-2.174	0.020*
		SD.	2.88	6.03		
	Fixation duration	Mean	0.41	1.30	-1.978	0.028*
		SD.	0.715	1.70		
	Fixation point	Mean	0.07	0.18	-2.514	0.009**
		SD.	0.11	0.13		
	Fixation length	Mean	0.18	0.85	-2.679	0.007**
		SD.	0.33	0.98		

*+ p<0.1; * p<0.05; ** p<0.01*

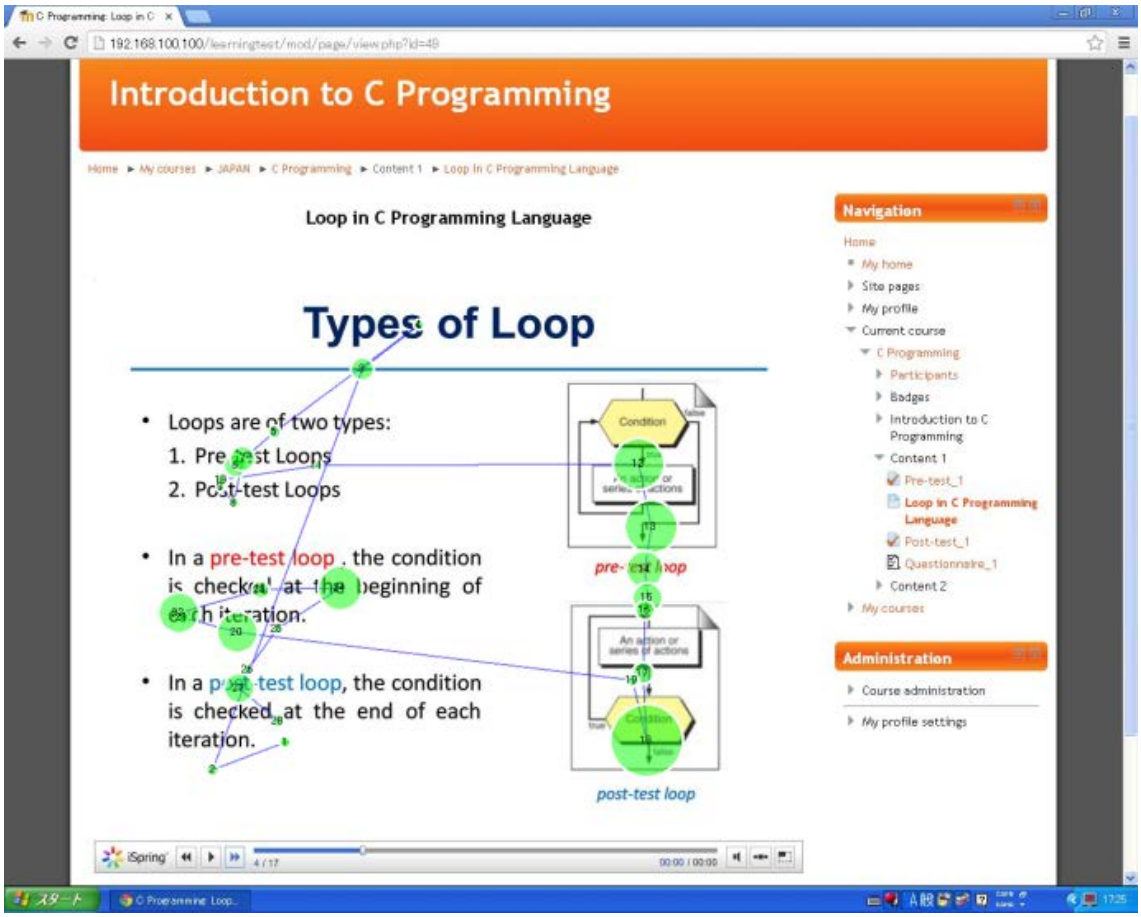


Figure 5.10: Example of fixation plot for content 1: user 04

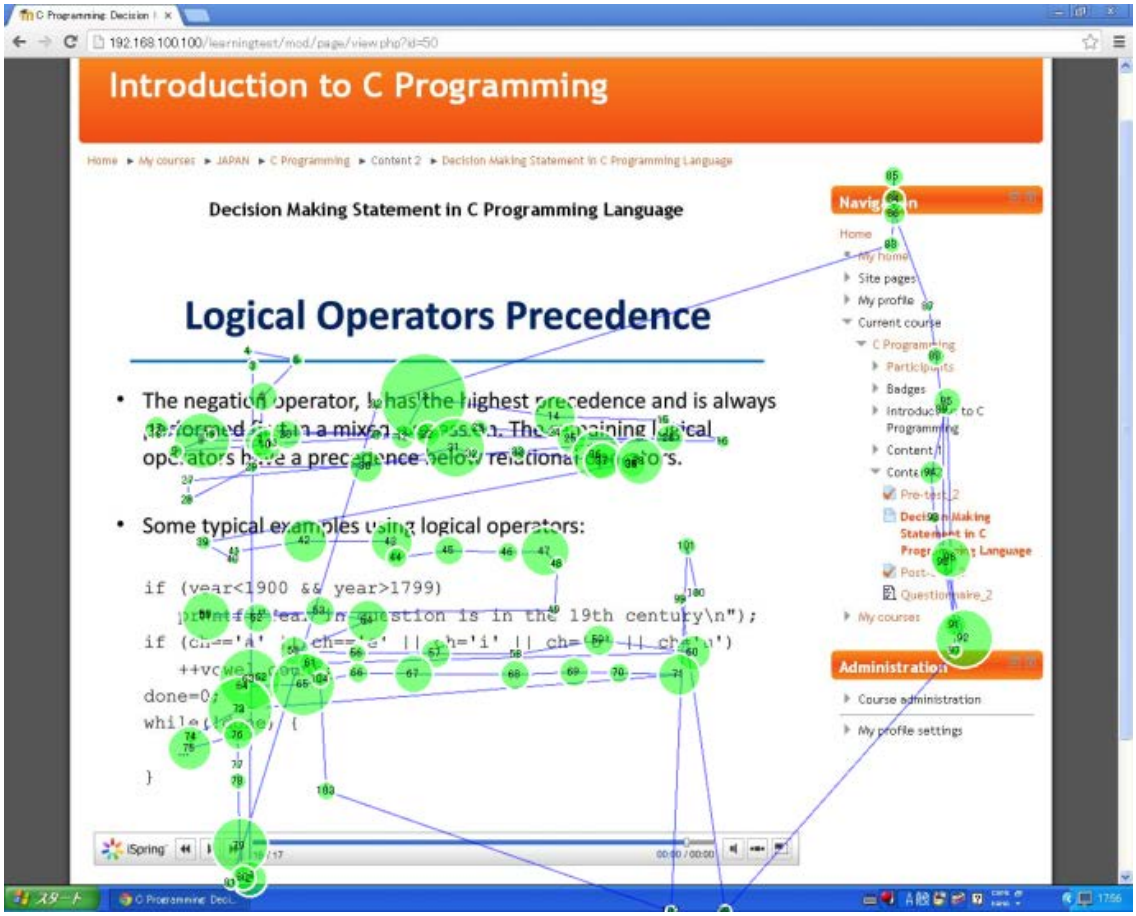


Figure 5.11: Example of fixation plot for content 2: user 04

These results show that user 04 watched OLA significantly longer in content 2 than in content 1. Figure 5.8 shows an example of fixation plot for the content 1 of user 04. Figure 5.9 shows an example of fixation plot for the content 2 of user 04. These figures are evidence for the results of Table 5.7.

I compared the eye metrics (Tables 5.4 – 5.7) and questionnaire (Table 5.3) results of user 04 and found the following:

- Eye metrics results (Tables 5.4 – 5.6)

  The number of fixation ratio and fixation duration ratios of content 2 are lower than content 1 (Table 5.4). Therefore, they are candidates of boredom (Tables 5.5 and 5.6). He felt bored during content 2, and his eye movement focused on disorganized sequences and jumped more to OLA in content 2 (Figure 5.11) than content 1 (Figure 5.10).
- T-test results (Table 5.7)

  His eye metric indexes in OLA show different scores between contents 1 and 2. When he felt bored, his eye movement focused on OLA (Figure 5.11).
- Questionnaire scores (Table 5.3)

  The boredom scores of his questionnaire answers in content 1 are higher than in content 2. Since he answered the questionnaire long after he finished the post-test, perhaps this lag affected his questionnaire results, which did not match the eye metrics.

I focused on the eye metric results because they are more precise than the questionnaire results, which could not measure learners' emotions in real time.

5.4 Conclusion

I designed, implemented, and experimentally evaluated a prototype with eye tracking. I proposed several eye metric indexes to indicate learners' emotions. The experiment results indicate that the eye metric indexes, namely the number of fixation ratio, the fixation duration ratio, and the pupil diameter ratio were practical and useful to divide learners' emotions into interest and boredom groups. I depicted the obtained data of each

learner's eye fixation on the focuses areas or AOI as fixation plots which were found useful to analyze the learners' emotions during the learning sessions.

Next chapter, I will explain about the system that employs eye metric indexes such as fixation duration, number of fixation, fixation point, and fixation length to measure and detect learners' emotions with real-time feedback eye tracking.

Chapter 6

Proposed E-learning System with Real-time Feedback from Eye Tracking

Based on the experiment in chapter 5, I found eye tracking indexes such as the number of fixation ratio, the fixation duration ratio, and the pupil diameter ratio that reflect learners' emotion. In this chapter, I employed two eye tracking indexes, fixation duration ratio and pupil diameter ratio, to detect the symptoms of learners' boredom. I performed a set of experiments to construct a prototype of an e-learning system with real-time feedback to escape boredom.

6.1 Implementation Prototype of System

I built a prototype of an e-learning system and experimentally evaluated it using eye tracking based on the system design in chapter 3. This chapter describes a set of

experiments with real-time feedback from eye tracking as shown in Figure 6.1.

1. First, eye tracking detects the symptoms of normal positions and movement of a learner.
2. While learning, eye tracking detects the symptoms of learner's current emotion and send it to the server for caution decision.
3. If learners get bored, caution will appear to make them concentrate and pay attention to the lesson.
4. Instructor, who creates and designs courses, contents, tests, quizzes, and evaluation criteria.

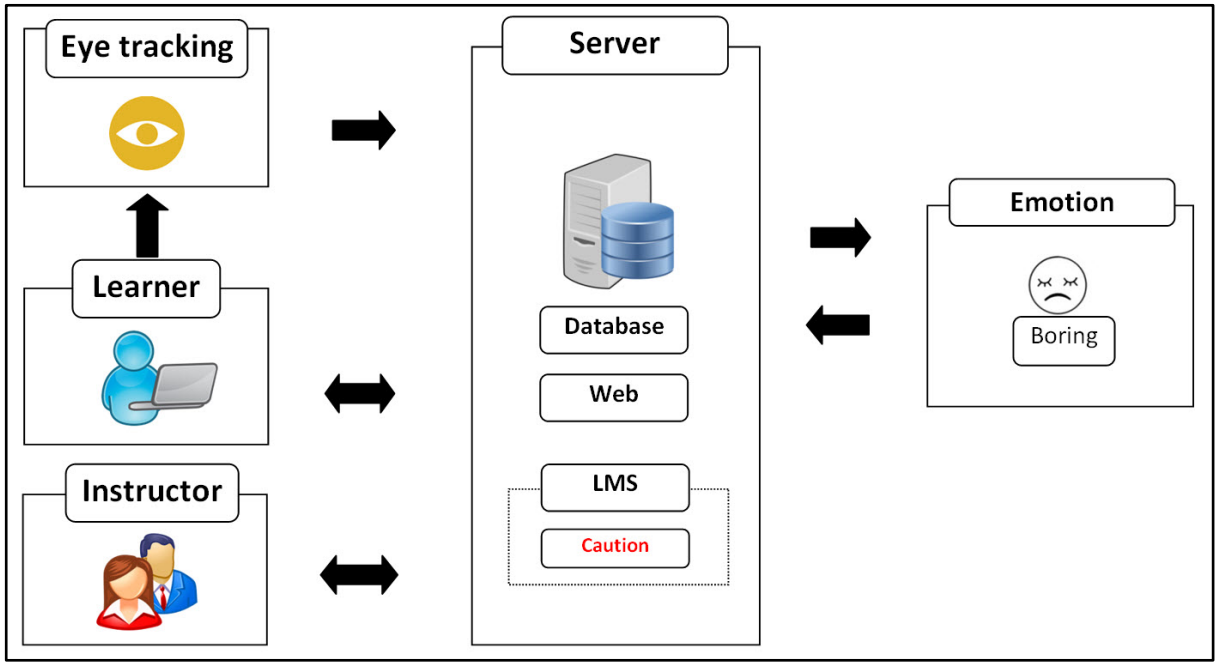


Figure 6.1: Overall design of the system with real-time eye tracking

The workflow of real-time feedback system using eye tracking shown in Figure 6.2 is explained as follows:

1. Getting eye tracking data in real-time using UDP (port 61000) to keep it in database server.
2. Analysis of learners' boredom
   - Get position of Area of Interest (AOI) from "detection and caution management." Positions of AOI consist of two areas, namely 1) learning area (LA) and 2) out of learning area (OLA).
   - Judge the learners' boredom from eye tracking data on database server, and AOI's position from "detection and caution management." The detail of the conditions will be described in section 6.2.2 (Tools and Materials). If learners' boredom is detected, this module will send caution notification and eye position to "detection and caution management."
3. Detection and Caution management

   This module consists of two parts as follows:
   - Detect position: This part gets AOI's position from LMS, and send it to "analysis of learners' boredom."
   - Caution management: This part decides which caution type (types 1 or 2), should be used from "Analysis of learners' boredom", and send the caution type and eye position to LMS.
4. LMS dispenses content. At the same time, caution will be shown if necessary.
5. Web server dispenses web pages as they are requested from LMS.

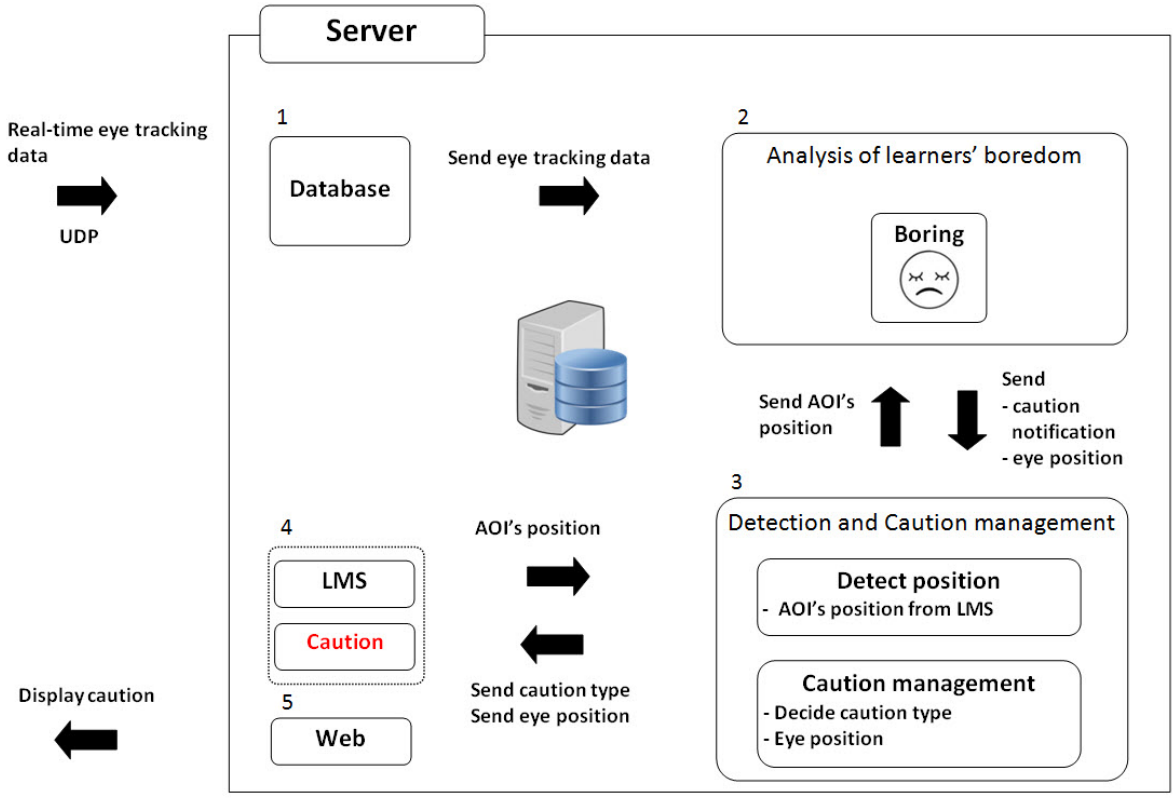


Figure 6.2: Real-time feedback from eye tracking

6.2 Experiment I

6.2.1 Objective of Experiment

The main objective is to construct a prototype of an e-learning system with real-time feedback to escape boredom.

6.2.2 Tools and Materials

The content is learning the THAI language lessons consisting of two parts:

1. Content 1: THAI 1
2. Content 2: THAI 2

I designed the content using power point (PPT) in the Japanese language. Each content consists of eight pages. I prepared two styles shown below:

1. Style A: PPT slides designed “with caution” (Figure 6.3).
2. Style B: PPT slides designed “without caution” (Figure 6.4).

The content is presented in two patterns (Table 6.1) The process of each is shown in Figure 6.5, and the details are described below:

1. Pattern I: Learners studied content 1 in style B and content 2 in style A.
2. Pattern II: Learners studied content 1 in style A and content 2 in style B.

Table 6.1: Content patterns

Content	Pattern I	Pattern II
1.	Style B	Style A
2.	Style A	Style B

Area of interface (AOI) was divided into two areas (Figure 6.6): 1) learning area (LA) and 2) out of learning area (OLA)

Figure 6.3: Interface design for style A (“with caution”)

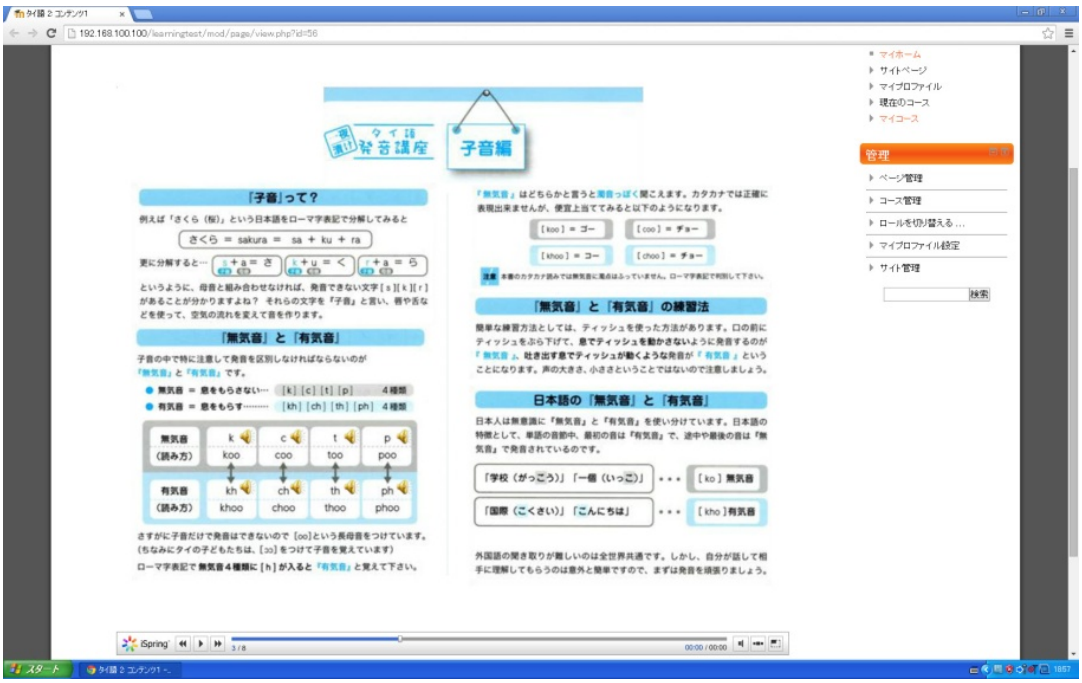


Figure 6.4: Interface design for style B (“without caution”)

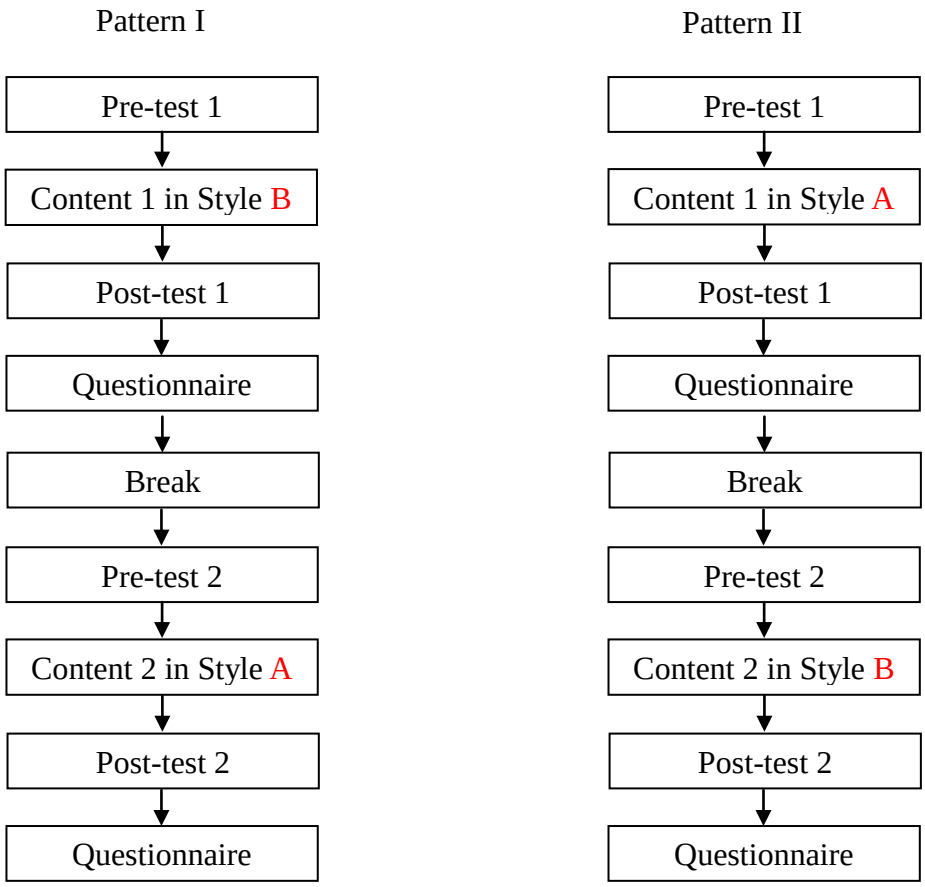


Figure 6.5: Process of the e-learning system

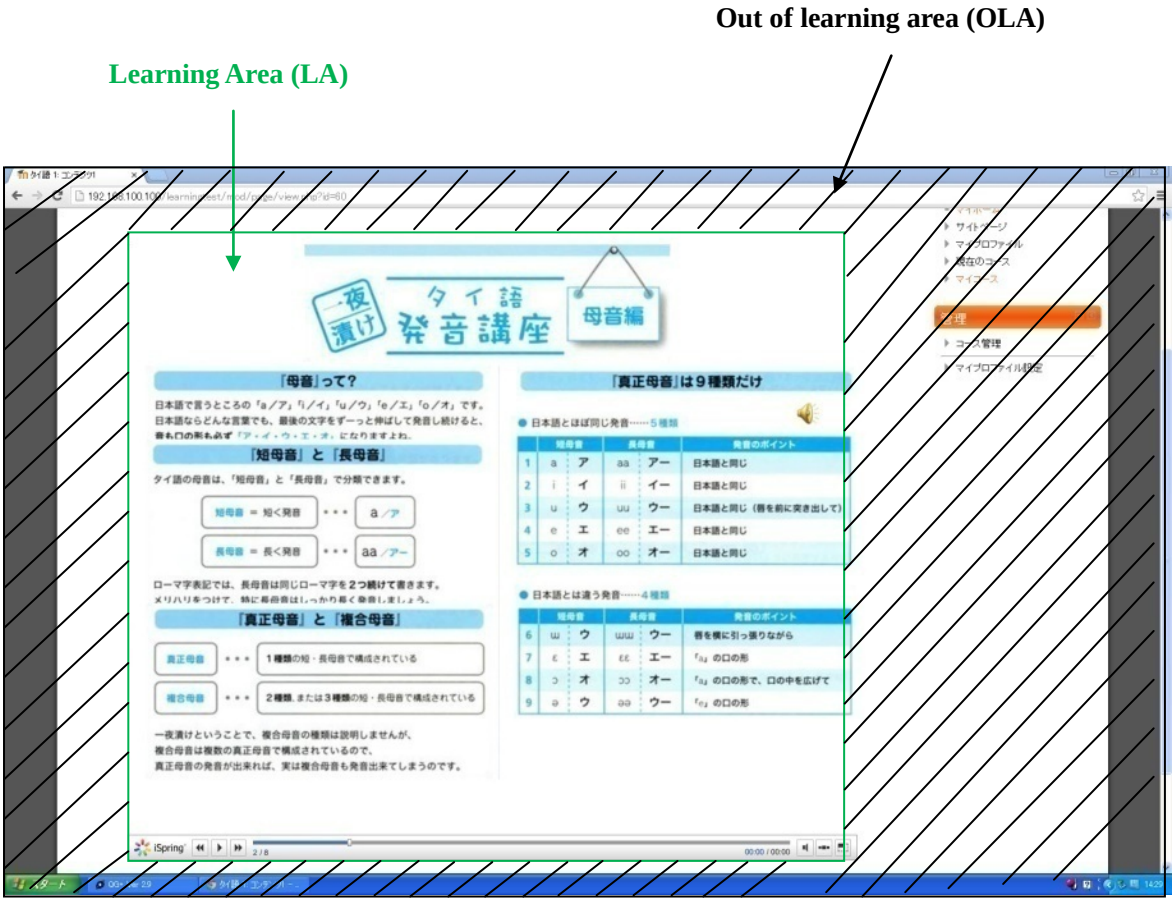


Figure 6.6: AOI of each area

The system showed cautions to make the learners concentrate on learning, when they got bored. From previous research results, Dharmawansa et al. confirmed that animations and cartoon have the potential to serve both affective and cognitive function so that learners will be attracted to pay attention on the learning materials and motivated to learn [74, 75]. Blinking and flashing are very powerful tool for drawing attention [76, 77]. Therefore, I used two these models of cautions as shown in Table 6.2.

Table 6.2: Detail of each caution

No.	Detail
1	Cartoon animation followed by eye movement and sound in OLA as shown in Figure 6.3
2	Flash with sound in LA

Examples of the pre-test questions for content 1 are shown in Table 6.3. Both tests consist of ten questions, each question is one point, and the highest score is ten. Pre-test has choice (e.) “I do not know” in case that participants did not learn Thai language before. If learners answer choice (e.), the score is zero.

The questionnaires provided seven questions related to the learners’ emotions in e-learning systems (Table 6.4). Learners answered on a 5-point Likert scale [61] where five is the highest (strongly agree) and one is the lowest (strongly disagree). I grouped the questions into two styles. Q1 and Q2 evaluated learners’ emotions, Q3 - Q7 evaluated cautions.

I used EyeTech and Quick Glance hardware version 5.0 to record the eye movements of the participants. The device has a sampling rate of 50 Hz.

I applied the following eye metric indexes related to the learners’ emotions.

1. Fixation duration ratio

   Fixation duration in LA divided by fixation duration in OLA

2. Pupil diameter ratio

   Pupil diameter in LA divided by pupil diameter in OLA

3. Blink rate

Blinking is a high speed closure movement of the eyelids of short duration [78]. The blink rate is number of blinking per minute.

Table 6.3: Examples of pre-test questions for lesson 1 (in Japanses).

Content 1 pre-test	
Q#	Content
1.	How many vowel sounds are there in the Thai language? a. 2 vowels b. 3 vowels c. 4 vowels d. 5 vowels e. I do not know
2.	Which one is the correct pronunciation of a? a. a b. aa c. o d. oo e. I do not know
3.	How many final consonant sounds are there in the Thai language? a. 2 b. 4 c. 6 d. 8 e. I do not know
4.	Which one is the final sound of the Thai word “hot”? a. -t b. -n c. -l d. -m e. I do not know
5.	How many tones are there in the Thai language? a. 2 tones b. 3 tones c. 4 tones d. 5 tones e. I do not know

Table 6.4: Items of Likert scale questionnaire

No.	Questions	Style	Evaluation
Q1	During you learning, you felt interested.	A and B	Learners' emotion
Q2	During you learning, you felt bored.	A and B	
Q3	Cautions appeared appropriately.	B	Caution
Q4	Cautions were effective to promote learning.	B	
Q5	Cautions were irritating.	B	
Q6	Flash was effective to continue learning	B	
Q7	Flash was annoying	B	

Based on the previous experiment in chapter 5, I found eye tracking indexes, namely fixation duration ratio and pupil diameter ratio are useful for learners' emotion analysis.

However, the system cannot use fixation duration ratio and pupil diameter ratio to detect learners' emotion in real-time. Therefore, I characterized two cases of detecting the learners' emotion in real-time, applying fixation duration in case 1 and pupil diameter in case 2 respectively as shown in Table 6.5. The details are described as below:

1. Case 1

   I used fixation duration in OLA to measure and analyze by the system. The procedures are described as below:

   - The system set up Threshold 1

     Threshold 1 is the value of fixation duration in OLA that is set to be 600 msec.

     Threshold 1 = 600 msec

   - The value of fixation duration in OLA was checked by the system.
   - Then, the system checked case 1 by fixation duration in OLA using the following condition 1 in which the caution will be shown in the system when fixation duration in OLA is greater than Threshold 1.

     Condition 1 is defined as below:

- If fixation duration in OLA > Threshold 1, the system will show caution no.1.

2. Case 2

I used pupil diameter in LA to measured and analyzed by the system. The procedure are described as below:

- The system set up Threshold 2

  Threshold 2 was set up according to the following equation

$$\text{Threshold 2} = \frac{\text{Pupil diameter calibration}}{0.98}$$

- The value of pupil diameter in LA was checked by the system.
- Then, the system checked case 2 by pupil diameter in LA using the following condition 2 in which the caution will be shown in the system when pupil diameter in LA is greater than Threshold 2.

  Condition 2 is defined as below:

  - If pupil diameter in LA > Threshold 2, the system will show caution no.2.

Table 6.5: Case of this system

Items	Case 1	Case 2
Eye metric indexes	Fixation duration	Pupil diameter
Areas	OLA	LA
Threshold	= 600 msec	Pupil diameter / 0.98
Condition	> Threshold 1	> Threshold 2
Caution	Cartoon animation followed by eye movement with sound in OLA (No.1 in Table 6.2)	Flash with sound in LA (No.2 in Table 6.2)
Purpose of caution	Back to the position	Back to concentrate

Real-time feedback

Figure 6.7 shows procedures related to real-time feedback from eye tracking. The procedures are described below:

1. The system calibrated the learner eye positions
2. The system measured their pupil diameter.
3. The system calculated threshold (TH). By checking the following 2 cases. The details are already described in Table 6.5.

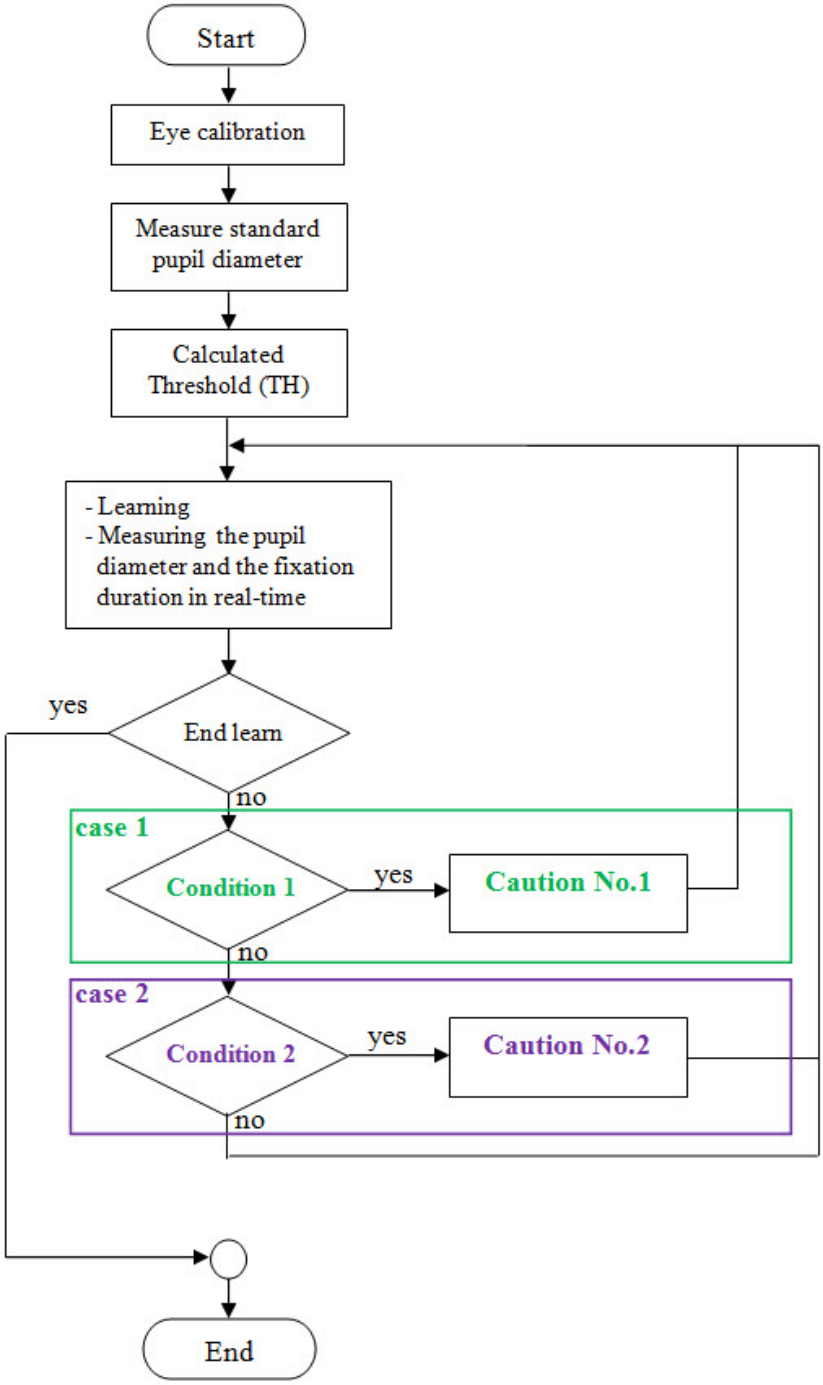


Figure 6.7: Procedure related to real-time feedback of eye tracking

6.2.3 Participants

I conducted the experiments by equally dividing ten Japanese students into two groups, and performed learning tasks using different learning methods. Conditions of participants are described as follows:

1. Participants are not wearing glasses.
2. Participants never learn Thai language before.
3. Participants are male Japanese between 21-23 years old.

6.2.4 Experiment Procedure

Figure 6.8 shows the experiment scene. The procedures are described below:

1. The system calibrated the learner eye positions (Figure 6.7).
2. Learners completed the pre-test 1.
3. They learned content 1 in style A or B.
4. They completed the post-test 1.
5. They answered the questionnaire 1.
6. They took a 5-minute break.
7. They completed the pre-test 2.
8. They learned content 2 in styles A or B.
9. They completed the post-test 2.
10. They answered the questionnaire 1

Their eye movement was measured in real-time by eye tracking while they were learning contents 1 and 2 (procedure numbers 3 and 8). The details are already described in next part (real-time feedback).

Figure 6.8: Experiment scene

6.2.5 Experimental Results

a) Pre-test and post-test results

The results of pre and post-test scores from the two groups of participants are summarized in Table 6.6. According to the statistical analysis results, there is not sufficient evidence to support that the mean difference between the two groups are distinct.

Table 6.6: Pre-test and post-test results

Groups	Pre-test		Post-test		Differences between Post-Pre tests		t-test	
	Mean	SD.	Mean	SD.	Mean	SD.	t	P-Value
"with caution"	1.6	1.64	7.2	1.39	5.6	1.71	1.56	.83
"without caution"	2.3	1.76	8.1	1.52	5.8	2.34		

*+ p<0.1; * p<0.05; ** p<0.01*

The numbers of answer choice (e.) "I do not know" are shown in (Table 6.7):

Content 1: The numbers of answer choice (e.) of seven participants are higher than median (5). This result indicates that they have never learned the Thai language before. However, the numbers of answer choice (e.) of another three participants are lower than median (5) which indicates that they have learned the Thai language before.

Content 2: The numbers of answer choice (e.) of seven participants are higher than median (5) which indicates that they have never learned the Thai language before.

Table 6.7: Number of answer choice (e.) "I do not know" in questionaaire results

	Number of answer choice (e.) "I do not know"									
User	U01	U02	U03	U04	U05	U11	U13	U14	U15	U16
Number of answer choice (e.) of content 1	7	4	4	6	6	4	5	7	10	6
Number of answer choice (e.) of content 2	10	6	9	9	10	9	5	9	9	10

b) Questionnaire results

In this experiment, I found out that one participant watched the caution, cartoon animation with sound in OLA when condition 1 was detected by the system, and another one watched the caution, flash and sound in LA when condition 2 was detected by the system. However, another eight participants did not watched cautions, which was corresponding to the result of questionnaires as shown in Table 6.8.

Table 6.8: Caution results

Numbers of Participants	Caution appear	Caution
1	1 time	No.1 in Table 6.2
1	6 time	No.2 in Table 6.2
8	No	-

This experimental result was not satisfied because cautions did not appear for most participants. Therefore, thresholds should be reconsidered.

c) Eye metric results

Table 6.9 shows results of fixation duration length in OLA of each user. The details are described as below:

- The column “range of time interval (msec)” shows fixation duration length in OLA that were divided into seven ranges; 1) <100, 2) 101-200, 3) 201-300, 4) 301-400, 5) 401-500, 6) 501-600, and 7) >600.
- The column “number of fixation duration length in OLA of each user” shows number of fixation duration length in OLA of range of time interval for each user.
- The column “number total” shows number of total fixation duration length in OLA.
- The column “accumulated ratio (%)” shows percentage of accumulated number of fixation duration length in OLA”

Table 6.10 shows results of fixation duration length in OLA of each range of fixation duration length in OLA. The details are described as below:

- The column “fixation duration length (msec)” shows fixation duration length in OLA that was divided into six ranges; 1) >100, 2) >200, 3) >300, 4) >400, 5) >500, and 6) >600.
- The column “number of total” shows number of total fixation duration length in OLA
- The column “accumulated ratio (%)” shows percentage of accumulated number of fixation duration length in OLA”

Figure 6.9 shows the graph of fixation duration length in OLA of participant U01. Figure 6.10 shows the graph of fixation duration length in OLA of participant U13.

Table 6.9: Results of fixation duration length in OLA of each user

Range of time interval (msec)	Number of fixation duration length in OLA of each user										Number Total	Accumulated ratio (%)
	U01	U02	U03	U04	U05	U11	U13	U14	U15	U16		
<100	19	6	3	11	0	38	8	7	27	66	185	45.12
101 - 200	7	0	1	2	2	15	28	1	10	27	93	22.68
201 - 300	2	2	0	3	0	18	6	3	7	16	57	13.90
301 - 400	2	0	0	0	1	12	1	1	2	9	28	6.83
401 - 500	2	0	1	0	0	9	0	0	0	4	16	3.90
501 - 600	1	1	0	0	0	2	2	0	2	0	8	1.95
>600	2	3	0	0	2	11	1	0	3	1	23	5.61
										Total	410	100

Table 6.10: Results of fixation duration length in OLA

Fixation duration length (msec)	Number Total	Accumulated ratio (%)
>100	225	54.88
>200	132	32.20
>300	75	18.29
>400	47	11.46
>500	31	7.56
>600	23	5.61

According to the results, I found the followings:

- Total count time of fixation duration in OLA is 28 for the range of time interval at 301 - 400 msec (Table 6.9).
- Total count time in percentage (%) of fixation duration in OLA is 18.29% for the range more than 300 msec (Table 6.10).

I found that learners spent more than 300 msec in OLA after they learned. For example, participants U01 and U13's performances are shown as below:

- Participant U01

  There were several times that he spent more than 300 msec in OLA, after he learned for 71 sec as shown in Figure 6.10.
- Participant U13

  There were several times that he spent more than 300 msec in OLA, after he learned for 15377 sec as shown in Figure 6.11.

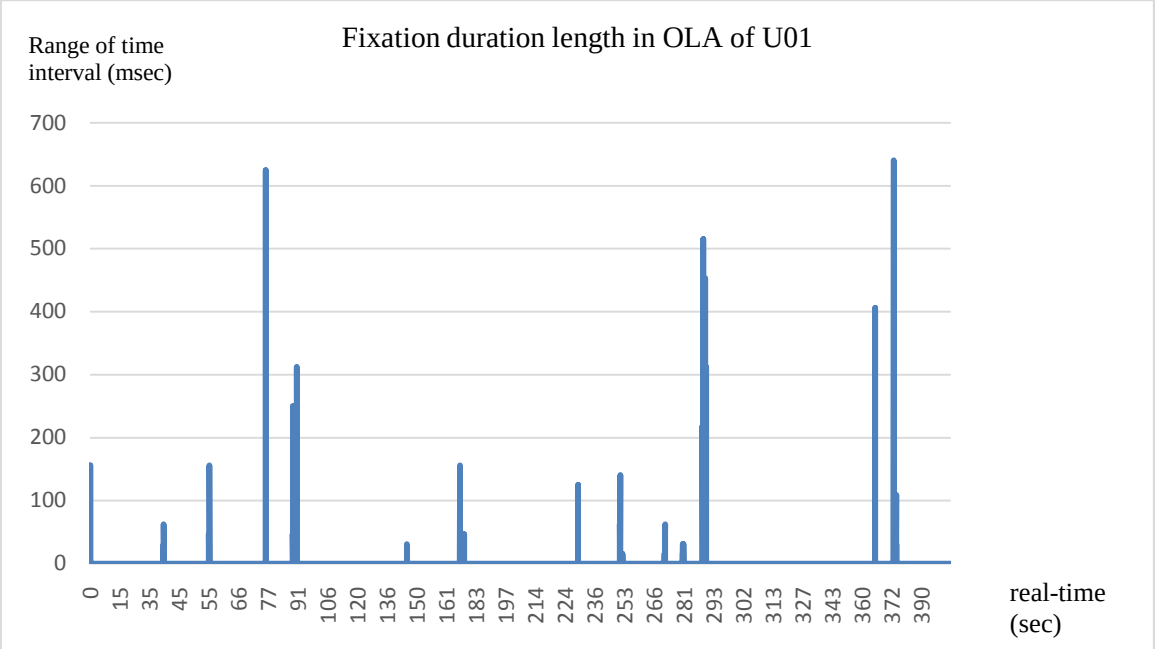


Figure **6.9**: Example of fixation duration length in OLA of participant U01

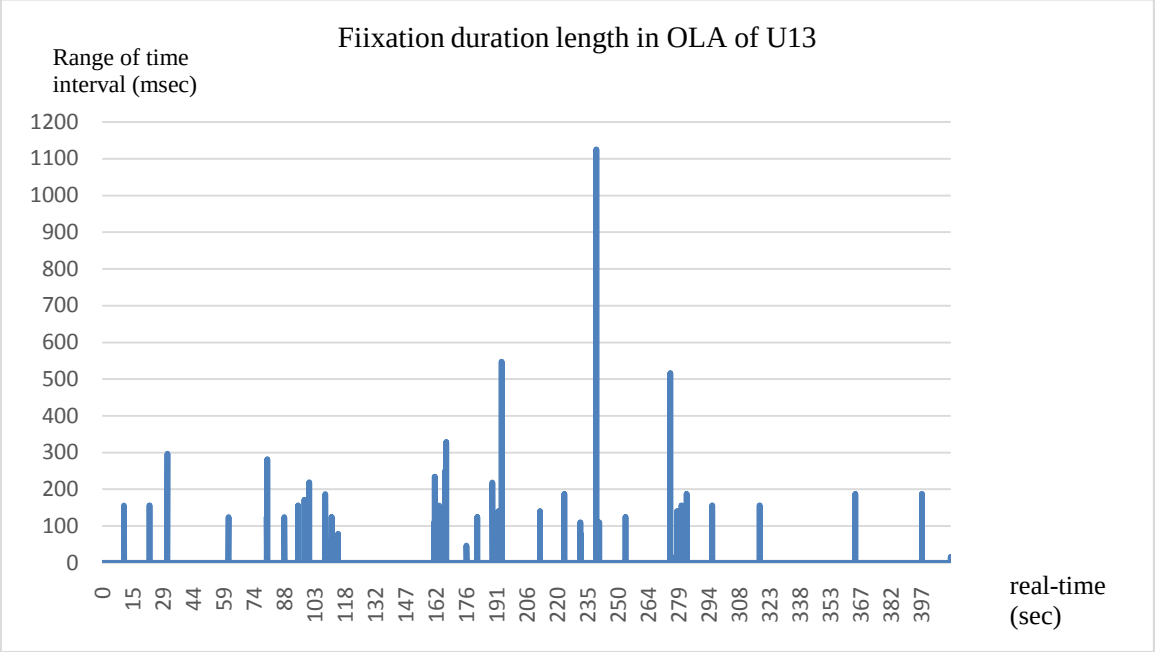


Figure 6.10: Example of fixation duration length in OLA of participant U13

The result is analyzed as follows. The fixation duration was chosen at 300 msec, count total at 20%. If the learners paid attention in OLA at equal or higher value, the cautions appeared too frequently which might annoy the learners. Another factor is the appropriate time interval between the beginning and middle of learning time. The value of 300 msec also counted from the beginning time until the time that the learner got bored, making it an appropriate value to use in the system. In contrast, the setting at values of 100 or 200 msec, detected eye movement and showed cautions every time the learner looked into OLA which was too frequent and could easily annoy the learners. Therefore, fixation duration (Threshold 1) was reduced from 600 msec to 300 msec.

Table 6.11 shows results of ratio of duration of larger pupil diameter in LA of each user for each threshold. The details are described as below:

- The column “pupil diameter threshold” shows pupil diameter threshold of which the value was divided into eight thresholds; 1) 0.980, 2) 0.971, 3) 0.962, 4) 0.952, 5) 0.943, 6) 0.935, 7) 0.925, and 8) 0.917.

- The column “ratio of duration of larger pupil diameter in LA of each user” shows duration of larger pupil diameter in LA of each user. Each threshold was divided by total time of learning (msec).
- The column “average” shows average of ratio of duration from larger pupil diameter in LA for each threshold.

Table 6.12 shows results of number of duration of larger pupil diameter in LA for each threshold. The details are described as below:

- The column “pupil diameter threshold” shows pupil diameter threshold of which the value was divided into eight thresholds; 1) 0.980, 2) 0.971, 3) 0.962, 4) 0.952, 5) 0.943, 6) 0.935, 7) 0.925, and 8) 0.917.
- The column “number of duration of larger of pupil diameter in LA of each user” shows the total count from pupil diameter in LA for each threshold.
- The column “Number total” shows total of number of duration of larger pupil diameter in LA for each threshold.

Figure 6.11 shows the graph of participant U02’s duration of larger pupil diameter in LA of each threshold. Figure 6.12 shows that of participant U15.

Table 6.11: Results of ratio of duration of larger pupil diameter in LA of each user

pupil diameter Threshold	Ratio of duration of larger pupil diameter in LA of each user (%)										Average (%)
	U01	U02	U03	U04	U05	U11	U13	U14	U15	U16	
0.980	25.06	34.99	61.34	47.06	30.14	30.70	38.95	17.25	46.18	53.59	38.53
0.971	19.81	28.92	57.68	36.75	14.64	24.27	30.68	13.05	37.39	51.17	31.43
0.962	17.18	22.81	53.10	26.86	11.80	20.47	23.48	10.38	28.63	49.08	26.38
0.952	12.92	18.38	46.09	18.49	9.87	15.17	16.94	7.48	22.71	45.87	21.39
0.943	9.27	15.20	36.37	12.00	7.26	8.44	11.77	5.63	17.34	43.93	16.72
0.935	6.45	11.99	21.54	7.30	5.60	7.59	7.99	3.37	12.71	41.65	12.62
0.925	4.62	9.55	4.19	3.64	3.86	7.33	4.32	1.99	8.63	38.49	8.66
0.917	2.19	8.13	1.08	2.11	0.57	6.63	1.61	0.22	5.83	33.74	6.21

Table 6.12: Results of number of duration of larger pupil diameter in LA

pupil diameter Threshold	Number of duration of larger pupil diameter in LA of each user										Number total
	U01	U02	U03	U04	U05	U11	U13	U14	U15	U16	
0.980	20	32	13	32	7	17	38	23	39	19	240
0.971	15	27	18	33	3	14	28	21	45	20	224
0.962	15	22	19	24	2	11	28	11	33	21	186
0.952	17	17	22	22	2	11	30	15	21	22	179
0.943	10	19	21	21	2	3	18	12	20	20	146
0.935	14	16	18	14	2	2	14	12	20	18	130
0.925	7	12	3	9	2	2	12	12	16	25	100
0.917	5	7	1	6	1	2	4	2	8	23	59

According to the results, I found the following:

- The average of ratio of duration from larger pupil diameter in LA is 8.66 % for pupil diameter threshold of 0.925 (Table 6.11).
- The average of ratio of duration from larger pupil diameter in LA shows an increasing tendency of threshold ranging from 0.917 to 0.98 (Table 6.11).
- The total number of duration of larger pupil diameter in LA shows an increasing tendency of threshold ranging from 0.917 to 0.98 (Table 6.12).

I found that their pupil diameter was at 0.925 in OLA after they learned. For example, participants U02 and U15's results are shown as below:

- Participant U02

  His pupil diameter ratio in LA is 9.55 % for threshold 0.925. (Figure 6.11)
- Participant U15

  His pupil diameter ratio in LA is 8.63 % for threshold 0.925 (Figure 6.12)

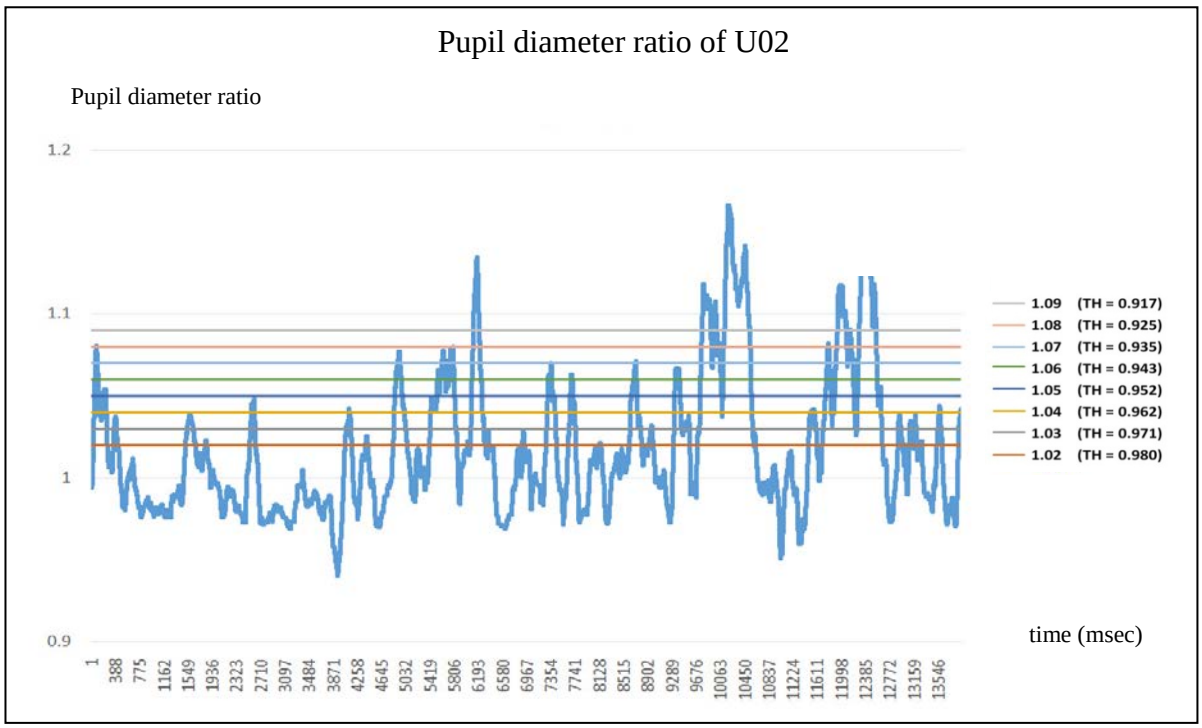


Figure 6.11: Example of paupil dimeter ratio of participant U02

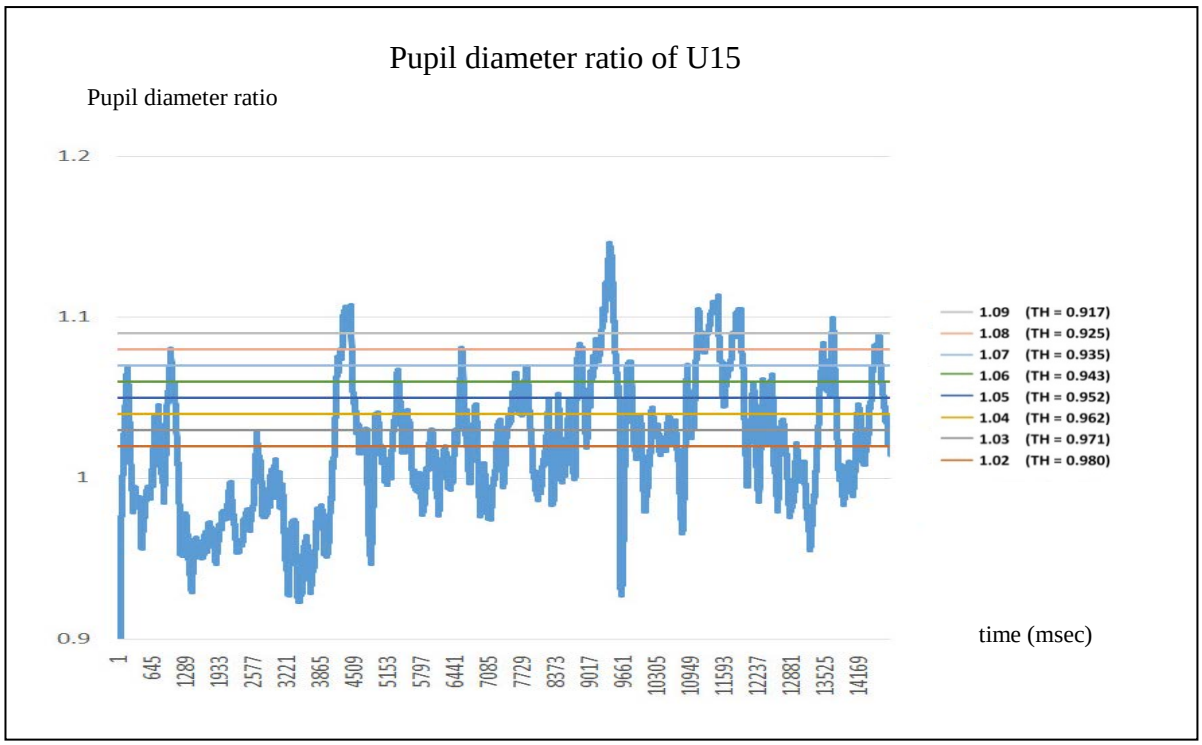


Figure 6.12: Example of paupil dimeter ratio of participant U15

The result is analyzed as follows. The threshold of pupil diameter was chosen at 0.925. If the learners paid attention in LA at equal to or higher than the threshold, the cautions appeared too frequently which might annoy the learners. The appropriateness of time interval between the beginning and middle of learning time is the main reason to choose this value. The threshold at 0.925 also counted from the beginning time until the time that the learner got bored, making it an appropriate value to use in the system. The setting at the threshold value of more than 0.925 detected eye movement and showed cautions every time the learner looked into OLA which was too frequent and could easily annoy the learners. Therefore, fixation duration (Threshold 2) was reduced from 0.98 to 0.925.

During the experiment, two out of ten participants watched cautions; however, the other eight participants did not, which did not correspond with conditions 1 and 2. In addition, questionnaire results show they felt interested during the learning session. This experiment failed. Therefore, it can be considered that the cautions in this system did not work, caution signs should appear more often, and content did not make learner bored. Therefore, I asked some questions to figure out appropriate cautions and boring content.

First, I divided caution signs into four types based on Table 6.2 as a 1) caution A: pop up and sound, 2) caution B: flash and sound, 3) caution C: only sound, and 4) caution D: cartoon animation and sound as show in Table 6.13.

Table 6.13: Detail of each caution

Caution	Detail
A	pop up with sound
B	flash with sound
C	only sound
D	cartoon animation with sound

Then, I added two sets of questionnaire to ask the participants as shown in Tables 6.14 and 6.15:

1. Questionnaires asked two questions related to cautions as shown in Table 6.14

Table 6.14: Questionnaire relates to cautions

No.	Questions
Q1	Please rate the caution in order of suitability as a warning. Reasons
Q2	Please rate the caution in order of irritation. Reasons

2. Questionnaires asked one question related to contents as shown in Table 6.15.

Table 6.15: Questionnaire relates to contents

No.	Questions
Q1	Please give your ideas or suggestions to make the content more boring

Based on the answers, I found the following results:

1. Questionnaire for caution appropriateness

This questionnaire provided two questions that related to appropriate caution. Table 6.16 shows results of the effectiveness of various types of caution.

Table 6.16: Results of the effectiveness of various types of caution

Participants	Rating of Q1	Rating of Q2
U02	D＞B＞C＞A	A＞C＞B＞D
U03	A＞D＞B＞C	A＞D＞B＞C
U04	D＞C＞A＞B	A＞B＞D＞C

According to the results, I found the followings:

- Caution D: cartoon animation and sound are appropriate.
- Caution A: pop up and sound are irritating

The participants gave suggestions for this e-learning system as following:

- If caution A: pop up and sound is changed to yellow blink and sound, it will urge them to move their eye back and concentrate on learning again.

- If the system gives only sound, the learners cannot move their eye back or concentrate on learning.
- If system shows cautions in LA, the learners move their eye back and continue learning.

2. The questionnaire for content appropriateness

   This questionnaire is open-question type (Table 6.15). They participants gave the suggestions on how to make the content boring as following:

   - The content should be changed into black and white colors.
   - It should be only textual content.
   - Voices of Thai native speakers should be used more frequently.

From these results, I modified the system according the comments. Two parts of the system are modified as follows:

1) Cautions to be used are shown below:
   - Cartoon animation in LA with sound
   - Yellow blink in LA with sound.
2) Content to be used are shown in below:
   - Black and write colors
   - Only text
   - More frequent voices of Thai native speakers

6.2.6 Discussion of Experiment I

In this experiment, I found that one participant watched the caution presented in the form of cartoon animation with sound in OLA when condition 1 was detected by the system, and another participant watched the caution presented by flash and sound in LA when condition 2 was detected by the system. However, another eight participants did not watch cautions, which did not correspond with the result of the questionnaires. According to the independent t-test of pre-test and post-test results, there is no difference in the results of

the testes between the group of participants learning with cautions and the other group learning without cautions.

This can be considered as following:

- Caution in this system did work.
- Caution signs should appear more often.

Therefore, I used other two sets of questionnaire with additional questions in order to find appropriate cautions and boring content. The results were that two caution signs of cartoon animation with sound in LA, and yellow blink with sound in LA drew the learners' concentration and motivate the learners back to learning. In term of the content, black and white colors, only text and more frequent voices of Thai speakers could make the content more boring.

Referring to the results of eye metric, I found that the value of eye tracking indexes: fixation duration (Threshold 1) at 300 msec and pupil diameter (Threshold 2) at 0.925, are appropriate tools to detect learners' boredom.

6.3 Experiment II

6.3.1 Objective of Experiment

Conducting this experiment, I modified two cautions and value for eye tracking indexes to detect learners' boredom from experiment I. The main objective is to construct a prototype of e-learning system with real-time feedback to escape boredom.

6.3.2 Tools and Materails

In this experiment, I modified the content and cautions based on results of experiment I as following:

1. Content

The two contents used in experiment were combined into one 16 pages content. Also, the content was designed to consist of text only and the colors were changed into black and write.

2. Cautions

I used caution strategy and caution methods.

- In term of caution methods:

  I modified two caution signs to be shown in LA, namely (1a) cartoon animation with sound (Figure 6.13) and (2a) yellow blink with sound (Figure 6.14).

- In term of caution strategy:

  I set up two values which are (1b) fixation duration in OLA (Threshold 1) to move eye back to the last position by using caution method (1a) and (2b) pupil diameter in LA (Threshold 2) to move eye back to concentrate by using caution method (2a).

Figure 6.13: Interface design for caution type 1a (cartoon animation in LA with sound)

Figure 6.14: Interface design for caution type 2a (yellow blink in LA with sound)

The system for the experiment is designed into two groups as: 1) “with cautions” and 2) “without cautions” as shown in Figure 6.15.

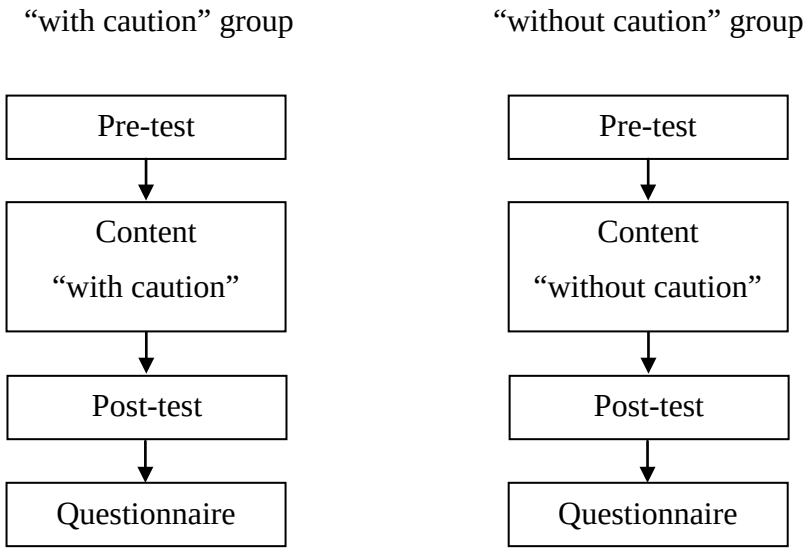


Figure 6.16: Process of the learning system

I modified pre-test and post-test only ten questions based on Experiment I (Table 6.3). Each question is one point, and the highest score is ten.

The questionnaire of each group consists of two parts that are related to measured emotion (Table 6.17). The details are described as below:

- Part I has two sections: one asking about the participants’ feeling during learning the Thai language and the other asking for their opinion.
- Part II has two sections: one asking about the participants’ feeling during learning the Thai language and the other asking for their opinion.

I used question Q1 and Q2 that asked the learners in without caution group and questions Q1-Q6 that asked the learners in with caution group.

Table 6.17: Item of likert scale questionnaire

Part	No.	Question
I	Q1	During the learning session, you felt interested. Reason:
	Q2	During the learning session, you felt bored. Reason:
II	Q3	The learner likes this e-learning system in which cautions are provided. Reason:
	Q4	This e-learning system is satisfying because it has the cautions to remind you to concentrate more on learning Reason:
	Q5	This e-learning system is annoying because it has the cautions that interrupt your learning Reason:
	Q6	Suggestions for this e-learning system for improvement (Please feel free to write it):

According to the judgment in Experiment I, the most appropriate value to be used for eye tracking indexes and cautions are chosen as follow:

1. Eye tracking indexes

   I set two thresholds for eye tracking indexes that are appropriate tools to detect learners' boredom.

   1.1 Fixation duration

   I set threshold 1 at 300 msec.

   1.2 Pupil diameter

   I set threshold 2 at 0.925.

2. Caution

   System will show cautions to the learners to make them concentrate and carry on learning, when they feel bored as following:

   2.1 Cartoon animation with sound will appear at the last position their eye movement focuses in LA when fixation duration corresponds to condition 1.

   2.2 Yellow blink with sound will appear at the last position their eye movement focuses in LA when pupil diameter corresponds to condition 2.

6.3.3 Participants

I conducted the experiments by equally dividing ten Japanese students into two groups, and perform learning tasks using different learning methods. The conditions of participants are the same as those in section 6.2.3.

6.3.4 Experiment Procedure

The detail of this part is the same as that in section 6.2.4.

6.3.5 Experimental Results

In this section, I obtained the following results by comparing the questionnaire results and eye tracking results.

a) Pre-test and post-test results

The results of pre-test and post-test scores of the participants learning “with caution” and those of the participants learning “without caution” are summarized in Table 6.18. The statistical analysis indicated that the mean difference between the post-test and pre-test results of the “with caution” group (3.80) was significantly lower than “without caution” group (5.80) ($p<0.01$)

Table 6.18: Pre-test and post-test results.

Groups	Pre-test		Post-test		Differences between Post-Pre tests		t-test	
	Mean	SD.	Mean	SD.	Mean	SD.	t	P-Value
“with caution”	1.6	1.14	7.4	0.54	5.8	1.09	3.78	.005**
“without caution”	1.0	1.17	4.8	1.78	3.8	0.44		

+ $p<0.1$; * $p<0.05$; ** $p<0.01$

The numbers of answer choice (e.) “I do not know” are shown in Table 6.19. The numbers of answer choice (e.) of seven participants are higher than median score (5). The results indicate that those participants did not learn Thai language before.

Table 6.19: Numbers of answer choice (e.) “I do not know” results

	Number of answer choice (e.) “I do not know”									
User	U01	U02	U03	U04	U05	U11	U13	U14	U15	U16
Number	10	10	9	6	10	10	8	9	7	8

b) Questionnaire results

Table 6.20 contains the questionnaire results. The following are the details:

- “With caution” groups

The mean scores of question Q1 (2.8) are lower than the mean scores of question Q2 (3.2). The interest scores from two out of five participants are higher than boredom scores. The interest scores from the other two out of five participants are lower than boredom scores. The interest score from one out of five participants is equal to the boredom score. These results did not clarify whether the learners felt interested or bored during the learning session. I focused on participants U09 and U10 because their boredom scores were higher than their interest scores. They gave opinions in the questionnaire as shown in Table 6.21.

- “Without caution” groups

The mean scores of question Q1 (3.8) are higher than the mean scores of question Q2 (2.2). The interest scores from four out of five participants are higher than boredom scores. Therefore, these results indicated the learners’ interest while learning.

Table 6.20: Questionnaire results

Groups	User	Question				
		Q1	Q2	Q3	Q4	Q5
with caution	U08	3	3	4	4	3
	U09	2	4	2	2	4
	U10	2	5	3	2	5
	U11	4	2	4	5	1
	U12	3	2	3	4	2
	Mean	2.8	3.2	3.2	3.4	3.0
	SD	0.84	1.31	0.84	1.34	1.58
without caution	U01	2	3			
	U02	4	2			
	U03	5	1			
	U04	4	2	-	-	-
	U06	4	3			
	Mean	3.8	2.2			
	SD	1.09	0.84			

Table 6.21: The opinion questionnaire results

Question	Detail of opinion questionnaire (Questionnaire scores)
Q1	• Sound and smoothing time was unpleasant. (2)
Q2	• When I looked outside, sound and caution appeared. I tried to look only inside, and I got bored. (4) • I was not motivated to learn the Thai language. (5)
Q3	• I could not concentrate on the lesson because I kept focusing on when the sound would be played instead. (3)
Q4	• I wanted to study quietly. (2) • The sound was irritating. (2)
Q5	• I could not concentrate on the lesson because I kept focusing on when the sound would be played instead. (4) • I was annoyed when I heard the sound. (4) • I minded the movement of person who was reflected on the monitor. (5)

From the opinions given in to the questionnaire, I found that the learners did not concentrate to continue learning because the sound interrupted them. Therefore, the sound for caution needs to be improved.

c) Eye metric results

In this section, I obtained the following results by comparing eye movement results.

Table 6.22 shows results of fixation duration of “with caution” and “without caution” groups. This results show only participants who move their eye into OLA more than 300 msec. The following are the details:

- The “count” column shows the number of eye movement away from LA to OLA.
- The “duration” column shows a period of time of eye movement away from and back to LA.

Table 6.23 shows the number of duration of larger pupil diameter of the participants in both groups. One time duration of eye diameter is counted from when the value of pupil diameter rises over 0.925 to when it lowers below 0.925. This results only show the time duration number of the users whose pupil diameter corresponds with condition 2. The following are the details:

- The “count” column shows the number of time that their pupil diameter corresponds to condition 2.
- The “duration” column shows a period of time since their pupil diameter corresponds to condition 2.

Table 6.24 shows results of t-test comparisons of fixation duration between “with caution” and “without caution” groups. Table 6.25 shows results of t-test comparisons of the number of pupil diameter’s time duration of “with caution” and “without caution” groups.

From Tables 6.22 - 6.25, I found the following:

- Fixation duration
    - Mean of fixation duration time of the participants in “with caution” group (413.24 msec) is lower than that of the participants in “without caution” group (2143.35 msec) (Table 6.22)
    - Since the variances of the two groups are not equal, Levene’s Test for

Equality of Variances is used to analyze the significance of variance. According to the statistic analysis results, the value of variance of fixation duration of “withcaution” group (85327.64) is significantly lower than that of “without caution” group (2364950.32) ($p<.01$) (Tables 6.22 and 6.23).

- The fixation duration of the participants in “with caution” group ($M = 413.24$, $SD = 292.11$) is significantly lower than that of “without caution” group ($M = 2143.35$, $SD = 1537.84$) ($p < .1$) (Table 6.25)
- Fixation duration in OLA of “with caution” is lower than “without caution” groups. Therefore, caution is effective draw the learners’ attention back to the lesson.

- Pupil diameter
  - Mean of duration of larger pupil diameter of the participants in “with caution” group (222.19 msec) is lower than that of the participants in “without caution” group (1154.74 msec) (Table 6.23).
  - The number of duration of larger pupil diameter of the participants in “with caution” group ($M = 222.19$, $SD = 378.96$) is significantly lower than that the “without caution” group ($M = 1154.74$, $SD = 694.747$) ($p < .01$) (Table 6.25).
  - Duration of larger pupil diameter in LA of “with caution” group is lower than that of “without caution” groups. Therefore, caution is effective to help the participants continue learning.

Table 6.22: Results of fixation duration of the participants in “with caution” and “without caution” groups

“with caution” group			“without caution” group		
U08	1	184.60	U01	1	80.00
	2	260.70	U02	1	3248.00
	3	372.60	U03	1	1861.90
	4	531.80	U06	1	3383.50
	5	196.80		Total	8573.40
U09	1	178.40		Mean	2143.35
	2	115.60		SD	1537.84
	3	182.20		Variance	2364950.32
	4	501.06			
	5	243.80			
	6	299.10			
	7	462.40			
	8	479.07			
	9	233.80			
	10	150.15			
	11	416.01			
	12	854.91			
	13	54.04			
	14	734.03			
	15	367.28			
	16	991.52			
	17	85.60			
	18	372.00			
	19	135.00			
	20	127.49			
	21	390.00			
U10	1	282.40			
	2	267.80			
	3	696.70			
	4	810.90			
	5	127.31			
	6	1064.34			
	7	306.99			
	8	899.30			
	9	1144.51			
U11	1	238.00			
	2	202.79			
	3	558.40			
	4	587.40			
U12	1	20.71			
	2	251.77			
	3	575.50			
	4	814.64			
	Total	17769.42			
	Mean	413.24			
	SD	292.11			
	Variance	85327.64			

Table 6.23: Results of the number of duration of larger pupil diameter of the participants in "with caution" and "without caution" groups

"with caution" group			"without caution" group		
User	Count	Duration (msec)	User	Count	Duration (msec)
U09	1	158.74	U02	1	26.04
	2	146.16	U04	1	1875.12
U10	1	1281.90		2	1056.58
	2	153.14		3	1408.80
	3	229.05		4	1407.17
U12	1	26.04		Total	5773.71
	2	127.00		Mean	1154.74
	3	33.10		SD	694.77
	4	45.87		Variance	482704.08
	5	20.89			
	Total	2221.89			
	Mean	222.19			
	SD	378.96			
	Variance	143612.01			

Table 6.24: T-test comparisons of fixation duration of the participants in "with caution" and "without caution" groups

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (1-tailed)
Fixation duration	Equal variances assumed	52.131	*.000***	6.794	45	.000**
	Equal variances not assumed			2.246	3.020	*.055*$^{+}$

*+ p<0.1; * p<0.05; ** p<0.01*

Table 6.25: T-test comparisons of duration of larger pupil diameter of the participants in "with caution" and "without caution" groups

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (1-tailed)
Pupil diameter	Equal variances assumed	2.132	.168	3.419	13	*.0025***
	Equal variances not assumed			2.800	5.227	.036*

*+ p<0.1; * p<0.05; ** p<0.01*

Table 6.26 shows results of blink rate of each area (All area, LA area and OLA area) of the participants in "with caution" and "without caution" groups. The "blink rate" column shows the number of blinks per minute.

Table 6.27 shows t-test comparisons of blink rate of each area between participants in the "with caution" and "without caution" groups.

From Tables 6.26 - 6.27, I found the following:

- The blink rate in All areas of the participants in "with caution" group (M = 18.01, SD = 9.39) is significantly lower than that of "without caution" group (M = 41.15, SD = 18.74) ($p < .05$).
- The blink rate in LA of the participants in "with caution" group (M = 17.82, SD = 9.50) is significantly lower than that of "without caution" group (M = 41.16, SD = 18.73) ($p < .05$).
- The blink rate in OLA of the participants has no significant difference between "with caution" and "without caution" groups.

The blink rate in all area and LA of "with caution" group is lower than "without caution" group. On the other hand, blink rate in OLA is not significant between the two groups. Negative emotional states that resulted in poor performance have been related to increase in blinking [78, 79]. Therefore, blink rate can indicate that learner in "without

caution" group had more negative emotion than those in "with caution" group did because cautions made learners concentrate on learning when they felt bored.

Table 6.26: Results of the blink rate of each area of the participants in "with caution" and "without caution" groups (number of blinks/min.)

"With caution" group				"Without caution" group			
User	Blink rate in of each area			User	Blink rate of each area		
	ALL	LA	OLA		ALL	LA	OLA
1	22.48	22.35	49.34	8	69.81	69.61	104.85
2	8.61	8.61	9.11	9	34.30	34.56	29.43
3	7.56	6.98	22.54	10	33.40	34.15	15.84
4	28.58	28.52	31.27	11	20.37	19.75	37.61
6	22.84	22.65	49.74	12	47.85	47.73	57.17
Mean	18.01	17.82	32.40	Mean	41.15	41.16	48.98
SD.	9.39	9.50	17.53	SD.	18.74	18.73	34.63

Table 6.27: T-test comparisons of blink rate of each area of participants in "with caution" and "without caution" groups

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (1-tailed)
Blink rate in ALL	Equal variances assumed	1.743	.223	-2.468	8	*.0195**
	Equal variances not assumed			-2.468	5.889	*.0245**
Blink rate in LA	Equal variances assumed	1.178	.309	-2.485	8	*.019**
	Equal variances not assumed			-2.485	5.928	*.024**
Blink rate in OLA	Equal variances assumed	1.574	.245	-.955	8	.183
	Equal variances not assumed			-.955	5.922	.188

*+ p<0.1; * p<0.05; ** p<0.01*

6.3.6 Discussion of Experiment II

This experiment is to construct a prototype of e-learning system with real-time feedback to escape boredom. According to Experiment I, the most appropriate value to be used for caution strategy and caution methods in LA are chosen. In term of caution strategy, I set up two values of eye tracking indexes which are (1) fixation duration in OLA (Threshold 1) at 300 msec to move eye back to last eye position and (2) pupil diameter in LA (Threshold 2) at 0.925 to move eye back to concentrate. Threshold 2 is set for individual. These two values are considered to be suitable for detection of learners' boredom and appropriate to be used in this prototype. In term of caution method, I modified two caution signs to be shown in LA, namely (1) cartoon animation with sound and (2) yellow blink with sound. The system will show cautions to the learners to make them concentrate and carry on learning, when they feel bored. The results show that learners did not concentrate to continue learning because the sound interrupted them. Therefore, the sound for caution needed to be improved.

The statistical analysis results, the mean difference between post-test and pre-test results of the participants in "with caution" group (5.80) and those in "without caution" group (3.80) is significant at the 1% level, where the result from the participants in "with caution" group is higher. This results show that the system "with caution" is more effective than that of "without caution" because it can keep the learners away from getting bored during the learning period and can encourage them to learn continuously.

The results from the value of variance of fixation duration "with caution" group and that of "without caution" group is significant at the 1% level, where the participants in "with caution" group had lower value. The result from fixation duration of the participants in "with caution" group and that of "without caution" group is also significant at the 10% level, where the participants in "with caution" group had lower value. Therefore, fixation duration in OLA of "with caution" is lower than that of "without caution" groups. Similarly, the result from pupil diameter of the participants in "with caution" group and that of "without caution" group is also significant at the 1% level, where the participants in

"with caution" group had lower value. Therefore, duration of larger pupil diameter in LA of "with caution" group is lower than that of "without caution" groups.

The result from blink rate in all area of the participants in "with caution" group and that of "without caution" group is significant at the 5% level, where the participants in "with caution" group had lower value. Similarly, the result from blink rate in LA of participants "with caution" group and that of "without caution" group is also significant at the 5% level, where the participants in "with caution" group had lower value. Therefore, blink rate can indicate that the learners in "without caution" group had more negative emotions than those in "with caution" group did because caution make learner concentrate learning when learner felt bored. These results can confirm that caution is effective to escape boring.

This e-learning system with real-time feedback focusing on escaping boredom has evidence to be applicable for helping learners to reduce their boredom and concentrate on learning continuously.

6.4 Discussion

At the present, there is no research on an e-learning system that focusing on real-time feedback from eye tracking. Therefore, I designed, implemented, and experimentally evaluated a prototype of e-learning system with real-time feedback to help learners escape from boredom. This system is newly initiated in order to enhance the learning efficiency by detecting learners' boredom and giving feedback to last eye position to make them get back to the lesson and carry on learning.

I used caution strategy and caution methods. In term of caution strategy, I set up two values which are (1) fixation duration in OLA (Threshold 1) to move eye back to the last position and (2) pupil diameter in LA (Threshold 2) to move eye back to concentrate. The threshold 2 is set for individual. In term of caution method, I employed two caution signs to be shown in LA, namely (1) cartoon animation with sound and (2) yellow blink with sound.

In real-time e-learning system, I provide appropriate feedbacks to the learners. Caution is a part of annotation system. Annotations can be created manually or automatically. Many researches employed annotation such as cartoon annotation, video annotation, and text annotation to help learner understand the content during a learning session [78, 79]. Caution is usually set from the first in general. However, cautions are generated automatically in real-time based on indexes of eye tracking in this system. According to the experimental results, I found that cautions make learner concentrate on learning, when learner feels bored. Therefore, caution is effective to keep the learners away from boredom and helps them carry on learning. However, this system is a prototype that employed caution to give feedback. According to the questionnaire results, I found that the sound for caution needed improvement or employing another appropriate annotation to give feedback.

In e-learning system research, this system is the new system that can give real-time feedback when detecting a symptom of learners' boredom.

At present, real-time feedback from eye tracking is used in driving system [80, 81, 82], where the feedback caution draws the driver's eyes back to the front. That is not enough for an e-learning system since a learner might not get back to the exact point. Then the caution should draw their attention to the last position from which they were distracted. Consequently, they know exactly where in the lesson they should focus and continue to learn.

From these results, I could confirm the e-learning system with real-time feedback focusing on escaping boredom has potential in helping learners to reduce their boredom and concentrate on learning continuously.

In case the learners are not interested, it can be implied that they might have some mental or health problems such as sickness, instead of boredom. This kind of health problems could lower the performance in learning, for example, the eye movement may not concentrate on the content, blinking becomes less frequent, pupil diameter becomes small until close, which is likely to affect the performance of eye tracker.

Another case is to concern that eyes tracked in learning area (LA) do not always imply that the learners are being interested. Some learners might take long time on a slide in LA, but do not actually concentrate on the slide's content itself. Therefore, including other eye metric indexes to the system will be useful to estimate learners' emotions, for example, long fixation length or eye movement to several areas means that the learners do not concentrate on the content, and larger pupil diameter means the learner is bored.

6.5 Conclusion

I designed, implemented, and experimentally evaluated a prototype of e-learning system with real-time feedback from eye tracking to help learners escape from boredom.

This system is newly initiated in order to enhance the learners' efficiency by detecting learners' boredom from eye metric indexes while learning and giving feedback to the last eye position to make them get back to the lesson and carry on learning. According the difference between post-test and post-test results, I found that caution is effective to escape boring. I employed eye metric indexes, namely fixation duration ratio, pupil diameter ratio, and blink rate to estimated learners' emotions. According to the results, I could confirm this e-learning system with real-time feedback focusing on avoiding the emotion of boredom has potential to be applicable for helping learners to reduce their boredom and concentrate on learning continuously.

Chapter 7

Discussion

Many educational academies apply e-learning technology to let their students to improve their knowledge by themselves. Convenience is one of the major advantages of the e-learning by which the learners are able to study at their own pace without the unyielding time restrictions of traditional learning. However, it also has some disadvantages compared to the traditional learning method. One remarkable method is that the learners' emotion cannot be noticed and the system cannot motivate the learners to hold their concentration throughout the learning period whereas these can be done by instructors in traditional learning system. Since recognition of learners' emotions in e-learning system are very promising. Moreover, improvement of the existing e-learning systems to effectively detect learners' emotion plus useful feedbacks to them has motivated me to conduct this thesis. Thus, I proposed a new e-learning system focusing on emotional aspect using biological signals. In order to achieve the overall research goal, the problem statement was set (Chapter 1) and I conducted the research step by step to address each problem and build each contribution. The procedures of conduction the research are

described as follows:

1. Proposing the design of a new e-learning system focusing on emotional aspects

One main question of the first step to achieve the goal is “How to design a new e-learning system focusing on emotional aspects?” To answer this question, I reviewed the existing researches in e-learning fields. I found that the existing e-learning systems are not intelligent enough because they have no ability to recognize learners’ emotions and cannot support them accordingly. Thus, the new e-learning system was designed to support learners based on their current emotions (Chapter 3). The feature of this system is detecting learners’ emotions while learning. It consists of five modules: learners, instructors, servers, biological signals, and especially an analysis of learners’ emotions. It analyzes learners’ emotions based on Russell’s ‘circumplex model’ which describes the human’s basic emotion space. This new e-learning system was used as a core prototype in the experiments which focused on the evaluation of emotions using biological signals.

2. Evaluation of various emotions to confirm importance of their detection

One main question of the second step is “How to clarify learners’ emotions?” To answer this question, I conducted the first experiment (Chapter 4) to evaluate learners’ emotions while learning using the new e-learning system. In this experiment, the learners studied two different contents through PPT or video and their emotions were evaluated using questionnaire method after they finished learning. The results from comparison between the mean test scores and results of the questionnaire for emotion, those suggest that emotional aspects should be taken into account to design interfaces or contents of an e-learning system at least for the difficult contents. However, using only the questionnaires to evaluate the learners’ emotions might not be enough to analyze their real emotions while learning because the emotion evaluation proceeded after learning. Therefore, measuring learners’ biological signals while learning is a way to improve the precision of the learners’ emotions analysis because the human emotions are clearly reflected through biological signals.

3. Estimation of learners' emotions by eye tracking

One main question of this step is "How to estimate learners' emotions by eye tracking?" To answer this question, I explored three biological signals and presumed that eye tracking is likely to be one of the appropriate biological signals for my e-learning system (Chapter 3) because eye tracking can dynamically capture users' attention [67]. Furthermore, the learners do not need to wear any sensors, so the eye tracking do not disturb them while they are learning. Consequently, the second experiment was conducted (Chapter 5) to estimate learners' emotions using eye tracking. In this experiment, the fixation indexes of eye tracking data depicted as fixation plots was measured to identify the learners' interested point in different parts of the interface. Moreover, the areas of interest (AOI) were measured to identify learners' emotions. I divided various emotions into two emotion groups namely, interest and boredom groups. The experimental results indicated that the positive correlations of fixation duration ratio, number of fixation ratio, and pupil diameter ratio were related to interest. On the other hand, their negative correlations were related to boredom. Hence, these indexes were useful to analyze learners' emotions. Moreover, I gathered data of fixation duration and duration of focused areas and visualized them as fixation plots with AOI. The illustrations is useful to analyze learner emotions. However, this experiment was conducted to analyze only the learners' emotions during learning, without providing appropriate responses to encourage their concentration and address their boredom. As a result, I built an e-learning system with real-time feedback from eye tracking.

4. The integration of new e-learning system with real-time feedback by eye tracking

One main question of the final step to achieve the research goal is "How to integrate the new e-learning system with real-time feedback by emotion detection?". To answer this question, I designed, implemented, and experimentally evaluated a prototype of e-learning system with real-time feedback to help learners escape from boredom. I used caution strategy and caution methods by giving real-time feedback from eye tracking. In term of caution strategy, I set up two values which are (1) fixation duration in OLA (Threshold 1) to move eye back to the last position and (2) pupil diameter in LA

(Threshold 2) to move eye back to concentrate. The threshold 2 is set for an individual. In term of caution method, I employed two caution signs to be shown in LA, namely (1) cartoon animation with sound and (2) yellow blink with sound. According to the results of the third experiment (Chapter 6), I found that the value of fixation duration in OLA, duration of larger pupil diameter in LA, and blink rate show the effectiveness of caution. Therefore, caution is an effective device draws back a learner's attention. I could confirm the integrated e-learning system with real-time feedback focusing on escaping the emotion of boredom has potential for helping learners to reduce their boredom and concentrate on learning continuously.

This system has some limitations that divided into three main problems as follows:

1. Content problem

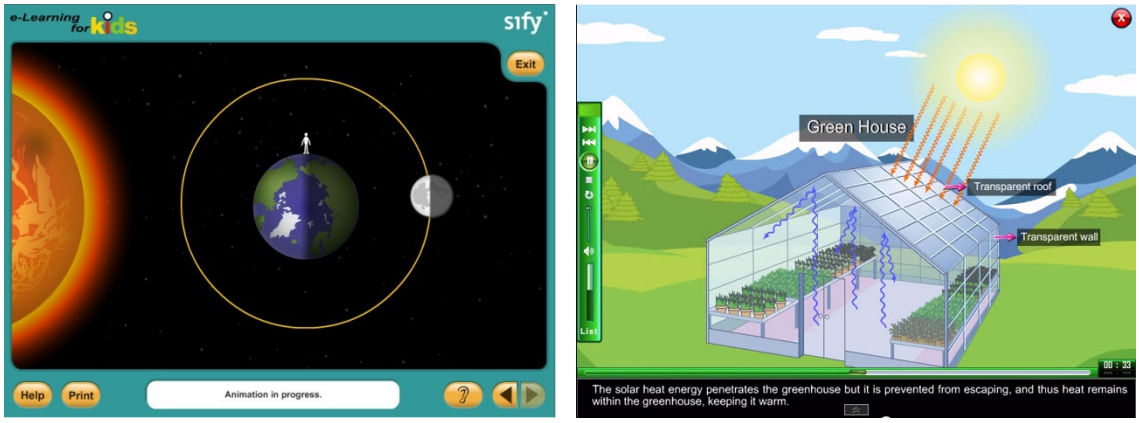
   The system was designed to use the "programming language" or "Thai language" contents which were represented to learners in two separated areas namely, (1) LA and (2) OLA. With this design, the eye movements of learners move from the left to the right side and from the top to the bottom in LA. If they feel bored, their eye will move to OLA. However, if the content changes, the layout of content should also be redesigned which area is appropriate. For example, the content is designed by picture (Figure 7.1 (a)) [83], or movie (Figure 7.1 (b)) [84]. Due to the difference of designs, the eye movements also vary. Therefore, the eye metric is dependency subject to the content.

2. Learner's position problem

   Due to limitation of the applied eye tracker, learners must not move their heads and change their posture during learning until the eye calibration process is done. As a result, they may feel uncomfortable before they start learning the lesson. Staying still in one posture for a long time may cause some kinds of negative emotions such as tiresomeness and exhaustion while they are learning. This limitation should be solved based on each condition of eye tracker.

3. Health or understanding the content problem

The eye movement may become abnormal and unexpected because learners may not either understand at all or be ill. My system may not work appropriately in those cases.



(a) by picture [83] (b) by movie [84]

Figure 7.1: Example of the content design

However, this e-learning system offers some possibilities to be applied in e-learning system field as follows:

1. If the eye pupil diameter becomes large while a learner focuses in LA for a long time, this system determines that the learner gets bored. After that, this system will generally show a caution to the learner to fix boredom. If the learner remains bored, a rest is recommended. Therefore, I recommended employing an appropriate annotation such as “please take a break”. This annotation is to be shown to both the learner and the instructor so that both parties acknowledge the learner’s emotion in real time.
2. Processing or calculating eye metric indexes in real-time takes quite a long time so that the adapted indexes were used as mentioned in Chapter 6. However, according to the result of Chapter 5, eye metric indexes are very useful to estimate learners’ emotions using the system in offline mode. Therefore, one of the

possibilities to make use of them in offline mode is to calculate stored data in certain durations (i.e. 10 sec, 20 sec, 1 min, etc.) and employ other annotations instead of a caution such as “Please have a rest”. Even though the system is not in real-time mode, the eye metric indexes can be used directly.

3. If this system detects learners’ boredom several times, I recommended to employ appropriate interactive annotations or games to help learners overcome boredom. For example, when the system detects learners’ boredom more than five times, the interactive annotations or games should be provided.
4. This system may employ other devices to detect eye movement such as HD webcam or Kinect. These devices are flexible and automatically detect eye movement when learners move their heads and change their posture during learning. Learners may be more comfortable. Therefore, employing this type of devices in place of the existing eye tracker probably improves the performance of the designed system.
5. If the content changes, the eye movement should be reconsidered. For example, the designed system uses two-window display, one window to write code on the left and the other output window on the right which I already mentioned in the discussion part of Chapter 4. I recommended employing the combination of eye metric indexes such as the fixation length, eye position, eye movement, or other indexes to estimate learners’ emotions.

Moreover, the eye metric indexes that I proposed can be applied to other applications such as entertainment, advertising research, packing design and shopping research, interactive TV, computer game, and so on.

According to those results, I have gained several evidences proving that I achieved my research goal. Then I confidently ensure the abilities of the new e-learning system as can estimate learners’ emotion, give feedback to learners, help them escape boredom and motivate them to concentrate on learning continuously.

This system takes emotional aspect into account, and can give real-time feedback to escape boredom that should be in the first priority to be concerned for e-learning system. Moreover, the improvement of increasing learners' interest during learning to encourage them remains future work.

Chapter 8

Conclusion and Future work

8.1 Conclusion

What significantly causes disadvantages in e-learning system is learners' negative emotions. In this thesis, the goal is to design and construct a new e-learning system focusing on the learners' emotion during their learning using biological signals. I found a problem of e-learning system that the learners' emotions are not taken into account and the system cannot motivate the learners to learn when they do not concentrate on learning. I surveyed the e-learning systems and learners' emotions. In this research, I designed a new e-learning system. The conceptual and framework design were described to generate an understanding of the strength of the system. It consists of five modules: learners, instructors, servers, biological signals, and analysis of learner's emotion. The system analyzed learners' emotions based on Russell's 'circumplex model' to describe their emotion space. The proposed e-learning system used LMS as a core for course, together with content, data, and evaluation managements.

I employed sets of questionnaires as a tool to clarify various learners' emotions

during the period of learning. Various emotions are attention, motivation, satisfaction, enjoyment, interest, anxiety, frustration, scare, and tiring. Questionnaire is to screen out only two emotion groups. These two emotion groups are appropriate for using with detection by eye tracking. Experimental results showed that the learners' emotions should be taken into account to design appropriate contents and the interface of the e-learning.

Then, I focused on two emotion groups which are interest and boredom groups. The main finding is that the eye tracking indexes can effectively detect the two emotion groups. I employed one biological signal, eye tracking, which is beneficial to learners' emotions analysis in the e-learning. In addition, fixation indexes such as fixation duration ratio, number of fixation ratio, and pupil diameter ratio were negatively correlated with boredom; therefore, they are candidates for indexes of boredom. Furthermore, these fixation indexes were positively correlated with interest, so that they are candidates for indexes of interest. I gathered raw duration of focused areas and visualized it as fixation plots with AOI. This illustration is useful to analyze learners' emotions.

Moreover, in real-time e-learning system, the most important function is to provide appropriate feedbacks to the learners. I evaluated effectiveness of various types of feedback in term of reducing or getting rid of boredom during learning period. The real-time feedback shows caution at the last eye position to make a learner concentrate and carry on learning when they felt bored. Caution is a part of annotation system. A caution module for giving feedback to the learners is added into the prototype. According the difference between post-test and post-test results, I found that caution is effective to escape boring. I employed eye metric indexes, namely fixation duration, pupil diameter, and blink rate to estimated learners' emotions. The results indicated that this e-learning system with real-time feedback focusing on escaping the emotion of boredom has potential to be applicable for helping learners to reduce their boredom and concentrate on learning continuously.

The designed system has some limitations such as content, learner's position, and health or understanding the content problems. Moreover, this e-learning system offers some possibilities to be applied in e-learning system field. For example, I recommend

employing the appropriate annotations, combination of eye metric indexes, and new eye metric indexes to improve the performance of the designed system. In addition, the eye metric indexes that I proposed can be applied to other applications such as entertainment, advertising research, packaging design and shopping research, interactive TV, computer game, and so on.

8.2 Future work

Since this research addresses some limitations and possibilities, further improvement is recommended. I recommended applying the possibilities of this system and employ other eye metric indexes or create some new ones that might be effective in solving problems. For future work, additional emotions should be included in a real-time feedback by emotion estimation using biological signals. Therefore, other potential biological signals such as EEG and ECG should be employed in the system to estimate learners' interest groups, e.g., interest, and satisfaction. Moreover, the aim of the further improvements should include how to increase learners' interest and the ways to encourage them to continue their learning.

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