UNIVERSITY OF SOUTHAMPTON
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Designing and Evaluating the Effectiveness of Using Digital Mobile-Based Behaviour Change Interventions (mBCIs) to Promote Critical Thinking Skills in the Context of Research Projects

by Yousef Asiri

A thesis submitted in fulfilment for the degree of Doctor of Philosophy in Computer Science

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ABSTRACT

FACULTY OF PHYSICAL SCIENCES AND ENGINEERING
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Doctor of Philosophy

DESIGNING AND EVALUATING THE EFFECTIVENESS OF USING DIGITAL MOBILE-BASED BEHAVIOUR CHANGE INTERVENTION TO PROMOTE CRITICAL THINKING SKILLS IN THE CONTEXT OF RESEARCH PROJECTS

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Digital behaviour change interventions (DBCIs) are techniques used to provide continuous support and tailored advice to learners wishing to change their undesirable behaviours through web and mobile platforms. DBCIs have been successfully used for learning new skills necessary to change unwanted habits in well-being and other fields. In education, university students' critical thinking skills and behaviours require interventions for almost every research task. Specifically, students demand regular supervision to aid their critical thinking skills while working on their research projects. Providing advice for each student through traditional classrooms or office meetings is time consuming and can be difficult when relying solely on traditional supervision. DBCIs can be effective tools through which to change students' behaviours in terms of their thinking during the research projects. As such, there is now a need for a system that is capable of facilitating DBCIs between students and their supervisors with less technical background. This research sought to understand students' interactions with digital mobile-based behavioural change interventions (mBCIs) designed to improve their critical thinking and research skills. An instrument was designed to measure students' self-perceived critical thinking abilities. Academic supervisors from different fields were interviewed to identify their expectations and requirements regarding the instrument and regarding the use of DBCIs in critical thinking and research skills. An experimental study was conducted with two groups to explore how students interact with a mBCI designed to support their critical thinking over two months of a research project. This research was conducted to examine the progress students made with their critical thinking skills before and after using the system. As a result, students self-reported some significant perceived improvements in critical thinking standards and elements. However, the academics assessment for the students' reports showed no improvement in students' critical thinking. Students' reflections indicated that the mBCI was useful and easy to use. In addition, the mBCI notifications helped to increase students' engagement with the system.

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List of Acronyms

BCI	Behaviour Change Intervention
DBCI	Digital Behaviour Change Intervention
DI	Digital Intervention
II	Internet Interventions
mBCI	Mobile Behaviour Change Intervention
POCT	Perceptions of One's own Critical Thinking
PT	Persuasive Technology
TPB	Theory of Planned Behaviour

Declaration of Authorship

I, Yousef Asiri, declare that the thesis entitled *Designing and Evaluating the Effectiveness of Using Digital Mobile-Based Behaviour Change Interventions (mBCIs) to Promote Critical Thinking Skills in the Context of Research Projects* and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, 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 others, I have made clear exactly what was done by others and what I have contributed myself;
- parts of this work have been published as: Asiri et al. (2018), Asiri et al. (2019) and Asiri et al. (2020)

Signed:....................Yousef Asiri..

Date:......................17th of November 2019...

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Chapter 1

Introduction

Critical thinking is an essential tool for university students, allowing them to analyse, assess and evaluate arguments in their research projects (Ennis 2018; Carpi et al. 2017; Yilmaz and Keser 2016). Research projects are research-based tasks that enable learners to study specific problems and examine all possible solutions that can be supported with reliable evidence (Devi et al. 2017). Research projects stimulate the ability of students to ask questions and seek out reliable information to better understand problems. Through research projects, students learn and practice how to analyse, assess, and evaluate arguments, which cultivates critical thinking skills while allowing students to work with real world problems (Dos Santos and Cechinel 2019). Students generally receive support and assistance in the form of supervision throughout their research projects. Traditional face-to-face meetings are commonly used to facilitate communication between students and research project supervisors (Ismail 2017; Clear 2014). Technology has therefore been used to overcome barriers to communication, such as time and place, alleviating some of the communication difficulties that can arise between students and their supervisors (Seifi et al. 2014).

However, providing individual support and critical thinking assistance for students during research projects by tailoring information based on the students' critical thinking abilities is important (Brew and Mantai 2017). The use of technical tools to deliver of critical thinking content to students, combined with relevant advice, must be compatible with the nature of critical thinking (Buckley et al. 2015; Haghparast et al. 2014). Therefore, when developing tools meant to assist both students and supervisors, a design that will enrich the individual and behavioural learning experience in the context of critical thinking must be carefully considered. Several attempts have been made to use technology for the promotion of critical thinking skills in different settings. For instance, a study was conducted examining the impact of an online learning environment on the teaching of critical thinking skills through collaboration (Alnuaim et al. 2014). Similarly, a recent experiment examined the factors that influence the critical thinking skills of students during online activities (Razzak 2016). However, university students still lack the critical thinking skills that are needed during the course of their research projects (Swart 2017; Asiri et al. 2018; Saade et al. 2012).

There are considerable gaps in the research regarding the use of technology for the development of critical thinking skills, which explain the lack of support for critical thinking development. First, a comprehensive definition that covers all aspects of critical thinking, not only as a skill but also as a lifelong behaviour that requires sufficient time to develop, must be identified (Al-Mubaid and Bettayeb 2017; Paul and Elder 2013). Second, there has been a lack of research examining critical thinking and research projects together, although they can be considered relatively associated tasks (Brew and Mantai 2017; Yilmaz and Keser 2016). Last, well-tested, suitable software platforms that can facilitate the creation of mobile or web-based interventions designed by academics and researchers to evaluate student progress and behaviour during the development of critical thinking skills should be developed, especially for those without the necessary technical knowledge (Swart 2017; Seifi et al. 2014). The currently available tools are mostly rigid and tend to be fixed once developed, with less flexibility, making them difficult to use in different iterations, on large scales, with randomisation, or for useful data collection.

1.1 Digital Behaviour Change Interventions (DBCIs) for Critical Thinking in Research Projects

According to the Theory of Planned Behaviour (TPB) (Ajzen 1991), behaviours are linked to the beliefs and attitudes that a person holds. The theory of planned behaviour states that attitudes toward behaviour, subjective norms, and perceived behavioural control, together, shape an individual's behavioural intentions and behaviours. Critical thinking, similar to other human activities, is a planned behaviour (Lee 2018; Celuch and Slama 2002), requiring a person to perform an action based on his or her beliefs and attitudes that can be practised and controlled. Critical thinking is not the ability to memorise facts and theories; instead, it is a set of skills that requires development and practice over time (Behar-Horenstein et al. 2011). According to Celuch and Slama (2002), critical thinking is a deliberate and effort-intensive behaviour. Critical thinking is considered to be both a behaviour and a skill, which was addressed in the literature (Stupple et al. 2017; Al-Mubaid and Bettayeb 2017; Celuch and Slama 2002).

The current study suggests that using digital behavioural change intervention (DBCI) methods could potentially offer convenient technical assistance to students during the development of critical thinking and research skills. DBCIs are techniques that can be used to provide continuous support and tailored advice, through web and mobile platforms, to those who wish to alter undesirable behaviours (Pinder et al. 2018). The DBCI model consists of three primary factors, as illustrated in Figure 1.1. First, the intervention developers provide the necessary tools for intervention experts and users to interact with each other digitally, through web or mobile platforms. Second, the intervention experts, who might not have the skills to develop these platforms, can design interventions for the users of these platforms. Third, the intervention users can receive the intervention from experts through the mobile- or web-based intervention platforms and can, in turn, provide data for the experts to use when creating the interventions. As argued by Wai et al. (2018), by using mobile technologies, which are available and accessible to users at all times, it is possible to associate critical thinking with behaviour. Mobile devices could be utilized as intervention devices, which could help students make positive changes in their behaviours with regards to how they think critically during their research work (Asiri et al. 2018; Wilde and Zaluska 2016).

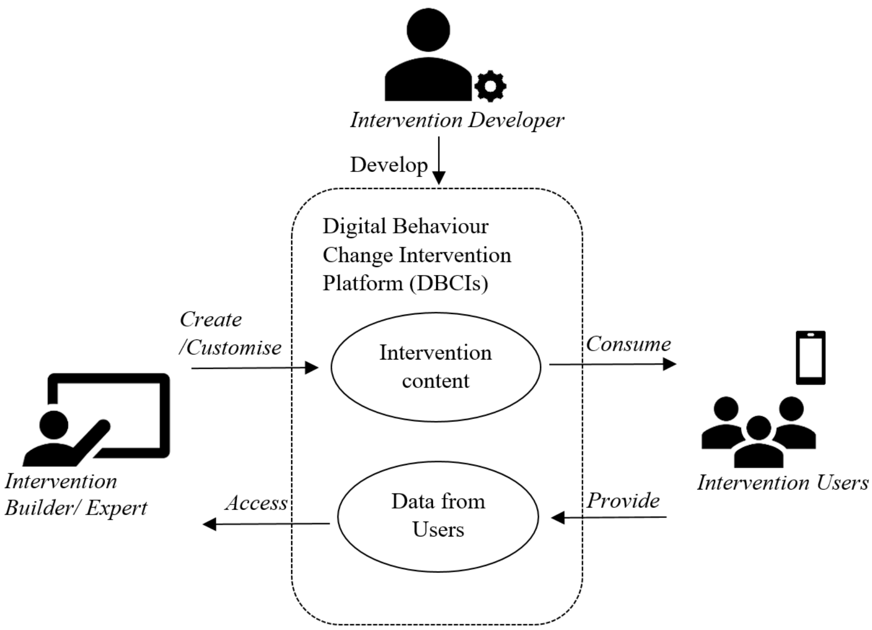

FIGURE 1.1: Main Factors in Digital Behaviour Change Intervention System

1.2 Motivations and Objectives

The aims of this study were to investigate the following: a behaviour learning model for students in higher education, using a digital, mobile-based behaviour change intervention to foster critical thinking during their research projects; and how to design a mobile application-based learning intervention within this behaviour-learning model. To achieve these aims, the following objectives were identified:

- To provide a critical thinking instrument for a research-based activity designed to measure and facilitate critical thinking, independent study, and self-reflection in a structured manner.

- To design and develop a DBCI to assist students' critical thinking in the context of research projects.
- To review the students' and supervisors' perceptions and requirements of the pedagogical usability provided by a mobile behaviour change intervention (mBCI).
- To study and evaluate the effectiveness of interacting with DBCIs that aim to foster critical thinking skills during real research projects.

In this study, mobile technology as an intervention tool has been suggested, due to its unique personalisation features, flexibility, connectedness, and portability (Grant 2019). Mobile technology is one of the most important technologies that affects almost every aspect of our lives, from personal interactions and social communications to education and work (Wai et al. 2018; Cardoso and Abreu 2015). Critical thinking is also an essential daily activity that could be assisted by mobile technology. Associating critical thinking with the daily use of mobile devices could help users, and specifically students, to monitor decision making, change behaviours, acquire intervention support, and track thinking patterns through the use of diaries, reminders and goals, at any given time and in any given location. The use of DBCI systems in blended contexts has the potential capacity to influence higher education in a variety of ways. First, for students, the systems can influence and shape or structure their approaches to learning and may stimulate communication. Second, for educators, DBCIs may assist the development and selection of online resources and change traditional teaching practices. Third, for institutions and researchers, DBCIs can provide large data sets that can be analysed and used to more deeply investigate the processes of learning and learner behaviour. An overview of the research topics addressed in this study is shown in Figure 1.2.

1.3 Research Questions

The purpose of the present study was to evaluate the effectiveness of DBCIs on the development of critical thinking behaviours when applied to students working on research projects. This study intended to examine the impact of using a mobile-application-based behaviour change intervention on the perceived improvement of critical thinking skills in third-year students working on research projects and to examine how the observed improvement relates to the mobile intervention components. Experimental studies with interviews were undertaken to identify the required elements of the intervention. This study investigated the effects of implementing a behavioural learning model on the promotion of critical thinking skills in higher education students. Within this model, students were provided with relevant information and regular advice, with the aim of positively changing their critical thinking behaviours during their research projects. In addition, this study could help predict the development of critical thinking behaviours and to support them with proper interventions, when necessary. The goal of this study is to evaluate whether a digital mBCI has the potential to measure and enhance the perceived critical thinking skills of students during their research projects. To achieve this goal, the following set of research questions (RQ) were proposed.

RQ1: What are the standards and elements for measuring students' critical thinking in the context of research projects?

This research question aims to understand the requirements for measuring and assessing the critical thinking skills of students. Investigating this question started by asking the following questions: *What are the students' self-reflections of their critical thinking skills? What are students strong and weak points with regards to critical thinking during research projects?* And *what are the standard and non-standard assessments used to measure critical thinking skills?* Answering these questions helped determine the requirements for designing an instrument to measure students' perceived critical thinking skills, based on the adopted Paul-Elder critical thinking framework (Paul and Elder 2013).

RQ2: What are the tools and techniques for using a digital mBCI to promote critical thinking skills in students?

The aim of this research question was to identify the specific methods for using a digital mBCI to promote students' critical thinking skills. This question involved investigating the supervisors' requirements for the use of DBCIs to foster critical thinking. This question aimed to identify the supervisors' perceptions and expectations for the adoption of DBCIs to promote their students' critical thinking by asking the following questions: *What are the supervisors' views regarding the instrument designed to measure the perceived critical thinking in the context of research projects?*, *what are the digital intervention components to support critical thinking in research projects?*, *What are the supervisors' experiences with using technology (web- or mobile-based platforms) to promote their students' critical thinking skills? What are students' experiences with technology that assesses and changes behaviours to promote critical thinking skills?* And *what are the practical methods for implementing DBCIs in critical thinking?*

RQ3: What are the technical methods for designing and implementing a digital mBCI for the improvement of critical thinking skills in students?

This research question aims to identify a designed framework for the implementation of DBCIs to foster students' critical thinking skills. This question investigated the usability and design of a mobile application-based system, using intervention components for this purpose. This question involved using and testing the practicality of using mBCIs, developed using the LifeGuide Toolbox, to improve the process of critical thinking for students by asking the following questions: *What types of supportive information and feedback would students require to change their behaviours positively in the context of critical thinking and research work? When is the proper time to intervene?* And *what* *are the advantages and disadvantages of implementing a notification system to increase engagement with DBCIs?*

RQ4: How does a digital mBCI improve critical thinking skills of students in the context of research projects?

This research question aims to unite the results from RQ1, RQ2 and RQ3. This question investigated whether the students' and supervisors' motivations and expectations were met and determined whether and how the mBCI contributed to critical thinking by asking the following questions: *What opportunities does an mBCI offer for the development of critical thinking in the context of research projects?* And *what are the factors within a DBCI that help to improve the critical thinking skills in the context of research projects?* By performing a mobile intervention usage analysis, interviews, and surveys, it is possible to determine the success of using a mobile intervention for the development of critical thinking skills. This research question also highlights those areas that require attention to improve the impacts of using the mBCI for future critical thinking situations. A mixed method approach, using pre- and post-experimental surveys, semi-structured interviews, and experimental studies, was adopted in this study.

The current research builds upon the literature around critical thinking definitions, measures and their relationships with digital interventions. Various approaches were used to analyse the gathered data, both descriptively and statistically, in this study. The findings were aligned with relevant studies to indicate the potential successes and existing challenges of using DBCIs to enhance critical thinking skills for students in the context of research projects.

1.4 Research Contributions

This study has contributed to the body of knowledge in the following aspects:

- An instrument was designed and validated to measure the perceived critical thinking skills in the context of research projects for university students.
- Intervention components were identified and reviewed by academics and research supervisors, which can help intervention builders design digital interventions for the promotion of critical thinking.
- Design principles were developed for implementing and testing digital mBCIs for the promotion of critical thinking skills in the context of research projects.
- The digital intervention tools seem better suited to helping develop certain types of critical thinking standards and elements which were studied and evaluated.

To the best of my knowledge, there is no generic framework that uses DBCIs to measure and support critical thinking skills in the context of research projects. As such, there

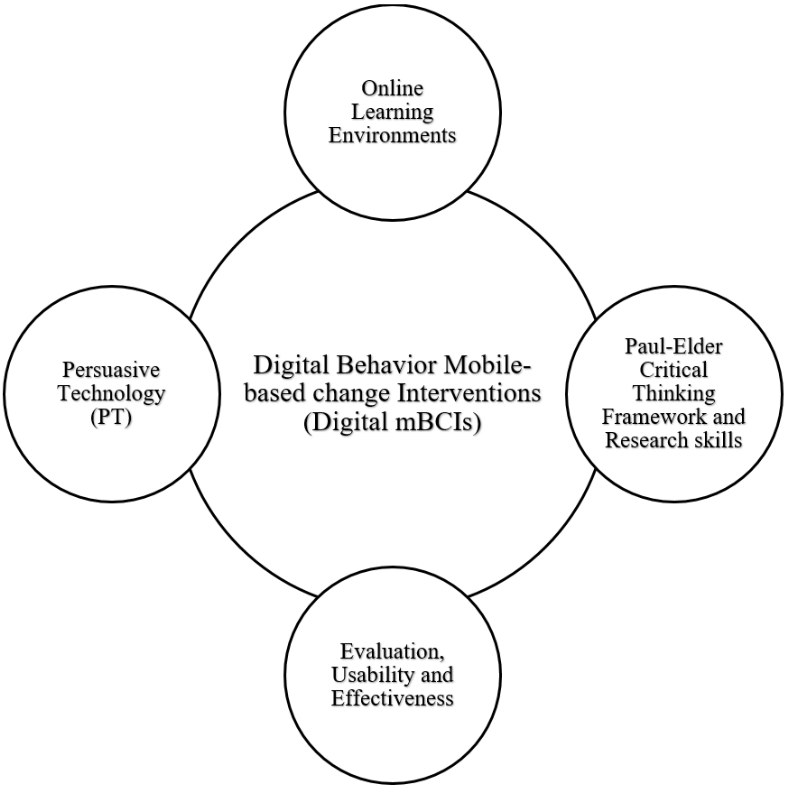

Figure 1.2: An Overview of The Research Areas

remains a need to provide supervisors with an authoring tool that can be used to design and deploy digital interventions for their students in the context of research projects in higher education. Such a tool would help intervention creators, i.e., supervisors, to develop digital interventions in different contexts and for a wide range of users. Students can receive supportive assistance for the development of their critical thinking skills using digital, smartphone-based interventions whenever they need assistance, regardless of place or time. For research supervision, this could be a cost-effective process for both supervisors and students. There is certainly the potential for success when using the exciting LifeGuide Toolbox framework to create mobile interventions to assist critical thinking skills. The LifeGuide Toolbox software package consists of an authoring tool that enables intervention builders with minimal programming backgrounds to easily create digital interventions (Morrison et al. 2018). More details regarding the LifeGuide Toolbox are discussed in Chapter 2. This tool could be widely used by a large number of researchers and scientists and can provide them with the data they require regarding student behaviours that pertain to critical thinking in the context of research projects.

1.5 Outline of This Thesis

The introduction has provided the foundation of this research. In particular, this research focuses on the impacts of using DBCIs to support critical thinking during research projects. The importance of this thesis is to provide understanding and insights regarding the use of DBCIs during the development of critical thinking skills, which could benefit both research supervisors and students. This thesis outlines how the methods were designed and the tools and studies that were used to assess the effectiveness of using DBCIs on the development of critical thinking and research skills, as shown in Figure 1.3.

Chapter 2 explores topics that are relevant to this study, including critical thinking, DBCIs, and LifeGuide Toolbox software tools. This chapter thoroughly examines recent studies that are pertinent to the present study and provides information from the literature review regarding how technology has been used to promote critical thinking. This chapter also identifies gaps in previous research to identify potential approaches to current problems.

Chapter 3 details the research methodologies that were adopted in this study to answer the four primary research questions. It illustrates the research design and methods used to conduct the studies. This chapter also includes a brief description of the procedures used to collect and analyse the data that were produced during the different stages of this study. A mixed methods approach was used in this study to provide understanding and insights into the problem.

Chapter 4 presents the development of the instrument and of the intervention components, as validated through three studies that investigated the levels of critical thinking in students, and describes how the requirements for the use of DBCIs for the promotion of critical thinking were identified based on interviews with supervisors.

Chapter 5 illustrates how an experimental study was designed, using an existing LifeGuide Toolbox framework and based on the Paul-Elder Critical Thinking Framework, to test a mobile intervention for third-year students, while highlighting the technical issues involved with the intervention implementation.

Chapter 6 presents a study using the remodelled DBCI framework, which was conducted to evaluate the DBCI for its ability to measure and improve the perceived critical thinking skills of students during a research project period. A pilot study was conducted using the designed instrument to examine the impacts of a mobile intervention on the promotion of critical thinking skills in students during their 3rd-year research projects. After a pilot study was performed, an experimental study was conducted which incorporated further changes and improvements to the methods and the design.

Chapter 7 presents the data gathered from the pre- and post-experimental online surveys and from the mobile intervention experiment. In addition, this chapter presents assessments by academics of the work done by the participants during the latest experiment.

Chapter 8 provides a discussion regarding the primary findings from the data that was collected and analysed during the various experiments conducted throughout this study. This chapter describes the significance of the overall results and compares them with previous results described in the literature. First, a brief summary of the work done in this study is presented. Second, the collected results from the research phases are then integrated and triangulated to provide a thorough understanding of how the use of the DBCI improved the critical thinking during research projects in university students.

Chapter 9 summarises the primary findings of this study on the use of digital mBCIs to foster critical thinking in students within the context of research projects.

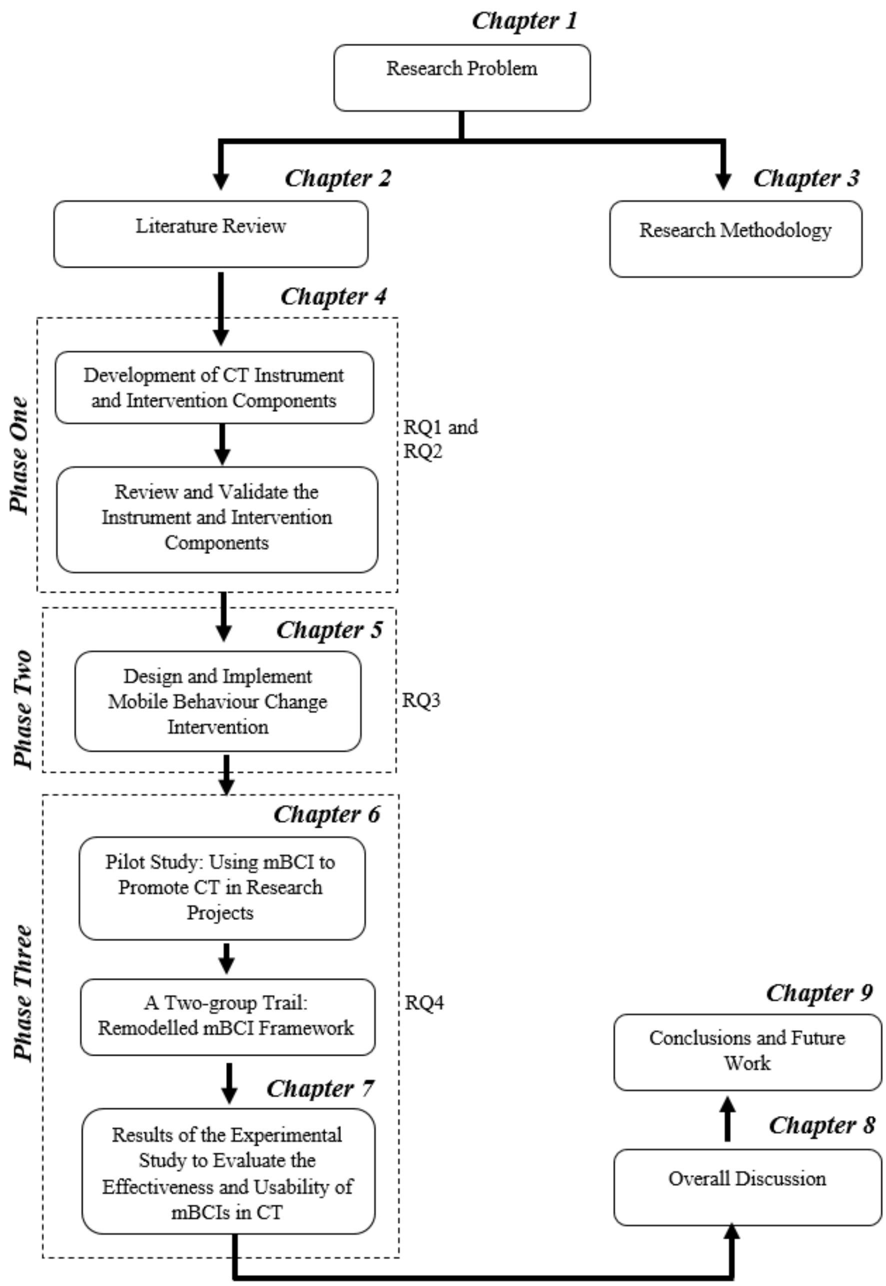

Figure 1.3: An Overview of The Research Process

Chapter 2

Literature Review: Critical Thinking, Online Learning Environments and Digital Behaviour Change Interventions (DBCIs)

This chapter provides an overview of the various definitions of critical thinking, including how critical thinking is measured, and theories, frameworks, and techniques for assessing and improving critical thinking. This chapter presents a review of the recent research that has examined different aspects of critical thinking when technology is used. Particularly, a discussion focuses on digital behaviour change interventions (DBCIs), research projects, and mobile learning as important technical fields in which to adopt critical thinking skills. This chapter also summarises the *Paul-Elder Critical Thinking Framework* and the *LifeGuide Toolbox*, both of which were adopted in this study. The aim of this chapter is to provide an assessment of the current state of research in the areas of critical thinking, mobile learning and DBCIs and how the combination of these ideas might result in successful improvements in these areas. This chapter also includes an extended review of the studies that are pertinent to the current study and identifies the gaps in the currently available research that must be filled to further develop these ideas.

This chapter begins by defining critical thinking skills and demonstrating their importance. The following section presents the studies that have been performed to improve critical thinking skills in students, followed by an extensive review of the mobile- and web-based technologies that have been adopted to teach or enhance critical thinking skills in university students. The technical methods and the evaluation protocols used to assess the existing learning tools are also discussed. Finally, the proposed technique for this study, the DBCI, will be described, including the *LifeGuide Toolbox*, which was primarily used to design the mobile application-based intervention tool that was used to promote critical thinking and research skills in students in the experiment described in this study. How DBCIs have been used in the past and the basis for using a DBCI in this study will be discussed.

2.1 Critical Thinking and Research Skills

Critical thinking is a metacognitive process that contains dispositions and a number of skills such as analysis, evaluation and inferences which enhance the ability to produce a reasonable conclusion for an argument or a problem (Dwyer et al. 2014). For many decades, researchers have focused on critical thinking as an essential skill for university students (McCann and Camp 2015). Critical thinking is an important tool for everyone, throughout all stages of life, to be able to evaluate arguments and to be make rational decisions. More specifically, there is a desire among educators to promote high order thinking skills for learners at every level (Kim et. al. 2013). Due to the importance of critical thinking skills, scholars in several fields have conducted studies to assess critical thinking concepts, including philosophy (Daniel and Auriac 2011), education (Cavus and Uzunboylu 2009; Garrison 1991), psychology (Toplak et al. 2014) and behaviourism (Goldberg et al. 2015; Lima and Nadia 2014). According to (Ennis 1993), adding critical thinking courses to the curricula was the first technical step towards adopting critical thinking skills in general. Gradually, other strategies have been used to improve critical thinking skills, such as collaboration (MacKnight 2000), puzzle and problem solving (Choi et al. 2014), scaffolding (Wass et al. 2011), peer assessment (Hwang et al. 2014), online gaming (Yang and Chang, 2013), and social interaction (Thormann et al. 2013), as shown in Table 2.1.

In the fields of psychology and philosophy, studies have addressed critical thinking as a habit of the mind, with critical thinking being viewed as a behavioural concern that must be trained and practised (Pithers and Soden 2000). As a result, a combination of different approaches, with the aid of technology, might lead to interesting results for the promotion of critical thinking. In fact, experimental and theoretical research, which has used various technologies to address critical thinking, has generally yielded significant results. As addressed by Paul and Elder (Elder and Paul 2013), we require critical thinking because of the misconceptions that can develop in our minds over time. Thinking critically can effectively reduce the likelihood that we will accept untrue myths as facts simply because we are told they are true by society.

Thinking critically helps us to revise our belief systems, the latter of which are based on distorted social definitions of the world around us (Elder and Paul 2013). Critical thinking techniques cannot be easily taught in schools and universities (Alnuaim et al.

2012). While they can be delivered to students through classes, it is necessary to practice them within well-designed educational frameworks over time. In fact, there is a great opportunity to use new technologies, such as smartphones, to employ novel methods for the promotion of critical thinking, not only for students but for almost anyone (Alnuaim et al. 2016). Online discussion forums have been created to help learners and educators practice their critical thinking skills, through online debates, questions and open conversations. However, these online environments generally lack the practical measurements required to assess the critical thinking skills of each participant individually (Abrami et al. 2015; Alnuaim et al. 2014). The teaching of critical thinking skills through direct instruction in the classroom setting was the start of embracing critical thinking in the educational context. However, the shift in teaching critical thinking began to result in significant outcomes when strategies, methods and specific tools were designed to help learners, such as discussions, asking questions, using context during critical thinking activities, and problem-solving techniques.

However, it can be difficult to measure critical thinking skills using normal learning tasks (Alnuaim et al. 2014). Additionally, critical thinking and problem-solving skills take longer to grasp (Willingham 2008). Celuch and Slama (2002) have proposed that critical thinking skills should be considered part of a lifelong development strategy. Critical thinking skills can be practiced using many types of educational tasks. For example, engaging students in scientific research can help them learn to think critically and collaboratively (MacKnight 2000). Unlike traditional class assignments, which are designed for problems with specific solutions, critical thinking questions should encourage open discussion, with the aim of arriving at thoughtful, inspired responses (Renaud and Murrayb 2008). Moreover, critical thinking tasks should be designed with no single solution but rather with many different approaches that can be practised and enhanced through research project tasks (Dwyer et al. 2014).

To gain a deeper understanding of critical thinking and how it has been studied, this section covers critical thinking skills from various perspectives, as critical thinking has been extensively studied in the fields of education, psychology, philosophy, and human-computer interactions. This section also discusses issues related to critical thinking skills, such as how critical thinking is assessed and the most commonly used frameworks for teaching and improving critical thinking skills, especially in higher education. In this section, the conventional techniques used to enhance critical thinking skills are also highlighted. The justification for selecting the Paul-Elder Critical Thinking Framework is stated at the end of this section. In addition, this section demonstrates the major aspects of undergraduate research projects, which were used as the context for practicing critical thinking skills during this study, including the challenges and hindrances to traditional research supervision that must be addressed and the potential for using digital intervention techniques as alternative approaches for overcoming some of these problems.

Technique	Purpose	Experiment	Citation
Collaboration	Using discussion to promote critical thinking skills through questions and debates.	Certain topics have been raided among students to discuss them through communication with each other.	(MacKnight 2000)
Problem Solving and Puzzle-based Problems	Using math problems with tricks to help students thinking critically.	Website or paper-based problems.	(Choi et al. 2014)
Scaffolding	To help students in their thinking skills by teachers' instructions.	Face to face meetings.	(Wass et al. 2011)
Peer Assessment	To facilitate students some tools that help students in their critical thinking through discussing various topics with each other.	By offering feedback through emails or meetings.	(Hwang et al. 2014)
Online Game and Discussion	To design online games or longs for critical thinking issues.	Using website by people to interact with each other.	(Yang and Chang, 2013)
Social Interaction	Using social media to think critically over several general topics.	Twitter or Facebook.	(Thormann et al. 2013)

Table 2.1: Approaches to Practice Critical Thinking Skills in Education

2.1.1 Definitions of Critical Thinking

Critical thinking first began to be addressed in the literature in the fields of philosophy and education in the 1940s and 1950s (Pithers and Soden 2000). Prior to this, discussion had focused on the concepts of being clear, reflective, and straight thinkers, but not necessarily critical thinkers (Niu et al. 2013). Philosophers, educators and researchers made important contributions to the definition later, including factors that affect the concept of critical thinking, such as disposition and attitude, both of which form the basis of thinking morally and intellectually (Daniel and Auriac 2011). Based on the literature review, definitions of critical thinking can be divided into two categories: thinking as a cognitive process (Foster et al. 2006) and thinking as a reflection of psychological and behavioural effects (Goldberg et al. 2015).

Though the various definitions for critical thinking, there is less agreement on the definition of critical thinking (Dwyer 2017). For example, critical thinking was defined as a reasoned, purposeful, and introspective approach to solving problems or addressing those questions for which there was incomplete evidence or information and for which an incontrovertible solution was unlikely (Baker et al. 2001). A significant definition for critical thinking was introduced by Halpern (2014) which descripts that "critical thinking is purposeful, reasoned and goal-directed thinking – the kind of thinking involved in solving problems, formulating inferences, calculating likelihoods and making decisions." Another definition defined critical thinking as the careful and deliberate determination of whether to accept, reject, or suspend judgement regarding a claim (Pithers and Soden 2000). Critical thinking is defined as the ability to assess, analyse and evaluate an argument logically, based on reliable information (Ennis 2018). According to Garrison et al. (2001), another significant definition of critical thinking was developed by Dewey (1933), who defined critical thinking as reflective thinking. Reflection refers to the act of a person consciously looking at and thinking about his or her experiences, actions, behaviours, feelings and responses and then interpreting or analysing them to learn from them. There are common concepts that can be taken from the various definitions of critical thinking, including the definitions shown in Table 2.2, such as logical evaluation, reasonable analysis, and careful self-reflection.

Despite the debate over the definition of critical thinking, there is one definition that has shown a reasonable conceptualisation of critical thinking and its skills. A total number of 46 experts in the area of critical thinking gathered to discuss several issues regarding critical thinking such as the definition, conceptualisation and assessment of critical thinking which yielded in producing the Delphi Report (Facione 1990). Critical thinking was defined in the Delphi Report as

> "a purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgement is based." (Facione (1990), p.3)

The outcomes of the Delphi Report showed that the majority of the experts (i.e. 95% agreement) stated that the core critical thinking skills are analysis, evaluation, and inference. According to Dwyer et al. (2012), there are significant positive correlations between these three critical thinking skills ($r = 0.40$, $p < 0.001$) between analysis and evaluation, ($r = 0.36$, $p < 0.001$) between analysis and inference, and ($r = 0.48$, $p < 0.001$) between evaluation and inference.

In this study, the critical thinking definition of Paul and Elder (2013) was adopted, which defined critical thinking as:

> "a systematic way to form and shape ones thinking. It functions purposefully and exactingly. It is thought that is disciplined, comprehensive, based on intellectual standards, and, as a result, well-reasoned. Critical thinking is distinguishable from other thinking because the thinker is thinking with the awareness of the systematic nature of high-quality thought, and is continuously checking up on himself or herself, striving to improve the quality of thinking."

The combination of the definition and the framework of Paul-Elder captures the behavioural and intellectual aspects of critical thinking (Ralston and Bays 2013; Novotny

Researchers	Critical Thinking Definitions	Source
John Dewey	"Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends."	(Dewey 1933)
Edward Glaser	"The ability to think critically . . . involves three things: (1) an attitude of being disposed to consider in a thoughtful way the problems and subjects that come within the range of one's experiences, (2) knowledge of the methods of logical inquiry and reasoning, and (3) some skill in applying those methods."	(Glaser 1941)
Richard Paul and Michael Scriven	"Critical thinking is the intellectually disciplined process of actively and skilfully conceptualizing, applying, analysing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action."	(Scriven and Paul 1987)
Peter Facione	"Purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based."	(Facione 1990)
Robert Ennis	"Critical thinking is reasonable reflective thinking that is focused on deciding what to believe or do."	(Ennis 2013)
Brooke Moore and Richard Parker	"The careful, deliberate determination of whether we should accept, reject, or suspend judgment about a claim, and the degree of confidence with which we accept or reject it."	(Brooke and Parker 2014)

TABLE 2.2: Various Definitions of Critical Thinking

et al. 2016; Al-Mubaid and Bettayeb 2017; Asiri et al. 2018, 2019) by providing multiple CT standards (clarity, accuracy, precision, relevance, logic, depth, breadth, significance, and fairness) and elements (purpose in reasoning, the question of the issue, assumptions, points of view, information, concepts, interpretations, and the implications we draw from reasoning) when it is used in the context of research projects, which was the primary reason it was adopted for this study. On one hand, the behavioural aspects can be recognised in the definition in the checking process on the one's thinking regularly to improve the quality of thinking. On the other hand, the intellectual aspect is stated in the standards and the elements of critical thinking. More details regarding the

Paul-Elder Critical Thinking Framework are discussed in section (2.1.5).

2.1.2 Critical Thinking Skills and Dispositions

Critical thinking is considered as a metacognition process which is associated with thinking about thinking (Dwyer et al. 2014). Critical thinking contains sub-skills which are the analysis, evaluation and inferences (Facione 1990). According to the Delphi Report, the analysis process in critical thinking is the ability to identify the propositions of the argument by recognising the essential conclusion, premises, relationships, and objections. The evaluation skills are the ability to assess an argument by asking questions with regards to the credibility, consistency and relevance of the conclusions to judge the overall strength or weakness in the argument (Facione 1990). The inference skill is the ability to draw conclusions from a well-established thinking by identifying the logical and relevant evidence related to the analysis and evaluation skills (Facione 1990). The three critical thinking skills are briefly presented in Table 2.3 which were adapted from Dwyer (2017).

The disposition of critical thinking is as important as critical thinking skills. The disposition of critical thinking is defined as the attitude or the tendency of the learners to be disposed to perform a critical thinking activity (Norris 1992; Valenzuela et al. 2011). The critical thinking dispositions is essential to understand how to think and to make the thinking better both in academic and everyday life (Siegel 1999). Many research studies have shown that there is a significant relationship between critical thinking and dispositions. For example, a study was conducted by Colucciello (1997) to understand the relationship between dispositions towards thinking and the ability to think critically for nursing students from different academic levels. Critical thinking was measured in Colucciello's study by using California Critical Thinking Dispositions Inventory (Facione and Facione 1992). The results showed that there is a significant correlation between critical thinking ability and a number of dispositions towards thinking such as open-mindedness, confidence, analyticity, maturity, truth-seeking and inquisitiveness. Another research study was conducted by Dwyer et al. (2011) also revealed that critical thinking was significantly correlated with a number of dispositions towards thinking such as confidence, inquisitiveness, truth-seeking and analyticity.

Skill	Description
Analysis	-To identify the intended and actual inferential relationships among statements, questions, concepts, descriptions or other forms of representation intended to express beliefs, judgments, experiences, reasons, information, or opinions -Examining ideas: to determine the role various expressions play or are intended to play in the context of argument, reasoning or persuasion; to compare or contrast ideas, concepts, orstatements; to identify issues or problems and determine their component parts, and also to identify the conceptual relationships of those parts to each other and to the whole -Detecting arguments given a set of statements or other forms of representation, to determine whether or not the set expresses, or is intended to express, a reason or reasons in support of or contesting some claim, opinion or point of view -Analysing arguments: given the expression of a reason or reasons intended to support or contest some claim, opinion or point of view, to identify and differentiate: (a) the intended main conclusion, (b) the premises and reasons advanced in support of the main conclusion, (c) further premises and reasons advanced as backup or support for those premises and reasons intended as supporting the main conclusion, (d) additional unexpressed elements of that reasoning, such as intermediary conclusions, non-stated assumptions or presuppositions, (e) the overall structure of the argument or intended chain of reasoning, and (f) any items contained in the body of expressions being examined which are not intended to be taken as part of the reasoning being expressed or its intended background.
Evaluation	-To assess the credibility of statements or other representations which are accounts or descriptions of a person's perception, experience, situation, judgment, belief, or opinion; and to assess the logical strength of the actual or intended inferential relationships among statements, descriptions, questions or other forms of representation -Assessing claims: to recognize the factors relevant to assessing the degree of credibility to ascribe to a source of information or opinion; to assess the contextual relevance of questions, information, principles, rules or procedural directions; to assess the acceptability, the level of confidence to place in the probability or truth of any given representation of an experience, situation, judgment, belief or opinion -Assessing arguments: to judge whether the assumed acceptability of the premises of an argument justify one's accepting as true (deductively certain), or very probably true (inductively justified), the expressed conclusion of that argument; to anticipate or to raise questions or objections, and to assess whether these point to significant weakness in the argument being evaluated; to determine whether an argument relies on false or doubtful assumptions or presuppositions and then to determine how crucially these affect its strength; to judge between reasonable and fallacious inferences; to judge the probative strength of an argument's premises and assumptions with a view toward determining the acceptability of the argument; to determine and judge the probative strength of an argument's intended or unintended consequences with a view toward judging the acceptability of the argument; to determine the extent to which possible additional information might strengthen or weaken an argument.
Inference	-To identify and secure elements needed to draw reasonable conclusions; to form conjectures and hypotheses; to consider relevant information and to deduce the consequences flowing from data, statements, principles, evidence, judgments, beliefs, opinions, concepts, descriptions, questions, or other forms of representation -Querying evidence: in particular, to recognize premises which require support and to formulate a strategy for seeking and gathering information which might supply that support; in general, to judge that information relevant to deciding the acceptability, plausibility or relative merits of a given alternative, question, issue, theory, hypothesis, or statement is required, and to determine plausible investigatory strategies for acquiring that information -Conjecturing alternatives: to formulate multiple alternatives for resolving a problem, to postulate a series of suppositions regarding a question, to project alternative hypotheses regarding an event, to develop a variety of different plans to achieve some goal; to draw out presuppositions and project the range of possible consequences of decisions, positions, policies, theories, or beliefs -Drawing conclusions: to apply appropriate modes of inference in determining what position, opinion or point of view one should take on a given matter or issue; given a set of statements, descriptions, questions or other forms of representation, to educe, with the proper level of logical strength, their inferential relationships and the consequences or the presuppositions which they support, warrant, imply or entail; to employ successfully various sub-species of reasoning, as for example to reason analogically, arithmetically, dialectically, scientifically, etc.; to determine which of several possible conclusions is most strongly warranted or supported by the evidence at hand or which should be rejected or regarded as less plausible by the information given.

TABLE 2.3: Main Critical thinking Skills in the Delphi Report (Adapted from Dwyer (2017))

As demonstrated in Table 2.4, a number of researchers have identified several disposition towards critical thinking. The dispositions that are represented in the table have similarities among them. In the Delphi Report (Facione 1990), there are many dispositions that are regarded as general dispositions which are approaches to the daily life activities when critical thinking is required such as open- and fair-mindedness, inquisitiveness, understanding people's opinions, considering other views, honesty, confidence, being aware of CT, and considering alternative judgement. Similarly, there are many dispositions that are regarded as specific dispositions which are approaches to certain or particular questions or situations such as clarity, complexity, truth-seeking, precision, relevance, closer attention to a particular issue, and persistence. For Halpern (2014), there are other dispositions towards critical thinking which are mindfulness, monitoring metacognition, flexibility, self-correction, seeking agreement, and willingness to plan. For Paul and Elder (2008), dispositions towards critical thinking are fair-mindedness, intellectual humility, courage, empathy, integrity, perseverance, confidence, and autonomy. Lastly, Dwyer et al. (2016) have identified and studied the dispositions towards critical thinking to be open-mindedness, truth-seeking, reflection, Scepticism, attentiveness, resourcefulness, inquisitiveness, and Intrinsic goal orientation.

According to (Ennis 2018), there is a difference between a disposition toward critical thinking and the ability to accomplish critical thinking. Ennis argues that studies of critical thinking demonstrated differences between critical thinking disposition and critical thinking abilities. For instance, ideal critical thinkers are disposed to do the following: search for and provide clear arguments or questions, search for and provide reasons, be able to explain the relationships between reasons and conclusions, attempt to be well informed, use reliable and credible information and sources, consider the overall situation and include context, be aware and open-minded in regards to other alternatives or points of view, stop making judgements in the event of insufficient evidence, change positions when reason and evidence is sufficient, and seek knowledge and truth when it is required. However, Ennis claims that the ideal critical thinkers have the ability to do the following: focus on the question by analysing the arguments with clarification, understand the basic tools of math and graphs to make better decisions, question the credibility and reliability of sources with observation and judgement, and define terms and make careful assumptions. Critical thinking requires certain factors and elements to achieve its standards. According to Fisher (2001), to become a critical thinker, a number of skills are required, as a person must learn to do the following: "identify elements in a reasoned case, especially reasons and conclusions, identify and evaluate assumptions; clarify and interpret expressions and ideas; judge the acceptability and credibility of claims; evaluate different arguments; analyse, evaluate, and produce explanations; analyse, evaluate, and make decisions; draw inferences; and produce arguments."

Many instructional ways have been used to teach and support critical thinking such as active learning, Argument mapping (AM), and eLearning. Argument Mapping (AM) is

Dispositions	Sources
General dispositions: Open- and fair-mindedness, inquisitiveness, understanding people's opinions, considering other views, honesty, confidence, being aware of CT, and considering alternative judgments. Specific dispositions: Clarity, complexity, truth-seeking, precision, relevance, closer attention to a particular issue, and persistence.	Delphi Report (Facione 1990)
Mindfulness, monitoring metacognition, flexibility, self-correction, seeking agreement, and willingness to plan.	Halpern (2014)
Fair-mindedness, Intellectual humility, courage, empathy, integrity, perseverance, confidence, and autonomy.	Paul and Elder (2008)
Open-mindedness, truth-seeking, reflection, scepticism, attentiveness, resourcefulness, inquisitiveness, and Intrinsic goal orientation.	Dwyer et al. (2016)

Table 2.4: List of Dispositions towards Critical Thinking

a method for analysing a thought by graphically presenting the relations between the factors to make or visual and clear to understand (Dwyer et al. 2014). Using RJ in an educational context to support critical thinking has shown significant improvement in learners' abilities to thinking critically. A study was conducted by Dwyer et al. (2014) used AM for a number of students to enhance their critical thinking. The assessment indicated that the students have higher scores in the post-test results in arguments, analysis and evaluation skills. E-Learning has been also used as an application to support critical thinking which are discussed in details in the section 2.2.

2.1.3 Critical Thinking and Reflective Judgement

One of the important concepts in applying critical thinking to a certain problem is the ability to imply a reflective judgement (King and Kitchener 1994). Reflective Judgement (RJ) is a critical thinking skill ability which indicates the understanding of an individual to reflect upon the held knowledge considering the nature, context, limits, and recognising the factors that might affect their reasoning or judgements (King and Kitchener 1994). In addition, Reflective Judgement is the ability of an individual to know that their views and opinions might be falsified by another evidence obtained later. Therefore, Reflective Judgement emphasises not only on the conclusions but also in the process of the individual reaches to it. Reflective judgement is deemed to be one of the critical thinking components which indicates the ability to acknowledge levels of certainty and uncertainty (Dwyer 2017). RJ is important when thinking critically because it helps the individual to recognise the influence of the hidden assumptions when judging or assessing a particular situation (King and Kitchener 1994). The ability of thinking critically can progressively develops by the level of applying RJ with higher complexity. RJ can be improved by the amount of active engagement with the problem or the situation when thinking critically (Brabeck 1981; Dawson 2008).

Several research studies have shown the relationship between critical thinking and reflective judgement (Brabeck 1981; Dawson 2008; Dwyer et al. 2011; King and Kitchener 1994). For instance, a study was conducted by Brabeck (1981) assessed both critical thinking and reflective judgement for 119 university students. In Brabeck's study, Watson–Glaser Critical Thinking Appraisal (WGCTA) (Watson 1980) was used to measure critical thinking, and the Reflective Judgement Interview (Kitchener and King 1981) was used to measure reflective judgement for the participants. The findings showed that there are positive correlations between assessments ($r = 0.40$, $p < 0.001$). Another recent study by Dwyer et al. (2011) studied the relationship between critical thinking and reflective judgement. In their study, Lectical Reflective Judgement Assessment (Dawson 2008) was used to measure reflective judgement, and California Critical Thinking Skills Test (Facione 1990) was used to measure critical thinking. Their finding has confirmed the findings of Brabeck's study. It revealed that there is a positive correlation ($r = 0.43$, $p < 0.01$) between critical thinking and reflective judgement.

2.1.4 Critical Thinking: Frameworks and Methods

Many critical thinking frameworks have been developed to facilitate and improve the development of the critical thinking skills of learners in higher education. Some researchers (Perkins and Murphy 2006; Garrison et al. 2001; Norris and Ennis 1989) have presented concise and comprehensive frameworks for the development of critical thinking skills. Research has shown inconsistencies among the suggested frameworks, which each consist of several factors that have been suggested to play major roles in the teaching of critical thinking. However, there has been an encouraging degree of overlap among these factors, which could lead to a better understanding of the major elements that should be considered when designing a model for critical thinking (Fahim and Eslamdoost 2014).

To identify the common elements among all of the critical thinking models developed by the abovementioned researchers, it is important to first describe the components that constitute these models. A short, five-step critical thinking model was developed by Norris and Ennis (1989) to identify the requirements for gaining critical thinking skills. The model consists of basic clarification, which includes support and inferences, and advanced clarification, which includes strategies and techniques. Another important model, illustrated by (Garrison et al. 2001), is comprised of events for triggering, discovering, provision, and goal setting. Likewise, Perkins and Murphy (2006) have developed a model to teach and support critical thinking that introduced five steps to embed critical thinking: clarification, evaluating evidence, inference, and strategy development. Other frameworks that have been used to enhance critical thinking skills include the Bloom's taxonomy (McNett and Harvey 2003) and Paul-Elder Critical Thinking Framework. For practical reason, this chapter will focus only on the two most commonly used frameworks.

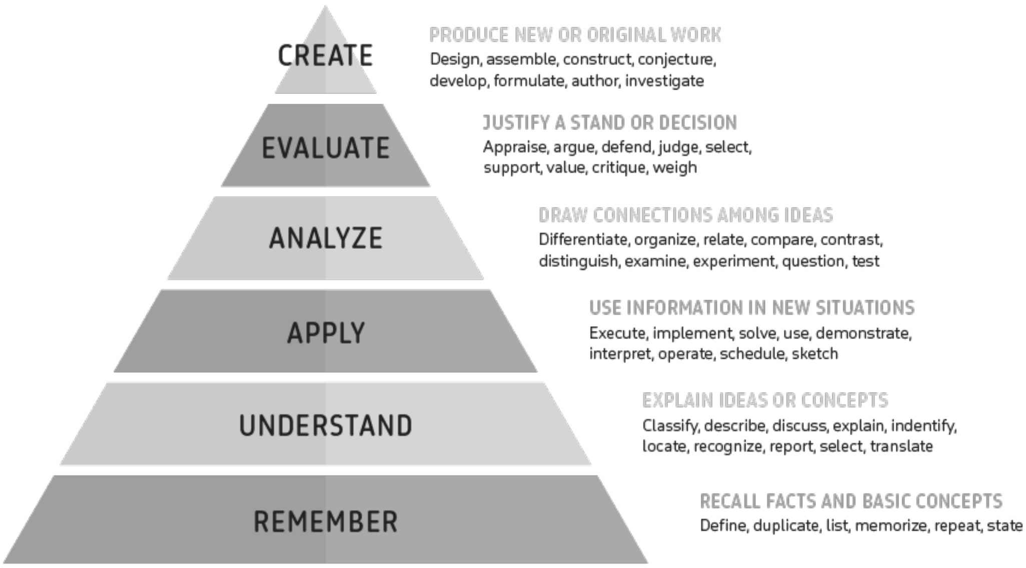

FIGURE 2.1: The Revision of Bloom's Taxonomy (Anderson and Krathwohl 2002)

As mentioned earlier, many educational techniques have been proposed to enhance the critical thinking skills of students. Some of these techniques have been profoundly well-designed, giving separate consideration to the different stages of critical thinking elements, such as the Paul-Elder Critical Thinking Framework (Figure 2.3) (Dwyer et al. 2014). The Bloom's taxonomy model is an of educational objectives that can be used to comprehend the process of thinking. The revision of Bloom's taxonomy (Figure 2.1) is comprised of six stages of cognitive development: memory, understanding, application, analysis, evaluation, and creation. This taxonomy has been used to assess and measure the ability of a single person to think critically (McNett and Harvey 2003). In contrast, the Paul-Elder Critical Thinking Framework consists of three primary components: elements of thought, intellectual standards and habitual traits (Paul and Elder 2013). Elements of thought refers to the primary stages of conducting research, such as defining the purpose, identifying questions, gathering information, and conceptualising relevant concepts and theories.

The revision of Bloom's taxonomy is illustrated in Figure 2.1 by (Anderson and Krathwohl 2002), showing a hierarchical system that represents thinking skills in order, whereas Paul's model is more circular and can be achieved through an iterative process. Another difference between the two frameworks is that the Bloom's framework is intended to classify individual thinking behaviours, such as memory and analysis, while the Paul framework addresses the process of thinking behaviour as a whole, with different thinking abilities working together.

The Marzano's framework (Marzano 2001) was developed as taxonomy of educational objectives based on an empirical research presented in a meta-analysis study (Marzano 1998). In Marzano's meta-analysis study (Marzano 1998), around 4000 effect sizes for more than 1.5 million subjects were studied. The findings showed that the effect sized for the studies that used domain knowledge is 0.60, for the self-system educational techniques was 0.74, for metacognitive interventions was 0.55, and lastly with effect size 0.75 for the cognitive interventions. there many ways to use in instruction to improve students' learning process. For instance, this study shows that that feedback is considered to be one of the most effective ways to improve learners in their learning.

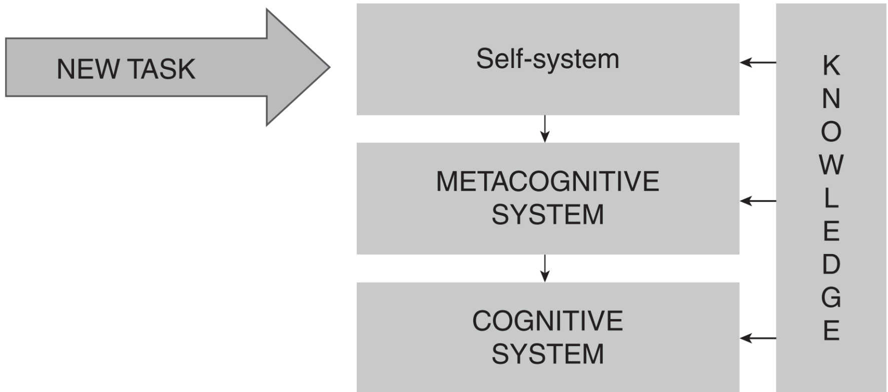

FIGURE 2.2: Marzano's (2001) 'New' Taxonomy of Educational Objectives (Adapted from Dwyer (2017))

This framework consists of three main elements: 1) self-system, 2) metacognitive system, and 3) cognitive system. The self-system is meant to be for the individual's goals, disposition, motivation, beliefs, and attention to undertake a task. The metacognitive system acts as an executive control for processes that individual is thinking about. In order to do that, the information that the individual has needs to be retrieved for the knowledge domain. This has to be an interactive process in the cognitive system which facilitates between the other systems in this taxonomy. The thinking process in Marzano's framework involves these three elements which are interacted to result the knowledge as shown in Marzano's New Taxonomy of Educational Objectives in Figure 2.2.

2.1.5 *Paul-Elder Critical Thinking Framework*: Definition, Theory and Assessment

The Paul-Elder Critical Thinking Framework is a highly useful model that demonstrates the nature of critical thinking (Novotny et al. 2016). The Paul-Elder Critical Thinking Framework consists of three components: (a) elements of thought, defined as the scientific steps necessary for critical thinking; (b) nine intellectual standards of thinking (clarity, accuracy, precision, relevance, logic, depth, breadth, significance, and fairness); and (c) the intellectual traits that make critical thinking habitual (Ralston and Bays 2013). The first step of applying this framework is learning to recognise the elements of thought (purpose in reasoning, the question of the issue, assumptions, points of view, information, concepts, interpretations, and the implications we draw from reasoning).

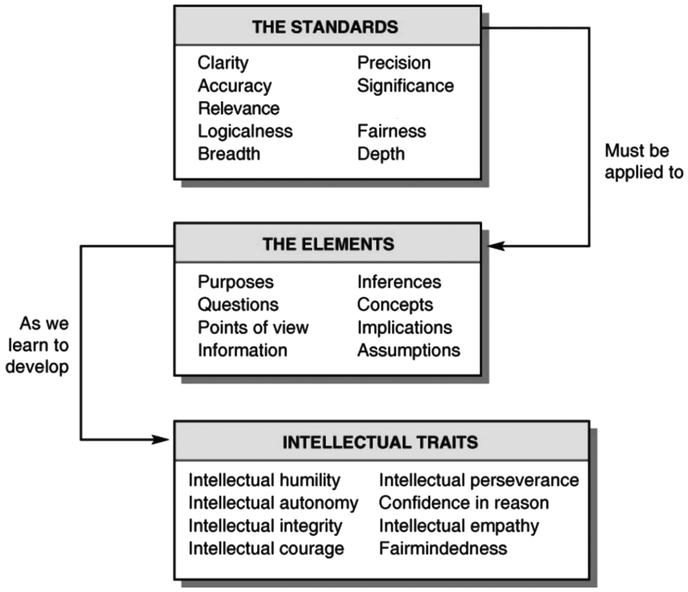

Figure 2.3: Paul-Elder Critical Thinking Framework (Paul and Elder 2013)

After these elements of thought have been established, they can be assessed by referring to intellectual standards. Both of these aforementioned elements (Elements of Thought and Intellectual Standards) make it possible to create transparent statements and to pinpoint interpretations and specific questions. According to Paul and Elder (2013), constantly practising critical thinking skills while incorporating these components helps to cultivate certain traits, such as perseverance, courage, autonomy, integrity, fair-mindedness, confidence in reason, and humility. This process also strengthens the tendency to consistently employ higher cognitive skills (Al-Mubaid and Bettayeb 2017; Yang and Chou 2008; McLean 2005). Of particular note, the Paul-Elder Critical Thinking Framework provides instructors and students with a communal language and a very structured approach that can be used to assess critical thinking skills on a situational

Standards	Definition
Clarity	A clear argument denotes that the ideas are understandable and that the justifications have been well-explained and demonstrated clearly, within an exact context, leaving the reader with no further doubts.
Accuracy	Accurate statements are strongly associated with evidence and with reliable resources that can be used to extract the information necessary to support any claims.
Precision	Precise arguments are clear, accurate, and relevant to the questions, and the information used to present ideas require no additional words.
Significance	Significant statements hold essential, consistent, and meaningful claims that require important, clear, accurate and precise facts, which can be ascertained by asking questions or acquiring information and by considering both positive and negative results.
Relevance	Relevance represents the connections and relationships that can be established to identify similar patterns among questions, information, and methods.
Depth	Deep and intense arguments consider difficult problems and require sophisticated thinking to answer certain questions.
Breadth	Arguments with breadth show different points of view and diverse aspects, with respect to relevance and significance.
Logic	Logical arguments follow valid and reasonable principles that examine consistency and avoid logical fallacies based on evidence and facts.
Fairness	Fair judgements are objective and free from hidden biases. Fairness standards minimise the effects of uncontrolled emotional statements by considering both objectivity and subjectivity during evaluation and analysis.

Table 2.5: Definitions of the Intellectual Standards

basis (Ralston and Bays 2013). This framework also aids observers in the identification of evidence related to critical thinking, which can be derived from discussions. Critical and considered discussion threads should simply and accurately illustrate the various elements of the framework.

The Paul-Elder Critical Thinking Framework uses a comprehensive and broad definition of critical thinking. The framework clearly states that critical thinking contains nine essential standards: thinking clearly, accurately, precisely, logically, fairly, significantly, relatively, broadly and deeply (Figure 2.3). According to Paul and Elder (2013), these standards, should be adopted by using systematic research steps, called the Elements of Thought: purpose, questions, information, inference, concepts, assumptions, implications, and point of view (Figure 2.4). The definitions of the intellectual standards and elements of thought are briefly presented in Table 2.5 and Table 2.6. The standards and elements are discussed in details in Chapter 4.

Indeed, Celuch and Slama (2002), used the Paul-Elder Critical Thinking Framework in their study to examine the elements underlying the theory of planned behaviour.

Elements	Definition
Purpose	In research, the purpose is the aim of study, including motives, intentions and functions.
Questions	Determining what question must be addressed, why they must be addressed, and what types of questions should be asked are all aspects of thinking critically.
Information	Information can be defined as the facts or data that emerge from evidence or as the experiences that are used to understand certain situations.
Inferences	The interpretations or conclusions that result from critical thinking exercises are referred to as inferences.
Concepts	The concepts in any theoretical work refer to the thoughts, ideas, and methods that are applied to generate hypotheses and to the principles required to understand phenomena.
Assumptions	Beliefs that exist at the subconscious or unconscious level and are taken for granted are called assumptions.
Point of view	The point of view is the position or perspective used to examine an issue.
Implications	Implications are truths or conclusions that logically follow other truths or conclusions.

Table 2.6: Definitions of the Elements of Thought

Celuch and Slama found that using this framework to teach critical thinking significantly improved attitudes toward critical thinking, self-efficacy with regards to the use of critical thinking skills, and self-identity as a critical thinker. In fact, Celuch and Slama found that the framework was effective for assessing critical thinking skills with regards to behavioural intentions, attitudes, social influences, perceived control, self-efficacy and self-image (Celuch and Slama 2002). In a relevant study (Ralston and Bays 2013), the Paul-Elder Critical Thinking Framework was used because of its comprehensiveness, disciplined neutral terminology and extensive high-quality resources. The study was conducted to enhance critical thinking skills across the undergraduate experience for engineering students, and the findings were significant, thus encouraging the use of this framework for other critical thinking experiences.

The Paul-Elder critical thinking framework has been used in studies that involves behavioural and cognitive objectives for critical thinking (Celuch and Slama 2002; Ralston and Bays 2013; Novotny et al. 2016; Al-Mubaid and Bettayeb 2017; Asiri et al. 2018, 2019). The reasons for using the Paul-Elder critical thinking framework in this study can be concluded into three main reasons. First, critical thinking is considered to be a behaviour that can be observed and changed (Haghparast et al. 2014; Saade et al. 2012). Second, critical thinking can be separated into multiple standards and elements, which allows each standard and element to be assessed separately (Al-Mubaid and Bettayeb 2017; Duron et al. 2006). Third, using this framework, research project-based work is the context for applying critical thinking skills. The integrating of the components of the Paul-Elder critical thinking framework (standards and elements) with the digital

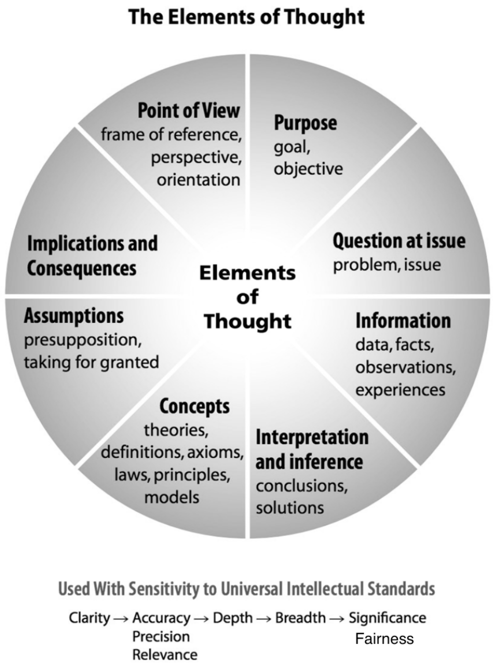

FIGURE 2.4: Elements of Thoughts As A Part of Paul-Elder Critical Thinking Framework (Paul and Elder 2013)

intervention has a feasible potential to be mapped together. For example, the the intervention components (project information, activities and training, practise tasks, short questionnaires, setting goals and plans, notifications for engagement, inquiries and answers, and providing feedback and instructions) were mapped into the standards (clarity, accuracy, precision, significance, relevance, depth, breadth, logic, and fairness) and the elements (purpose, questions, information, inferences, concepts, assumptions, points of view, and implications) of critical thinking as demonstrated in the different studies in this research (Chapter 6 and Chapter 7).

In this research, the two main sections of the Paul-Elder framework were used to facilitate the skills and the behaviour of critical thinking in the context of research projects. For instance, the elements of thought consist of the essential steps for conducting a research project which requires asking questions to identify the aims from the research projects, finding a purpose, gathering information, making inferences, using and employing concepts, testing assumptions, considering other points of view, and concluding the implications from the research projects. Accordingly, the intellectual standards are used to make the claims and arguments in the research projects clear, accurate, precise, significant, relevant, deep, with breadth, logical, and fairly balanced. The skills and the behaviour of critical thinking was supported by using the digital mBCI techniques and components.

2.1.6 Assessment and Measurement of Critical Thinking

The ability to access massive amounts of information has increased rapidly with the advent of the internet (Renaud and Murrayb 2008). Communication among people increases every day. Books and educators are no longer the only available sources of knowledge. There are no restrictions on the types of information individuals can receive from others (Holzer et al. 2015). For these reasons, the development of critical thinking tools that allow individuals to assess the information that they are exposed to is highly encouraged (Garrison et al. 2001).

Thinking critically would be more difficult if we were not aware of our own human nature (Paul and Elder 2008). Indeed, without thinking, humans can be biased, ignorant, and subject to change based on our habits of mind and the different contexts we inhabit (Abrami et al. 2015). Therefore, our thoughts must be reviewed, assessed and discussed by others, and more specifically, by experts. Moreover, collaborating with others, by thinking and clearly expressing our mental images of ourselves, is another method of critical thinking (Paul and Elder 2006). Using the input of others to evaluate our ideas and to view problems from different perspectives is extremely useful during the development of critical thinking skills. More importantly, being aware of evaluation standards and thinking criteria can serve to increase critical thinking skills (Clear 2014).

However, measuring critical thinking skills is not easily accomplished, and various effective and regular assessments are required; indeed, most of the available standardised tests for the examination of critical thinking skills are generally considered to be insufficient (Ennis 2013). Three widely used tests are the Cornell Critical Thinking Test, the Watson-Glaser Critical Thinking Appraisal, and the California Critical Thinking Skills Test. These tests use multiple-choice pre- and post-tests to assess critical thinking abilities. According to Ennis (2013), this approach might not provide useful and accurate data; while these tests could measure certain factors, they cannot tell us the reasoning behind any specific answer. In fact, the problem with many of the instruments used to measure critical thinking is the lack of separate data collection for the different contexts or aspects of critical thinking. Each element of critical thinking should be measured in isolation first, after which, the context of the whole process should be examined to gauge the degree of development, especially in the context of research projects (Barak and Levenberg 2016). For instance, dividing initially the concept of critical thinking into nine standards (clarity, accuracy, precision, significance, relevance, depth, breadth, logic, and fairness) and eight elements (purpose, questions, information, inferences, concepts, assumptions, points of view, and implications) can help to examine later the overall critical thinking development for the learner as presented in Paul-Elder critical thinking framework.

The literature review shows that there are many standard methods for evaluating critical thinking skills (Table 2.7), including measuring the ability to work on multiple problem-solving tasks, such as location-based or puzzle-based learning, both of which involve setting prior rubrics for specific skills. Using Bloom's taxonomy model is another method for evaluating the educational objectives of critical thinking skills; indeed, this model has been found to generally provide a better understanding of the critical thinking skills of individuals (Dwyer et al. 2014). Many scholars have opined that several educational concepts, such as ubiquity, personalisation, interactivity, collaboration, scaffolding, and peer assessment strategies, should be merged for a more meaningful evaluation of critical thinking skills (Stupple et al. 2017). Argument maps technique has shown to play effective roles in the measurement and the development of critical thinking skills (Dwyer et al. 2012).

Measuring and examining the critical thinking skills of students is possible. In fact, standard tests such as Halpern assessment, Cornell test, Watson-Glaser appraisal, and Ennis-Weir essay test have been used to measure critical thinking skills. However, these standard tests only examine critical thinking for learners in general domains (Barak and Levenberg 2016). The literature review revealed the lack of an available instrument to measure critical thinking skills in the context of research projects. Therefore, an instrument was designed to fill this research gap. The instrument (presented in 4) was specifically designed to measure critical thinking skills of students during the process of undertaking research projects. This instrument was used before, during and after the digital intervention to indicate the perceived improvements in critical thinking skills based on self-reflections.

Critical thinking skills can be measured and evaluated using both standard and nonstandard tests; however, these evaluations should be performed with a great deal of careful consideration regarding the established criteria that are used to assess critical thinking skills (Ennis 2013). More importantly, the evaluation of critical thinking skills should no longer rely on a single assessment tool; it must include multiple measures of skill, knowledge, behaviour, and attitude (Alnuaim et al. 2012). Most research in the critical thinking literature has been theoretically focused on how to assess and measure critical thinking skills. In addition to contributing to theoretical approaches, research should also focus on helping educators establish the objectives, outcomes, and learning goals that they wish to measure, based on the standards of critical thinking and with the aid of new technologies.

Instrument	Format	Skills
Watson–Glaser Critical Thinking Appraisal	Forms of pre and post-tests with 80 items which takes 45-60 minutes.	Inference; Recognition of assumptions; Deduction; Interpretation; Evaluation of arguments.
California Critical Thinking Skills Test	Multiple choice form with34 items in the form of pre and post-tests which approximately takes about 40 minutes.	Analysis; Evaluation; Inference; Inductive reasoning; Deductive reasoning.
Ennis–Weir Critical Thinking Essay Test	Essay forms.	Getting the point; Seeing reasons and assumptions; Stating one's point; Offering good reasons; Seeing other possibilities; Responding appropriately and/or avoiding legal arguments.
Cornell Critical Thinking Test	Different levels of assessment for different ages in 60-70 items which takes 50 minutes to complete.	Induction; Deduction; Value judgement; Observation; Credibility; Assumptions; Meaning + semantics, definition and prediction in planning experiments.
Halpern Critical Thinking Assessment	25 items which requires 60-90 minutes to finish.	Verbal reasoning; argument analysis; thinking as hypothesis testing; likelihood and uncertainty; decision-making and problem solving.
Thinking Skills Assessment	50 items in 15 minutes to complete.	Problem-solving skills, including numerical and spatial reasoning. Critical thinking skills, including understanding argument and reasoning using everyday language.

Table 2.7: Standard Tests for Critical Thinking Assessment

2.2 Critical Thinking in Technology-Enhanced Student-Centred Learning Environments

This section provides an overview of the use of technology to aid the adoption of critical thinking skills. This section defines online learning environments (OLEs), how OLEs have previously been designed and used effectively, and the advantages and disadvantages of OLEs. In this study, the focus was on developing an OLE to teach, promote, and enhance critical thinking and research skills. Accomplishing this goal required an overview of the current methods and frameworks used to create effective OLEs for the improvement of critical thinking and research skills.

An OLE is defined as a virtual environment where learners can use a set of digital tools to learn, communicate and share ideas (Rusdi and Umar 2015). OLEs have previously been used in the form of web- and mobile-based applications that accommodate the learning process between students and educators. Many effective learning environments have been successfully designed and implemented. According to Saade and AlSharhan (2015), in OLEs, students can attend online lectures, ask questions, share comments and feedback, interact with different materials, in the forms of texts, pictures and videos, and evaluate the work of other students. OLEs provide practical opportunities for learners from different backgrounds and with different goals to practice their thinking in a general context (Yilmaz and Keser 2016). Indeed, technology might also be used to provide critical thinking guidance, as an intervention for use during the supervision of research projects.

Technology has a huge impact on almost every aspect of our lives. Critical thinking is one aspect that has been practised and improved upon by technological adaptations (Lee and Choi 2017; Cicchino 2015). For example, online discussion forums have been designed for educators and students to collaboratively enrich their critical thinking skills for several educational purposes (Salleh et al. 2012). Learners can openly discuss many topics, brainstorm ideas, share thoughts, interact with different views, and evaluate each other in many ways. These forums provide opportunities for learners from different majors and with different goals to practice their thinking in a general context (Yilmaz and Keser 2016). Indeed, technology (web- or mobile-based), in the form of a digital learning intervention, might be used to promote critical thinking skills. A previous study (Alnuaim et al. 2014) used mobile technology as a contextual device to foster interaction design skills and reported significant findings, which they attributed to certain unique features, such as connectedness, real-time interactions and personalisation, that could be integrated into daily tasks. These results could be associated with the concept of ubiquitous learning, which is defined as the ability to learn anywhere and at any time, and is therefore closely linked with the affordability of mobile technologies. The portability of computers and computing devices has allowed differences between formal and informal learning to be bridged, especially in terms of supporting critical thinking skills.

2.3 Online Mobile- and Web-based Applications to Improve Critical Thinking

Web-based platforms are currently being utilized in higher education, and many schools utilize online discussion forums that have been designed to collaboratively enrich the critical thinking skills of educators and students for educational purposes (Salleh et al. 2012). More recently, educators have used general online tools to design specific content for learners, such as massive open online course (MOOC) platforms, Google documents and Facebook pages (Alrasheedi et al. 2015). These tools offer flexibility in environmental designs and settings, allowing educators to easily create groups, deliver messages, and promote group discussion. Similarly, for mobile devices, mobile learning applications have been used to engage educators and learners in the process of designing

OLEs. This section will focus more on mobile technology than on web-based technology, as mobile technology was the primary tool used for this study. The advantages and disadvantages of using mobile-based tools to support the learning of new skills will be highlighted in this section.

Mobile learning helps learners to actively engage with different educational environments (McCann and Camp 2015). Engagement is no longer limited to specific times or places. Students and teachers can remotely interact with each other on various topics, and communication can occur in different places or contexts, which can produce varying results (Kumar 2011). Mobile technology has become one of the most important aspects of modern life, with the majority of people possessing some type of mobile device at all times (Alhassan 2016). These devices can be used for voice or text communications as well as many other applications, such as social interactions and entertainment (Jones et al. 2013). Nowadays, most people, including students, have smartphones or mobiles. This has led educators to more strongly consider the possibility of using mobile technologies for various educational aspects. In fact, mobile technology has been demonstrated to be capable of successfully supporting students and educators in the achievement of some of their goals (Alnuaim et al. 2016).

Mobile technology is easy to use and does not necessitate much training for users wishing to learn (Motiwalla 2007). These characteristics have led us to consider all of the possible methods through which mobile technologies could serve as useful educational tools. Many educational activities can be adopted using mobile technology (Wilmer and Chein 2016). These activities might include a variety of tasks, including taking notes, sharing, watching lectures, making voice recordings, creating videos, accessing information and data on the Web, engaging in group discussions, and communicating with educators and other students. According to Farley et al. (2015), a mobile device can act as a personal organiser, with users able to set alarms, access calendars, and utilise maps for navigation; indeed, all of these aspects can help individuals improve their daily behaviours.

Mobile technology adaptations can be implemented to support critical thinking. The ability to contact educators, experts and researchers at any time and from any location is a great advantage for students and allows them to practice high level thinking within the context of advanced research tasks (Heflin 2017). However, to achieve this goal, systems should be developed with consideration given to technical, pedagogical, design and ethical issues. Mobile technologies must also account for limitations, such as the occasional lack of wireless networks and small screens, which can be hindrances (Chen and David et al. 2008).

Mobile learning has the advantage of helping people learn within various contexts. Mobile learning has fewer limitations in terms of place and time and can thus facilitate interactions between people. These types of features are helpful when promoting the cognitive skills that are required to work in many different environments (Reychav and

Wu 2016). In fact, the portability of mobile technology has become one of its greatest traits for use in classroom-based mobile learning experiences and outdoor environments (Zheng et al. 2016). Using mobile technologies, researchers have the opportunity to invent new educational methods, across almost every aspect of teaching and learning, that can help teachers achieve their goals. Designers of curricula can create suitable content for mobile technology that can also facilitate new methods of communication and interaction among researchers, educators, and students (Heflin 2017).

The advanced features of mobile technology, such as individualised interfaces, real-time access to information, context sensitivity, quick communication, and instant feedback, have great potential for fostering positive learning behaviours in users (Hsu and Ching 2015; Achterkamp et al. 2016). These features can help not only students but also educators to achieve the educational goals and learning outcomes they seek. Most studies concerning mobile learning have focused more on the content side than on the technical side. Moreover, only a few studies have concentrated on higher-level skills (Nicholas and Raider-Roth 2016). Therefore, more research must be conducted on these skills to fill the gaps between real classroom environments and outdoor environments.

2.3.1 Using Mobile Technology to Enhance Critical Thinking Skills

Many attempts have been made to utilise mobile devices in education. As shown in Table 2.8, several studies have used mobile devices (smartphones, tablets, and cell phones) to enhance thinking skills. For instance, Boyinbode and Ng'ambi (2015) designed MOBILect to study the idea of using mobile devices to foster learning. MOBILect is an interactive mobile lecturing tool that helps students and professors in higher education more easily utilise podcasting and video-casting to promote deep learning. MOBILect was developed to foster out-of-class, face-to-face interactions between students and their teachers through the use of mobile phones. The present study shows that students demonstrated positive attitudes towards using mobile devices to engage in social learning environments designed to foster their knowledge. Moreover, the personalisation features offered by mobile phones allow students to be active in different contexts during their activities. In fact, students view their mobile devices as a more engaging method of staying connected with their lecturers than traditional communications.

Another study by Wong (2013) assessed the extent to which a mobile application called CritlQ could enhance the abilities of students to learn and communicate. CritIQ is a mobile critique platform that enables and motivates undergraduates learning communication design to design platforms together and to critique each other's work. Engaging student designers to collaborate through mobile devices resulted in significant improvements in their creative designs and critiques.

Technique	Purpose	Experiment/results	Citation
MOBILect	An interactive mobile lecturing tool that helps students and professors in higher education to overcome the challenges in podcasting and video-casting to promote deep learning.	Students' deep thinking was improved.	(Boyinbode and Ng'ambi 2015)
CritIQ	A mobile critique platform for undergraduate communication design Learners to enable and motivate designers to co-design with each other and also criticise each other's work.	Designers' ability to thinking critically enhanced.	(Wong 2013)
sLearn app	A location-based learning application to support human-computer interaction students in their critical thinking to understand the context for design.	Human-computer interaction's students showed improvement in design skills.	(Alnuaim et al. 2014)
BaloneyMeter	A mobile learning application that provides support for teaching critical thinking skills in general.	The app helped to provide students information about thinking skills.	(Holzer et al. 2015)

Table 2.8: Mobile Apps to Enhance Students' Learning and Thinking Experience.

A study by Alnuaim et al. (2014) used a location-based application (sLearn app) to support human-computer interactions to develop the designing skills of students and to aid their attempts to understand the context of design. In this study, the location of the assignment was the primary factor underlying the design. The study focused on simple educational tasks that were given to students in certain locations and tracked which students worked on the tasks while receiving support from their instructors via their mobile devices. The decisions made by the students, both before and after the implementation of the mobile application, were studied. The results revealed general significant improvements in the abilities of the students to think critically and make decisions.

However, in this short-term study, some students did not notice any improvements in their critical thinking skills. Critical thinking requires time to develop (Dwyer et al. 2015). Moreover, critical thinking involves several stages and standards that should be tested separately, such as clarity, accuracy, precision, relevance, breadth, fairness, logic, depth and significance. No accurate assessments of the growth of student critical thinking skills were performed by the authors [i.e., Alnuaim et al. (2014)]. The sole focus of their study was the effects of the locations where students were required to complete their assignments, and the study lacked continuous interactive interventions between students and instructors.

This thesis attempts to identify and address issues that have not been addressed by previous studies. Suggestions will be made regarding how to implement the use of mobile behaviour change interventions (mBCIs) between students and instructors to enhance the process of learning how to think critically; these suggestions will be made in the behavioural learning context. This study suggests that the design of any instrument utilised for critical thinking activities will be more useful if the software tool is reusable, as with the inclusion of an authoring tool. Reusability will allow intervention builders to re-design their scalable content for various contexts. Therefore, the present study utilised the LifeGuide Toolbox software tool, which is a reusable tool that allows intervention designers to develop mobile apps based on their specific requirements. Details of the LifeGuide Toolbox software tool will be discussed in Chapter 5.

2.3.2 The Designs, Frameworks, Evaluations, and Usability of Mobile Learning Systems

As stated by Rikala (2015), it is important to determine the proper mobile design and methods for evaluation prior to conducting studies, which requires identifying a suitable framework and a model that facilitate the process of implementation and learning. The contexts for which the mobile learning platform and the evaluation methods were designed should be consistent with the context that is being studied to provide an effective mobile learning environment. The method used to design a mobile learning platform in this study is based on human-computer interactions, to better focus on the factors associated with this type of interaction. According to Botha et al. (2010), mobile human-computer interaction is defined as the study of the relationship between users and mobile system applications that are used on a daily basis. The purpose of studying mobile human-computer interactions is to understand the implications of using and interacting with a mobile system. According to Hsu and Ching (2015), the interaction process between users and mobile systems can be studied based on the expectations of the users, user behaviours, system usability, system capabilities, and how the mobile system can be effective and useful with respect to the needs and requirements of the users. This definition suits the objectives of the current study and form the two primary aspects of any mobile learning framework: designing the tools and developing the content that supports the users.

As shown in Table 2.9, there are many learning theories that have been applied to mobile learning. For instance, the behaviourist learning theory of mobile learning indicates that mobile devices can be useful for the support of learning as a behaviour. According to Park (2011), the behaviourist leaning theory posits that the process of learning can be achieved by facilitating the reinforcement between a motive and a response. Mobile learning applications that are supported by learning materials that use relevant knowledge as motivators can entice learners to respond by learning from the

Learning theory and themes	Key researchers	Tasks and activities
Behaviourist learning	Skinner, Pavlov	Drill and feedback, Classroom response systems
Lifelong and informal learning	Vygotsky	Mobile computer, Supported collaborative learning (MCSCL)
Learning and teaching support	N/A	Support for administrative duties (e.g. attendance)
Constructive learning	Piaget, Bruner, Papert	Participatory simulations
Situated learning	Lave, Brown	Problem and case-based learning, Context awareness
Collaborative learning	Eraut	Supporting intentional and accidental learning, Episodes, Personal organisation

Table 2.9: Mobile Learning Theories (Naismith et al. 2004)

designed content. Another mobile learning theory is the lifelong and informal learning theory, which studies the learning that occurs when interacting with mobile content in an informal context. Other mobile learning theories and themes, such as constructive, situated and collaborative learning, are shown in Table 2.9, as suggested by Naismith et al. (2004).

2.3.2.1 Challenges to the Design of Mobile Learning Systems

There are several challenges to the design of an effective mobile learning system (Grant 2019). These challenges have been identified by many researchers and must be considered when designing or implementing a mobile learning system.

First, there can be technological challenges, which can include mobile connectivity due to limited or poor internet signals that prevent users from communicating with each other or accessing necessary information (Vavoula and Sharples 2009; Elias 2011). Other technological challenges can be caused by differences in the operating systems or mobile devices being used, which have different models or settings. In addition, small screens and short battery lives can be technological challenges that might limit the ability of a user to interact with the mobile system.

Second, there can be design challenges, which represent the most important challenges for developing a mobile learning system (Elias 2011). Design challenges can denote difficulties in system design or in learning content design. Design challenges can occur throughout the developmental process, from gathering the necessary materials for the design of the mobile learning system to the implementation of the prototype. Fourth, there can be evaluation challenges, which refer to difficulties associated with the assessment and evaluation of the outcomes, achievements, and progress of the learning process and to difficulties associated with the evaluation of the effectiveness and the efficiency of the system itself (Vavoula and Sharples 2009).

2.3.2.2 Frameworks for Mobile Learning Systems

Mobile learning frameworks are different from eLearning frameworks, based on the challenges mentioned above. This section discusses the primary mobile learning framework developed by Parsons et al. (2007), which is relevant to the objectives of this study. This framework was considered when designing the mobile intervention, which will be discussed in detail in Chapter 6. Moreover, this framework has been widely used in experimental studies within the context of education and human-computer interactions. The Parsons framework identifies the requirements for designing a mobile learning system. The three primary aspects addressed by this framework are illustrated in Figure 2.5. First, generic mobile issues, which are issues associated with mobile environments, such as addressing the context of mobility for the device and the user interface. Second, mobile learning contexts, which include six components, such as identity, learners with the attitudes, individual activities performed by the learners, collaboration, the spatiotemporal details, and the type of the mobile device, also referred to as the facility. Third, learning objectives and experiences, which are the new, improved, social or team skills that the learners are meant to acquire from the mobile learning experience, including goals and objectives.

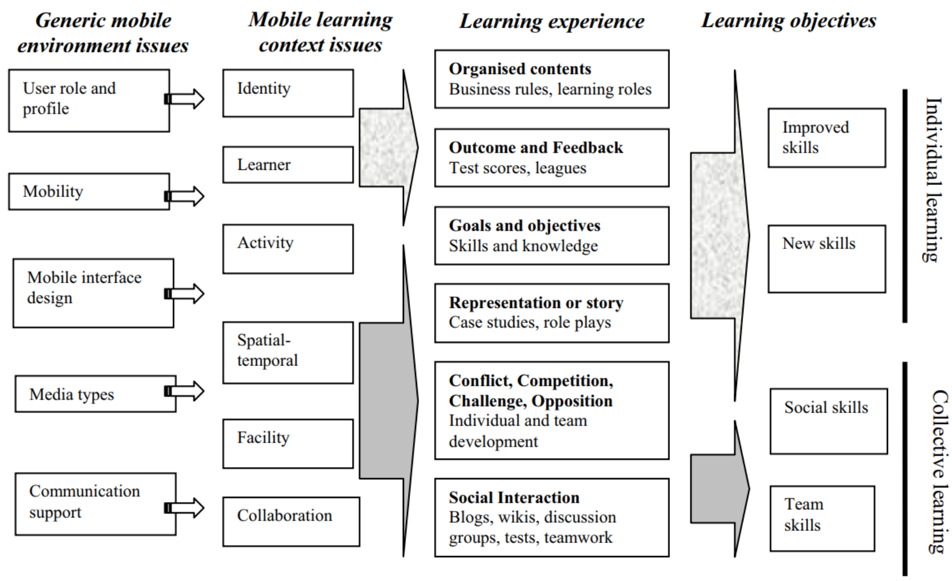

FIGURE 2.5: A Framework for mLearning Design Requirements by Parsons et al. (2007)

According to Herrington et al. (2009), there exist common principles for designing a mobile learning system for students in higher education, which can be described as follows:

- Relevance to the real world: the mobile learning system must have authentic settings.
- The context of the mobile system: the contexts that the learners will be in, whether it is ubiquitous or on-the-go.
- Exploration: the technology must be easy and familiar for the learner to use.
- Blended environment: the mobile environment is blended, including both mobile and non-mobile tasks in the activity.
- Whenever, wherever and whomever: spontaneous formal and informal use for the mobile system, in any place and at any time, by learners, both collaboratively and non-collaboratively, during learning.
- Affordability: the mobile system makes use of the affordability of mobile technologies.
- Personalisation: Enabling users to personalise their experience with the mobile learning system.
- Mediation and knowledge production: the mobile learning system facilitates and delivers knowledge and content to the learners.

To evaluate a mobile learning system, this study focused on two primary components: evaluating the mobile learning experiences for users, and evaluating the mobile design, usability, and user experience. In this study, a well-established approach, developed by Vavoula and Sharples (2009), was utilized to evaluate the mobile application-based intervention, based on design and user experiences, after it was used by students to enhance critical thinking skills in the context of research projects.

This evaluation approach consists of three levels, as shown in Figure 2.6. First, the micro level, which examines the individual activities of the mobile users and the technologies being used. Second, the meso level, which examines the mobile learning experience and its relationship with the activities being performed. Third, the macro level, which examines the impacts of learned skills and their practice within educational institutions.

2.4 Summary of the Online Learning Environments Used in Critical Thinking

This section provides an overview of the technology that has been adopted to develop critical thinking skills. This section defines OLEs, how they have been designed and used effectively it has, and discusses their advantages and disadvantages. In this study,

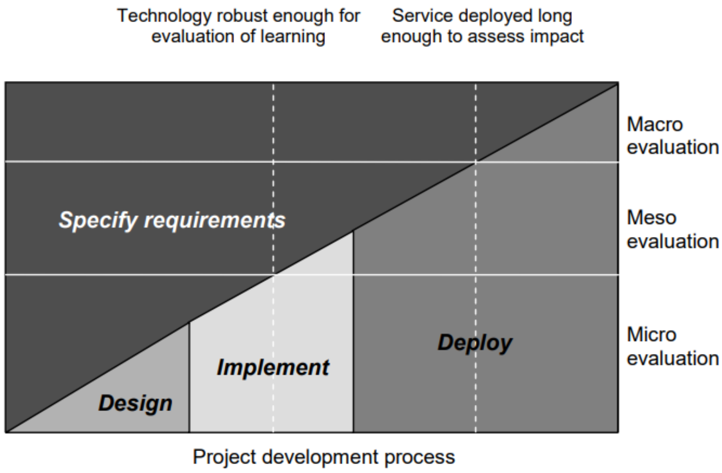

FIGURE 2.6: Evaluation Activities at the 3 Levels over the Project Phases by Vavoula and Sharples (2009)

the focus was on the design of the OLE to teach, promote, and enhance critical thinking and research skills. This process required an overview of the current methods and frameworks used to create effective OLEs for the improvement of critical thinking and research skills. This section provides the foundations for the theories and frameworks used to design and evaluate the mobile learning system for critical thinking that was used in the experiments described in this study.

2.5 Undergraduate Research Projects: Digital Tracking Systems and Supervision

This section will provide an overview of the current studies using research projects to approach the teaching of critical thinking skills. Additionally, this section will identify the web-based or mobile-based platforms that have commonly been used to assess or organise the supervision process. The methods and frameworks that have been used for this process demonstrate the current technological attempts to bridge and facilitate communication between supervisors and their students in the context of research projects.

2.5.1 Critical Thinking in the Context of Research Projects

Research projects are generally tasks that are assigned to undergraduate students at the end of their studies to teach them how to work on a research experiment (Bakar et al. 2011). Students require a specific set of skills to perform well during research projects. According to Brewer et al. (2012), during undergraduate research projects, critical thinking skills are considered to be among the most necessary skills that a student must demonstrate. Other skills, such as academic writing skills and the ability to conducting an experiment, are also important. Undergraduate research projects are important because they help students learn to apply their knowledge to critique other work and develop new thinking skills (Seifi et al. 2014; Ralston and Bays 2013). Research projects also allow students to practice integrating new information or data, through processes such as gathering relevant data, performing data analyses, and evaluating arguments (Pejic et al. 2017). Research projects place students in the scientific thinking mind-set, where they must be prepared to support their views with evidence, logic and reasoning. According to Hajdarpasic et al. (2015), there are many other aims when working on research projects, which include communication skills, independent study, and becoming a researcher instead of a student.

Other terms have been used to describe the educational activities associated with research projects (Brew and Mantai 2017), including problem-based task, research-based project, inquiry-based learning, and action learning theory. A problem-based task is a learning concept where learners work on problems to acquire the skills required to solve, manage, and communicate the solutions for similar problems in the real world. Similarly, the inquiry-based method is a process for teaching learners the necessary skills for asking questions and proposing possible scenarios, rather than thinking only with regards to existing facts. All of these terms have the same goals but use slightly different implementations.

Critical thinking is one of the most essential objectives that students are expected to achieve when research-based tasks are involved in a project (Ogden 2018; Stupple et al. 2017). In fact, using critical thinking skills is crucial for every step during research. The students must be aware of the implications of the critical thinking process and must be reminded to consider these implications during their projects. However, a study by Norouzi et al. (2012) showed that students lack knowledge regarding critical thinking and how to apply these skills in practice, especially in the context of research-based projects. Moreover, students have been shown to exhibit a level of disengagement throughout their research projects (Linn et al. 2015). Therefore, it is important to address cognitive and behavioural support, which could maintain student engagement during the research process. Using technology can facilitate the requirement that students practice their skills. In fact, well-designed technology can help students overcome the barriers of time and location. Current technological attempts to foster critical thinking will be addressed in the next section.

The main idea of Ogden's book (Ogden 2018) is to use the scientific research steps to teach critical thinking. This book starts by answering the question: why do we need CT? This is followed by presenting the scientific research process for conducting a research and it's called 'Critical Tool Kit'. For instance, it introduces the research methods, study design, measurement. Accordingly, the book shows how to apply critical thinking skills with exercises on methods, study design, measurements, data analysis. Finally, a chapter was written to pay attention to how think critically about the presentation of an idea or argument.

2.5.2 Research Projects Supervision

Generally, students are assigned an academic advisor to mentor, guide, and support them during the research project. However, it is not always helpful or cost-effective for students to improve their critical thinking skills only through classroom lessons or through meetings with their supervisors (Clear 2014). Students require continuous assistance throughout their research projects, to guide them with relevant information. In addition to the benefits of working on a research project, there are many challenges that students might face when conducting research. Moreover, undergraduate students tend to have only a basic level of experience with research-based learning (Kim et. al. 2013).

Supervisors and their students often interact face-to-face in regular meetings. When face-to-face communication is not possible, students and supervisors generally interact through basic tools, such as email, for text-based communications, and audio recordings (Voelkel et al. 2018) or Skype, for video-based meetings (Vereijken et al. 2018). Some supervisors and students are familiar with other types of tools that allow them to maintain contact, such as online supervisory tracking systems (Bakar et al. 2011). These methods allow both supervisors (with limited programming backgrounds) and students to collaborate easily and flexibly with regards to time and place. However, these systems have limited settings, and the interfaces cannot always be designed to accommodate desired formats and content. The problems with the current tools can be overcome using the tools and frameworks proposed in this current study, which would enable both supervisors and students to communicate effectively and easily.

In this study, both critical thinking skills and research skills are considered. Based on the Paul-Elder Critical Thinking Framework, the potential that students learn to successfully using both critical thinking and research skills increases. Additionally, with the help of mobile interventions, students will be reminded of the actual steps required to achieve higher-order thinking skills. Relevant information and tailored advice can be delivered by experts, whenever and wherever these students require support (Scanlon et al. 2005).

2.5.3 Undergraduate Projects in the Context of this Study

Academics and undergraduate students were the subjects of the experiments performed in this study. The students involved in the experiments described in this study participated in undergraduate engineering projects in the Electronics and Computer Science

Department of the University of Southampton. The University of Southampton was approached with the aim of obtaining long-term ethical approval for these studies to be conducted. However, this research is applicable to other universities and fields. In addition, according to Shaw et al. (2013), descriptions of undergraduate research projects have been found among similar programmes and with similar requirements at many different UK universities. Therefore, the targeted participants should not vary much from the general population of students involved in research projects.

2.5.4 Summary of the Critical Thinking and Research Projects

This section begins by identifying the definitions of critical thinking skills and their importance. This section presents the methods that have been used and studies that have been performed to improve the critical thinking skills of students. The literature demonstrated a lack of digital tools design specifically to support critical thinking development in the context of research projects. Therefore, the hypothesis being tested here is that DBCI could bridge this research gap and that studying the feasibility of designing, implementing and evaluating such a system could promote the development of critical thinking skills in the context of research projects.

2.6 Digital Behaviour Change Interventions (DBCIs)

The digital behaviour change intervention (DBCI) is a model for supporting both the intervention creator and the intervention user during the development of a system designed to change undesirable behaviours (Pinder et al. 2018; Yardley et al. 2016). Digital interventions have been used in health education fields to facilitate communications between doctors and patients. According to Lustria et al. (2013), there are many components within digital interventions that must be considered when designing an effective digital intervention (Figure 1.1). Identifying the content to be delivered through the internet is one of the essential factors for DBCIs. The content, which is designed to provide users with information or advice, can be designed by intervention builders, who are technological experts, or by researchers in the field. The data generated from web- or app-based tools can be later studied to evaluate how both experts and users interact with the system, to identify when and how information is delivered to users, and to identify behaviour patterns (Ritterband et al. 2009).

According to a survey by McCully et al. (2013), using the internet as a platform for delivering BCIs on a large-scale is becoming more viable as more people seek help concerning their health and well-being issues. With increasingly widespread and low-cost access to the Internet, BCIs are being adapted for online use. Utilizing the internet to deliver these interventions can address many of the drawbacks of offline and conventional

BCIs (Griffiths et al. 2006). In addition to the personalisation and adaptation possibilities, the cost-effectiveness of behavioural interventions, anonymity, confidentiality and accessibility are other potential benefits of DBCIs. These benefits are being successfully harnessed through a number of web-based interventions, which will be described in the next subsection. To provide further flexibility, such as providing end-users with on-the-go access and easier self-monitoring capabilities (Kraft et al. 2008), several mobile-based interventions have been implemented, as discussed in section 2.6.2.

2.6.1 Web-based Interventions

Web-based BCIs, such as the LifeGuide (Hare et al. 2009), provide intervention builders with the ability to create their own digital interventions, without requiring any programming knowledge. Web-based interventions offer the possibility of reaching large groups of individuals, and raising awareness regarding the availability of these interventions is important. For example, Crutzen et al. (2009) proposed using online word-of-mouth messaging to motivate individuals to visit online interventions.

2.6.2 Mobile-Based Interventions

Although the use of mobile phones for DBCIs is not new, the limited capabilities of earlier phones meant that only basic features could be implemented for these systems, such as the use of the Short Message Service (SMS), as proposed by Fjeldsoe et al. (2009); in some limited instances, personal digital assistant (PDA)-based applications were used to provide increased interactivity (Riley et al. 2011). However, some degree of personalisation was already available through the use of personalised text-messages to end-users, such as the Text2Quit study by Abroms et al. (2012), which tracked the number of cigarettes smoked by end-users and sent them tailored messages.

With smartphones becoming more popular, DBCIs have also been developed in the form of mobile phone applications (Weal et al. 2012), which are closer to individuals and can enhance the level of customisation through the use of contextual data provided by sensors embedded in phones. This merging of BCI applications with the sensing capabilities of smartphones has also been explored by Lathia et al. (2013). Lane et al. (2013) presented a personal health application for smart phones that used sensors, such as the accelerometer, digital compass, and GPS, to automatically monitor personal aspects of end-user activities, including sleep, physical activity and well-being. The application then provided customised feedback to each end-user. Another example using smart phone sensor capabilities was demonstrated by Pejovic and Musolesi (2014), who created a mobile application intended to address depression. This mobile application worked by monitoring end-user movements, lack of socialisation, and irregular sleep patterns through a combination of sensors, such as GPS, accelerometers and Bluetooth. Whenever signs of depression were detected, the end-users were provided with an adapted intervention tool through the application, such as a web link to buy theatre tickets for two people when a lack of social contact was determined.

However, much remains to be achieved in this area, as smart phones with advanced sensors are relatively recent, and their impacts on the outcomes of interventions are largely still being evaluated. As with most innovations, the initial feedback from users, as gathered by Dennison et al. (2013), showed some degree of reluctance and feelings of embarrassment in cases where end-user engagements with these types of applications could be broadcast widely. As more end-users utilize these types of applications, they will eventually become more socially acceptable due to peer influence. In addition, including some control mechanisms that empower end-users to choose what types of information are shared may inspire more trust (Alkhaldi et al. 2016; Bradbury et al. 2014).

2.6.3 DBCIs in Educational Contexts: Reflection and Engagement

Traditionally, behavioural intervention has been conducted through face-to-face meetings. Face-to-face meetings allow experts to interact with people who require support or help. During traditional interventions, experts provide advice regarding specific issues. However, Morrison et al. (2018) and Yardley et al. (2016) identified two primary problems when behavioural interventions are delivered in face-to-face sessions. First, the time spent consulting with experts is expensive, making it difficult for experts to provide each individual with as much support as may be needed. Second, limits on the experts' time can lead to reductions in the number of people they can see. In the educational context, research project supervisors face similar problems when supervising students during research-based projects (Hajdarpasic et al. 2015; Clear 2014).

Traditional interventions have been used in education to help students with their studies or their disabilities (Briz-Ponce et al. 2016). According to Vainio et al. (2014) and Mooney et al. (2005), many learning strategies have been used as intervention strategies. For instance, self-regulation, self-reporting, and self-monitoring have been used as indicators that students require educational or behavioural support. These techniques refer to self-generated ideas, beliefs, behaviours, feelings, and actions that are planned in advance and can be implemented to enhance student learning during the academic experience. Accordingly, interventions can be performed when learners self-report and reflect on their current perceptions of a situation (Mace et al. 1989). Interventions can play major roles in how learners approach goals, tasks, and challenges (Mooney et al. 2005). Many indicators have been examined for determining when a student is in need for assistance. The following are some examples:

- Reflection: a process involving a person consciously looking at and considering his or her experiences, actions, feelings and responses and then interpreting or analysing those experiences to learn from them (Boud et al. 1994).
- Self-monitoring: a two-stage process involving a person observing and recording his or her own behaviour, requiring that (a) the student discriminates between the occurrence and non-occurrence of a target behaviour and that (b) he or she self-records some aspect of the target behaviour (Mace et al. 1989).
- Self-evaluation: a process involving a student comparing his or her performance with a previously established criterion that is set by another student or teacher (e.g., improvement of performance over time) and being awarded with reinforcements that are based on achieving the criterion (Zimmerman 2013).
- Self-instruction: a process involving a student using self-statements to direct behaviour (Harris 1990).
- Goal setting: a process involving a student self-selecting a behavioural target (e.g., term paper completion), which serves to structure efforts, provide information regarding progress, and motivate performance (White 2002).

2.6.4 LifeGuide Toolbox with A Web-based Authoring Tool

The LifeGuide project[1], which started in 2009, was designed by computer science and psychology researchers at the University of Southampton, the University of Cambridge, and the University of Birmingham. The original LifeGuide project developed LifeGuide, a Web based platform. The subsequent UBhave project developed the LifeGuide Toolbox, which was a mobile extension of the LifeGuide platform. The aim of these projects was to develop a software tool that could help researchers with no programming experience to design DBCIs and create interactive web or mobile content to support learners (Hargood et al. 2012; Yardley et al. 2009). The software was mainly used by researchers in the fields of Behavioural and Health Sciences. The software tool has successfully been used for health behaviour changes, such as weight management, physical activity support, hand hygiene, and smoking cessation (Weston et al. 2015; Hargood et al. 2014).

The LifeGuide Toolbox software package was primarily developed to provide designers with a tool that could be used to create internet-based interventions to help users change their undesired behaviours (Figures 2.7 and 2.8). The LifeGuide Toolbox contains a set of features that enable users to set goals, plans, and perform certain activities, as well as to answer questionnaires or polls, with no limits on time or place. These digital tasks help researchers study how effectively users interact with the intervention and to evaluate user engagement with the tool (Williams et al. 2013).

[1]LifeGuide Project Website: https://www.lifeguideonline.org/

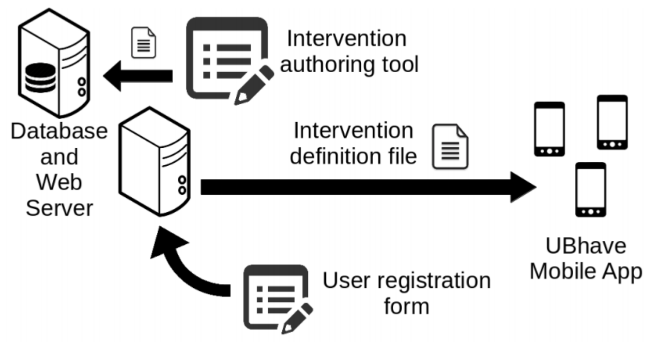

FIGURE 2.7: Overview of the LifeGuide Toolbox Framework by Hargood et al. (2014)

In addition, the notification system provided with the tools can easily be adjusted for different experiments. The tools are designed to help both the author and the learner, i.e., the students and the supervisors, generate multi-cross applications for effective communication and collaboration. The following steps must be taken to create a mobile intervention:

- Authors design the interventions using the authoring tool.
- The intervention is hosted on a central server.
- Participants select and download the application (intervention) on a mobile platform.
- The mobile application interprets the intervention design and presents the specified content.

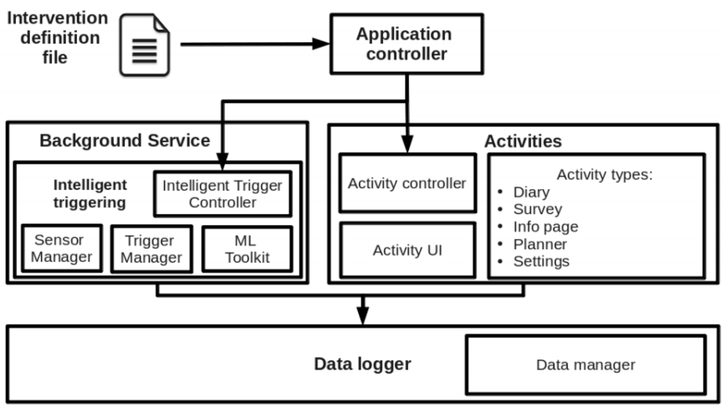

FIGURE 2.8: Implementation of the LifeGuide Toolbox Framework by Hargood et al. (2014)

The following types of recorded data are included in the LifeGuide Toolbox digital intervention:

1. Intervention data: responses to surveys, diary entries, and planner entries.

2. Usage data: logs detailing when users access different activities or receive notifications.
3. Sensor data: data from a range of sensors, including accelerometers and GPS, recorded at regular intervals.

The LifeGuide Toolbox features are suitable for this study because they provide the necessary tools to develop cross-platform applications for critical thinking cases. The LifeGuide Toolbox contains several features that are beneficial for this study and its experiments, such as designing activities, short questionnaires, planner, goal setting, and text boxes for diaries or notes.

According to Osmond et al. (2009), there are many factors that make the LifeGuide unique and different from other tools, such as HTML editors or App Inventor[2], which can be used to design internet-based interventions. Features in the LifeGuide include the following:

- The LifeGuide is designed to create complex interventions and interactive web pages that can change their contents in response to different conditions.
- The LifeGuide creates pages that will record the data generated by participants, without browsing server logs.
- The LifeGuide offers the ability to randomise and stratify participants or to use data gathered from previous users, which authors may want to use to deliver statements.
- The LifeGuide is designed with a framework for running trials and generally allows for repeat visits, a necessary feature for many interventions.
- The logic editor is the most crucial component of the authoring tool and sets the LifeGuide Toolbox apart from standard HTML editing software, allowing interventions to be more than a series of static web pages. The logic editor enables authors to express logic in ways that are natural and that do not require specialist training.
- Suggestions regarding a graphical interface for the logic are proposed, with pages in the intervention being represented as nodes and arrows that link pages together, visually illustrating the ability to move from one page to another.

2.6.5 Persuasive Technology: Techniques to Change Behaviours

Persuasive technology encompasses the computing systems or tools that are designed to change the behaviours or attitudes of users. According to the Fogg (2009) model (Figure 2.9), the question underlying persuasive technology is how to understand human behaviours when interacting with computing tools, such as computers and smartphones.

[2] App Inventor Website: http://www.appinventor.mit.edu/explore/

These devices are capable of sending and receiving user data through direct inputs, such as texts, voice recordings and videos, and through indirect inputs, such as sensors. This capability has led to the design of tools that can effectively persuade users to improve their knowledge, skills, or practices in the contexts of education or well-being.

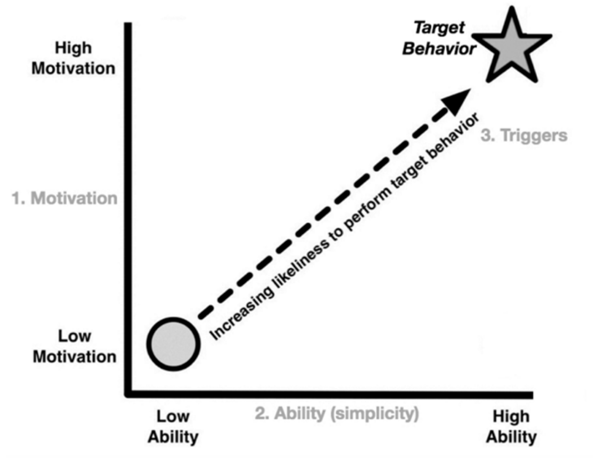

FIGURE 2.9: The Fogg Behaviour Model (Fogg 2009)

Combining the concepts of persuasive technology and DBCIs has been addressed in the literature. For example, Weal et al. (2012) detailed the benefits of DBCIs, which are primarily that they allow users to change their behaviours by interacting with persuasive interventions. The convergence between persuasive technologies and DBCIs, such as understanding the effects of the designed computing tools on human behaviours, was one motivation for the design of this study. Both persuasive technology and DBCIs have the potential to improve behaviours and contribute to the development of critical thinking skills. Therefore, persuasive technology strategies were pursued in this study, with the aim of applying effective theoretical methods of persuasive technology to improve DBCI outcomes.

2.7 Summary

This chapter provides an overview of the various definitions of critical thinking, including its measures, theories, frameworks, and the techniques for assessing and improving critical thinking skills. This chapter presents a review of the recent research that has examined critical thinking in different areas, including when technology has been used. Particularly, the discussion focuses on DBCIs, the context of research projects, and mobile learning as an important technical field for the adoption of critical thinking skills. This chapter also summarises the Paul-Elder Critical Thinking Framework and the LifeGuide Toolbox, which were both adopted in this study. The aim of this chapter was to provide an assessment of the current state of research in the areas of critical thinking, mobile learning and DBCIs and how the combination of these ideas might provide a potential pathway for success. This chapter also includes an extended review of the pertinent studies that are associated with the implications of this study. Prior to designing this study, it was essential to identify gaps in these areas that had not been addressed by previous research studies. This chapter began by identifying the definitions of critical thinking skills and their importance. The next section presented the methods and studies that have been performed to improve the critical thinking skills of students. Later, mobile- and web-based technologies that have been adopted to teach or enhance critical thinking skills in university students were reviewed. This review involved identifying the technical aspects and evaluation methods that have been used to assess existing learning tools. Finally, the technique utilized in this study, the DBCI, was described in conjunction with the LifeGuide Toolbox, which was used to design the mobile application-based interventions used to promote the critical thinking and research skills of students in the experiments described in this study. This chapter explained how DBCIs have been used previously and why it was chosen for this study.

Chapter 3

Methodology

This chapter details the research methodologies that were adopted in this study to answer the four primary research questions. This chapter illustrates the research design and methods used to conduct the studies. This chapter also includes a brief description of the procedures used to collect and analyse the data that were produced in the different stages of this study. However, detailed descriptions regarding the sampling, research design, and the ethical approvals for collecting and analysing the data for each study are presented in the following chapters.

3.1 Research Methods

Quantitative, qualitative, and mixed methods are the primary methods utilized in the field of human-computer interaction. Determining the most appropriate research method depends on the problems being addressed, the experience of the researcher, and the intended audience of the study (Creswell 2013). In the following sections, each type of research method will be briefly introduced. This will be followed by presenting the methods that were applied in this research.

3.1.1 Quantitative Research Methods

The quantitative research approach involves the collection and analyses of numerical data using statistical methods (Creswell 2013). The most common approach for the application of the quantitative research method is the questionnaire (Lazar et al. 2017; Preece et al. 2015). Questionnaires are used to collect specific data regarding participants by allowing them to answer and reflect on a set of statements based on different levels of choices. The primary advantage of using questionnaires is that they enable the researcher to easily survey a large number of participants (Preece et al. 2015).

There are two main methods for analysing quantitative data: descriptive analysis and inferential analysis (Preece et al. 2015). Descriptive analysis includes the application of statistical techniques to parse the data through the calculation of means, maximum and minimum values, and standard deviations. These techniques help identify relationships among different variables within the dataset. In contrast, inferential analysis can be performed to deduce inferences by comparing groups of variables to test a hypothesis.

3.1.2 Qualitative Research Methods

Qualitative research is an approach for collecting and analysing data that are not represented in numerical formats (Creswell 2013). The aim of qualitative research methods is to obtain an in-depth understanding of the explored problems or phenomena (Creswell 2013). Qualitative research can be applied to a studied problem through the use of four primary methods: interviews, observations, the examination of written documents or the examination of audio or visual recordings (Creswell 2013). Compared with quantitative research, the results of qualitative research are more likely to be reported using a flexible structure, concerned only with interpretations of the collected data (Creswell 2013). According to Lazar et al. (2017), interviews are considered to be the most commonly used qualitative research method.

There are three primary types of interviews, which can be categorised based on the amount of control the interviewer has and the types of questions being investigated: unstructured, semi-structured and structured (Lazar et al. 2017; Preece et al. 2015; Creswell 2013). Other factors can contribute to the classification of interviews, such as whether the interview involves a group of interviewees or whether the interview is conducted on a one-to-one basis (Preece et al. 2015). The following is a description of each type of interview, according to Lazar et al. (2017) and Preece et al. (2015):

- *Structured interviews*

  Structured interviews have a set of identical questions that are asked with specific answer options. This type of interview allows the interviewer to easily collect and analyse data, as it is a prepared process. The disadvantage of this type of interview is that it limits the scope of opinions that can be explained or expressed by the interviewee. In addition, structured interviews leave the interviewers with no options for adding, modifying or deleting questions, which could affect the quality of the gathered data.

- *Semi-structured interviews*

  Semi-structured interviews are a combination of structured and unstructured interviews, containing both closed- and open-ended questions. In this type of interview, the interviewer has a script containing questions to guide the interview, allowing more flexible interactions with the interviewee than a structured interview. This type of interview requires more time to transcribe and analyse the interviews.

- *Unstructured interviews*

  Unstructured interviews involve questions that can be asked with no advanced predetermination of the possible answers. The interviewers are able to ask new open- and closed-ended questions that are related to previous questions, as needed. The disadvantage of this type of interview is that the process of transcribing and analysing these interviews can be difficult, as every interview can contain a slightly different set of questions.

- *Group or focus group interviews*

  Group or focus group interviews consist of interviewing a panel, composed of between three and ten participants, to discuss certain issues. This type of interview has the advantage of enriching a topic by receiving different views and opinions from different perspectives. The disadvantage of this type of interview is that the interviewer must be skilled in managing the discussion, as it can easily drift towards irrelevant topics. Moreover, arranging a suitable time and place for multiple participants can be difficult when arranging this type of interview.

3.1.3 Mixed Methods

A mixed-methods study involves combining both quantitative and qualitative methodologies. This combination of the two approaches should be maintained throughout all stages of the study, including the initial summary, the data collection stage, the analysis, and the conclusion stage (Creswell and Plano 2007). However, a study cannot claim to use a mixed-methods approach simply because various research strategies are being employed. Indeed, it is essential that the data emerging from the research is mutually illuminating (Alan Bryman 2012). The primary advantage offered by the mixed-methods approach is that each method can compensate for the weaknesses of the other methods. Whereas certain questions might remain unanswered if only one method was being employed, this is unlikely to occur with a mixed-methods approach (Alan Bryman 2012).

For many studies, using both quantitative and qualitative approaches is necessary, including the current study examining the impacts of using web- or mobile-based technologies to enhance the critical thinking skills of learners. The data that emerges from studies using only the quantitative method tends to be extensive and rich in nature. In contrast, employing the qualitative method results in an increased focus on exploring the concepts and theories that are directly related to the researcher's viewpoint, which can yield reliable data (Alan Bryman 2012). In terms of the present study, the quantitative approach was determined to be the most useful for assessing and gauging the extent of the perceived improvements in the critical thinking and research skills of students, both before and after employing the digital intervention. However, consideration was also given to the fact that this study required a more detailed comprehension of learning behaviour, engagement and knowledge, which would be difficult to achieve using quantitative methods alone. Moreover, it was concluded that employing the qualitative approach would likely minimise researcher bias (Alan Bryman 2012) and allow the respondents to contribute to the experiment by expressing their own views on the subject. Both qualitative and quantitative methods were determined to be essential to the present study, and thus, the mixed-methods approach was selected.

To identify recurring patterns and themes from the qualitative data, the approach for thematic analysis, proposed by Braun and Clarke (2006), was adopted. The thematic analysis is a method for analysing and studying the qualitative data by finding the themes and understanding the topic in depth. The thematic analysis was chosen for this study because it provides an inductive and deductive analysis for the themes and patterns emerges from the interviews.

In the field of critical thinking and online web- and mobile-based learning technology, the primary focus appears to be on qualitative research. While qualitative research is crucial, the advantages of the quantitative approach must also be considered, as it can provide researchers with a more thorough comprehension of engagement, knowledge and behaviour. The mixed-methods approach has only been adopted by a small number of studies in this research field. However, the landscape has begun to change, starting with a study from Alnuaim et al. (2014), who successfully employed a mixed-methods approach to address a subject in this research field. The present study sought to ascertain exactly how, why, and in what ways digital mBCIs can be used to improve critical thinking skills using a mixed-methods approach.

3.2 Research Methodology Design Applied in this Research

The research methodology employed in this study can be divided into three phases, as illustrated in Tables 3.1 and 3.2. The aim of the first phase was to investigate how and why students and supervisors require digital mBCIs when employing critical thinking skills in the context of research projects. This phase included the validation of the instrument and the identification of intervention components. The second phase aimed to specify the design principles for implementing and testing a mobile intervention designed to foster critical thinking skills in the context of research projects. The third phase aimed to evaluate the possible impacts of mBCIs on the critical thinking skills of students in the context of research projects for two groups of participants.

As mentioned above, a mixed-methods approach was used in this study to answer the four research questions. The goal of this study was to evaluate how a digital mBCI can be used to measure and enhance the perceived critical thinking skills of students. To achieve this goal, the following research questions (RQs) were proposed:

RQ1: What are the standards and elements for measuring students' critical thinking in the context of research projects?

RQ2: What are the tools and techniques for using a digital mBCI to promote critical thinking skills in students?

RQ3: What are the technical methods for implementing a digital mBCI for the improvement of critical thinking skills in students?

RQ4: How does a digital mBCI improve critical thinking skills of students in the context of research projects?

This research was conducted to obtain a better understanding of the issues that might occur when deploying a mobile learning application in a behavioural learning context to promote critical thinking in research projects. Each research question in this research required specific methods and research designs to be identified and then tested, which will be explained in the following sections. To achieve this aim, several objectives were identified (Chapter 1).

The first objective was to identify the requirements for designing an instrument to measure students' perceived critical thinking skills in the context of research projects. This involved examining the students' and supervisors' motivations and experiences with using mobile interventions to foster critical thinking skills. Initially, a survey was designed to study the levels of critical thinking and research skills of university students. The initial survey also asked students about their technological preferences for effective communications with their supervisors when attempting to improve critical thinking skills during research projects.

The second objective was to review the supervisors' perceptions and requirements for the pedagogical and technological usability provided by the digital mBCI. This involved validating the instrument that was designed and used in this research. Supervisors were interviewed to determine potential methods for enriching the critical thinking skills of students by investigating their expectations and experiences with critical thinking techniques that have been successfully implemented to improve their students' perceived thinking skills. This process also involved the identification and validation of the intervention components used in this research.

The third objective was to adjust an existing LifeGuide Toolbox framework, assisted by a web-based authoring tool, to facilitate the delivery of critical thinking interventions to students in the context of research projects. To achieve this objective, relevant mobile critical thinking intervention was developed and evaluated with a sample of participants. This objective aimed to study and evaluate the user experience and their patterns for interacting with a DBCI to foster critical thinking skills in research projects.

	Research questions	Objectives/description	Data collection methods	Purpose
Phase One	(RQ1) How can the perceived critical thinking skills of university students be measured in the context of research projects when a digital mBCI is considered?	Identify different methods of assessing critical thinking skills and behaviours in the context of research projects.	Literature review.	To design an instrument for measuring the perceived critical thinking skills of students and explore the preferences of students with regards to the use of mobile technology to enhance critical thinking skills.
		Collect information regarding the critical thinking skills of students in the contexts of research projects, information regarding previous experiences students have had with technology designed to improve critical thinking and research skills.	Online surveys distributed to students.	
		Identify the standards and elements necessary to assess the perceived critical thinking skills in students and determine the required intervention components.	Interviews with supervisors.	
	(RQ2) What are the technical methods for using a digital mBCI to promote critical thinking skills in students?	To explore and identify the requirements and expectations of supervisors.	Interviews with supervisors.	To uncover a deeper understanding of critical thinking concepts and the use of digital mBCIs to improve critical thinking for students.
		To review the instrument designed to measure the perceived critical thinking skills and intervention components to ensure they address the intellectual standards (clarity, accuracy, precision, relevance, significance, depth, breadth, logic, and fairness) and the elements of thought (purpose, questions, information, inferences, concepts, assumptions, points of view, and implications). Determine which of the following should be used as intervention components: activities, tasks, short quizzes, goals and plans, inquiries or feedback.	Interviews with supervisors.	

TABLE 3.1: Overview of Methodology Design: Phase One

	Research questions	Objectives/description	Data collection methods	Purpose
Phase Two	(RQ3) What are the design principles required to implement a digital mBCI to improve critical thinking skills in students?	Manipulate the *LifeGuide Toolbox* to develop intervention components that can be used by participants and the researcher for the purpose of improving critical thinking and research skills.	A pilot study for mobile intervention with pre and post online questionnaires.	To study the critical thinking skills of students following the use of the mobile intervention.
		To study the impact of using digital mBCIs to promote critical thinking skills in the context of research projects.		
Phase Three	(RQ4) How does a digital mBCI improve critical thinking skills of students in the context of research projects?	To validate the instrument, the content of the mobile app-based intervention, and the intervention components.	Interviews with academics.	To validate the instrument and intervention components.
		To evaluate the impact of using digital mBCI to improve critical thinking skills of participants in the context of research projects by studying how the participants interact with the digital mBCI.	An experimental study for two groups with pre and post online questionnaires.	To evaluate the effectiveness of using a digital mBCI to promote the critical thinking skills of students in the context of research projects by comparing two groups of student.

TABLE 3.2: Overview of Methodology Design: Phase Two and Three

3.3 Methods

The following sections describe the methods, with justifications, that were used in this study to provide answers for the research questions and to achieve the research objectives. The relationships between the methods and the research questions are presented in the following sections.

3.3.1 Phase One

This phase aimed to identify the proper method for assessing critical thinking skills in the context of research projects when using a digital mBCI, which required specifying the standards and elements to be examined. This phase aimed to answer the first two research questions: determining how to measure the perceived critical thinking skills of students in the context of digital mBCIs and determining the technical methods for using digital mBCIs to promote the critical thinking skills of students; and determining what intervention components to use and what design principles are necessary for implementing digital mBCIs for the purpose of fostering the critical thinking skills of students in the context of research projects. A detailed explanation regarding the participants, study design, ethical approvals, and analyses can be found in Chapter 4. Qualitative and quantitative data were gathered by using student surveys and interviewing supervisors, as described in the following sub-sections.

3.3.1.1 Initial Survey: Students on Critical Thinking, Mobile Technology and Research Projects

This online survey (Appendix A) aimed to gather quantitative and qualitative data to gauge the level of critical thinking skills in university students, using the instrument designed to measure the perceived critical thinking skills (see Chapter 4). This study has partially contributed to answering the first research question, which was how to measure the perceived critical thinking skills in university students in the context of research projects when using a digital mBCI. To answer the first research question, an online survey was implemented to investigate the perceived critical thinking skills of students in the context of research projects, the use of technology to improve critical thinking by students, and the difficulties students encounter during research projects. The survey was designed according to the literature review and aimed to explore the important issues involved in the use of technology for critical thinking.

The survey consisted of an instrument designed to measure the perceived critical thinking skills in the context of research projects. The instrument was inspired by the Paul-Elder Critical Thinking Framework (Paul and Elder 2013) and contained statements based on the nine intellectual standards and eight elements of thought (see Chapter 4).

The survey also contained questions regarding the difficulties faced by students during research projects and regarding the experience students have with using technology to improve critical thinking skills. According to Novotny et al. (2016), surveys have been used in the field of critical thinking to evaluate the requirements of learners by allowing them to self-reflect on the issues with which they require assistance. The initial survey primarily investigated the self-reflections of students regarding their critical thinking skills, where students scored themselves as being either strong or weak with respect to critical thinking and research skills, and the experiences students have had using technology to assess and promote their critical thinking skills in the context of research projects. These questions helped to identify ways to refine the instrument designed to measure the perceived critical thinking skills of students in the context of a digital mBCI.

Reviewing the literature was necessary to form this question and to design the proper methods to investigate it. This study adopted the Paul-Elder Critical Thinking Framework for the conducted surveys and for the technical implementation. The framework has been described in detail in Chapter 2 (the Intellectual standards (IS): *Clarity, Accuracy, Precision, Relevance, Significance, Depth, Breadth, Logic, and Fairness;* and the Elements of Thought (ET): *Purpose, Questions, Information, Inferences, Concepts, Assumption, Point of view, Implication*). This framework was chosen for this study because it clearly depicts critical thinking as a series of stages, e.g., a process or an experience. This approach seeks to contextualise the other models and theories surrounding critical thinking. In fact, unlike other models and theories, the Paul-Elder Critical Thinking Framework appears to fall into two categories, namely, the cognitive process and the behavioural experience (Novotny et al. 2016; Ralston and Bays 2013; Celuch and Slama 2002). Indeed, this framework enables the evaluation of critical thinking abilities from various learning perspectives.

3.3.1.2 Interviews with Supervisors: Identifying Requirements and Expectations

The second research question investigated the technical methods for using digital mBCIs to promote the critical thinking skills of students in the context of research projects. This question was answered by interviewing academics who have experience supervising research projects (Appendix B). Validation from academics is important during research work, as academics have years of experience and are familiar with the requirements in their fields. The interviews gathered qualitative data that allowed us to explore and identify the requirements and expectations of supervisors (academics) with regards to using a digital mBCI technique to enhance critical thinking skills in the context of research projects. Interviews were used to validate surveys or to explore the technical requirements for users, similar to the interviews that have been used by a number of studies when designing tools to promote critical thinking (Ralston and Bays 2013; Celuch and Slama 2002). The first aim of the interview was learn the views of the supervisor with regards to the instrument designed to measure the perceived critical thinking skills. The second aim was to understand the experiences of the supervisors with regards to using technology (web- or mobile-based platforms) to promote the critical thinking skills of students. The two aims allowed the identification of practical methods for using digital mBCIs for critical thinking and research projects, including identifying the intervention components necessary to facilitate the technical interaction between supervisors and their students to improve critical thinking and research skills. The intervention components (see Chapter 5) that were identified here were used in the next study to examine their impacts of a digital mBCI on the critical thinking research skill of students.

The two studies (student surveys and academic interviews) have resulted in the design and refinement of the instrument (a survey-based tool) used to measure students' perceived critical thinking skills through self-reflection regarding certain critical thinking standards and elements. Additionally, supervisors and academics were interviewed in the present study regarding their potential use of the Paul-Elder Critical Thinking Framework during research tasks. They agreed that the Paul-Elder Critical Thinking Framework is technically compatible with DBCI techniques and their components.

3.3.2 Phase Two

This phase aimed to answer the third research question, regarding what design principles are necessary for the implementation of an mBCI designed to promote the critical thinking skills of students during their research projects over a period of time. A detailed explanation regarding the participants, study design, ethical approvals, and analysis can be found in Chapter 5 and 6.

3.3.2.1 Pilot Study: mBCI for Two Months

This study extended the *LifeGuide Toolbox* framework to implement a digital mBCIs designed to foster the critical thinking skills of students. Experimental studies are necessary for evaluating the effectiveness of using technology to enhance critical thinking skills (Alnuaim et al. 2014). In this study, qualitative and qualitative data were gathered from participants to evaluate their critical thinking skills before and after using the mobile intervention. This study tested the practicality of using the digital mBCI to improve the process of critical thinking for students by determining what types of supportive information students require and when they require it. Pre- and post-intervention online surveys (Appendix C) were used to evaluate the perceived improvements in the critical thinking skills of students after two months of using the mobile intervention in the contexts of research projects. The results from the second stage of this study were published, which shows the potential success of using digital mBCIs to improve critical thinking skills in the context of research projects (Asiri et al. 2018).

3.3.3 Phase Three

Finally, the fourth study examined how the digital mBCI technique improved critical thinking and research skills of students. This study involved a detailed examination of the practical benefits of using a mobile intervention to improve critical thinking skills in the context of research projects. This research question aims to unite the results from RQ1, RQ2 and RQ3, investigating whether the expectations of students and supervisors were met and determining if and how the mBCI contributed to the perceived improvement of critical thinking skills by identifying what types of opportunities the mBCI offered to students. Analysing mobile usage, interviews, and surveys enabled the evaluation of the effectiveness of the mBCI on enhancing critical thinking skills in the context of research projects. These analyses also highlighted those areas that require attention to improve the usability and utility of the intervention for the future. A detailed explanation regarding the participants, study design, ethical approvals, and analysis can be found in Chapter 6.

While some of the techniques, tools, and methods used were validated, some amendments were necessary to improve this study. To consider the essential recommended suggestions, four major changes were made in phase three. First, in order to broaden the findings from the pilot, supervisors from different disciplines were interviewed to better understand the generalisability of critical thinking interventions. Second, a control group was added to the experimental study described in the second stage of this study to determine what perceived improvements in the critical thinking skills of students, if any, were due to the use of the mobile intervention. Third, new intervention components were enhanced or added to the mobile intervention, such as notification and nudge features. Fourth, formative and summative assessments of the participants' work were performed by university academics. Other minor changes were made, which are described in detail in Chapter 6. The results from the third stage of this study were published, which shows the potential success of using digital mBCIs to improve critical thinking skills in the context of research projects (Asiri et al. 2019). The following section contains a brief description regarding the studies conducted in this stage of this research.

3.3.3.1 Interviews with Academics: Review and Confirmation

The second research question attempted to determine the technical methods of using digital mBCIs to promote critical thinking skills of in the context of research projects. This question was answered in the first stage by interviewing academics with supervisory experience (Appendix B). However, the process of reviewing and validating the instrument and the intervention components remained necessary (see Chapter 6, Section 6.2). Validation from academics is important in research, as they provide years of experience and a knowledge of the requirements for their fields. The interviews gathered qualitative data that allowed the identification of requirements and expectations of supervisors (academics) regarding the use of the digital mBCI technique to enhance critical thinking skills in the context of research projects (Appendix F).

The first aim of the interviews in this stage of this study was to determine the best process for validating the instrument and the intervention components. The second aim was to understand the views of the supervisors with regards to the designed mBCI and its authoring tool for the promotion of critical thinking skills in students. The two aims, together, identified more practical methods for using mBCIs to promote critical thinking during research projects, which involved identifying the intervention components necessary to facilitate technical interactions between supervisors and their students. The intervention components (Chapter 4) that were identified and refined were used in the next study to examine the impacts of these interventions on the critical thinking and research skills of students in the context of mBCIs. The interviews resulted in the design and refinement of an instrument (a survey-based tool) to measure the perceived critical thinking skills of students through self-reflections regarding certain critical thinking standards and elements.

3.3.3.2 A Trial: Mobile Intervention Experiment with A Control Group

This experimental study aimed to answer the third and fourth research questions regarding the design principles necessary for implementing an mBCI to promote the critical thinking skills of students during their research projects over a period of time (Appendix H). This study extended a designed framework to implement a digital mBCI to foster the critical thinking skills of students. Experimental studies are essential for evaluating the effectiveness of using technology to enhance critical thinking skills. In this study, qualitative and qualitative data were gathered from participants to study their critical thinking skills before and after using the mobile intervention. This study examined the practicality of using the mBCI to improve the process of critical thinking in students by determining what types of supportive information students required and when they required them. Pre- and post-intervention online surveys (the designed instrument) were used to examine the improvements in critical thinking after two months of using the mobile intervention in the context of research projects for two groups. A detailed explanation of the study design, sampling, and procedures can be found in Chapter 6. As suggested in a relevant study by Weston et al. (2015), this study investigated the practicality of using a mobile application-based system for the purpose of enhancing critical thinking skills in students by gathering feedback regarding the proper timing of interventions and determining the advantages and disadvantages of implementing a notification system for increasing the engagement with digital mBCIs.

3.3.3.3 Formal Assessment of Research Reports and Mobile Texts by Academics

In the experimental study, participants were provided with an instrument that allowed them to self-reflect on their critical thinking skills in the context of research projects, both before and after the intervention. However, the instrument (pre- and post-intervention online surveys) only measures the students' perceptions of improvement with regards to their critical thinking skills and lacks any objective assessments of their critical thinking skills. To bridge this gap, the academics who were previously interviewed were asked to assess the critical thinking skills demonstrated by the participants' work. The assessment of the critical thinking skills of participants involved two types of inputs: the participants in the intervention group answered questions through the mobile intervention regarding their tasks, project information, short surveys, goals and plans, in a text-based format, and both intervention and control groups were required to submit their research project reports. The assessment consisted of survey-based statements by academics that rated the work submitted by students on a scale from 1 (lowest) to 5 (highest), based on the intellectual standards specified in the instrument (Appendix I). Text boxes were also provided for the assessors to include their reviews and feedback. The assessment process is described in detail in Chapter 6.

3.4 Summary

In summary, this chapter discussed the three primary research methods adopted in this study: the qualitative method, the quantitative method, and mixed methods. This chapter presented how these methods were used in this study to answer the four research questions. The first stage of this study aimed to examine the levels of the perceived critical thinking skills in university students and to explore the requirements of supervisors by using surveys and interviews. The second stage aimed to identify the design principles necessary for the implementation of a digital mBCI to enhance critical thinking in the context of research projects. The third phase aimed to evaluate the effectiveness of using a digital mBCI to promote critical thinking skills in university students in the context of research projects. This chapter illustrates the overall research design and methods used to conduct these studies. However, detailed descriptions regarding the sampling, research design, and the procedures for collecting and analysing the data for each study are presented in the following chapters. Chapter 4 presents the initial surveys and interviews with supervisors and academics and their results. Chapter 5 shows the design principles of implementing the digital mBCI, including technical components and content. In Chapter 6, the pilot study is described, including the results and a discussion of the results. Chapters 7 and 8 describe and discuss the experimental studies and the results of the pre- and post-intervention surveys, the interactions with the intervention, and the assessments of the participants' work by academics.

Chapter 4

Development of An Instrument to Assess and Support Critical Thinking in the Context of Research Projects

This chapter details the data analyses that were performed for the first phase of this study. This chapter addresses the first research question, regarding how to measure the critical thinking skills of university students in the context of research projects, and describes the instrument that was designed for this purpose (Table 4.1). This chapter also investigates how students and supervisors perceive the benefits of using mobile technology and digital mobile-based behaviour change interventions (mBCIs) to measure and improve critical thinking skills in the context of research projects. This chapter describes the data that was collected from students using a comprehensive survey that was designed to allow the students to self-reflect on their critical thinking skills. This chapter also describes the qualitative data analysis performed on the data gathered from interviews with supervisors and academics regarding their needs and expectations for both the instrument and the use of mBCIs to foster critical thinking skills. The aims of the interviews were to identify the requirements of supervisors and academics for the use of digital interventions designed to enhance critical thinking skills in the context of research projects and to validate the designed instrument.

4.1 Instrument for Measuring Critical Thinking Skills in the Context of Research Projects

As mentioned in Chapter 2, the Paul-Elder Critical Thinking Framework (Paul and Elder 2013) was adopted to measure the perceived critical thinking skills throughout the different experiments conducted in this study. There are several reasons for using this framework. First, critical thinking is considered to be a behaviour that can be observed and changed (Haghparast et al. 2014; Saade et al. 2012). Second, critical thinking can be separated into multiple standards and elements, which allows each standard and element to be assessed separately (Al-Mubaid and Bettayeb 2017; Duron et al. 2006). Third, using this framework, research project-based work is the context for applying critical thinking skills.

The combination of the three reasons has led to choose P-E framework. Each framework has its own preferable components but the only suitable framework for this study is the P-E framework. The P-E framework has been used to consider critical thinking as both a behaviour a skills which was supported with the given references. In addition, the third reason indicates that P-E framework has standards and elements that can be integrated with the context of research projects. These standards and elements facilitate the examination of the critical thinking development by measuring which standard or element in the research projects needs support and enhancement for the learner in the intervention.

The survey-based instrument (Table 4.1) used in this study was designed based on the Paul-Elder Critical Thinking Framework. The instrument was then validated by supervisors and academics with previous experience helping students develop critical thinking skills and supervising research projects. The instrument was improved throughout the different stages of this study, and the final version is presented in this chapter. The final version of the instrument was used for both pre- and post-intervention assessments to measure the progression of the perceived critical thinking skills in students during the course of their research projects (Chapters 5 and 6). Using this instrument, students were to answer the following "To what extent do you agree or disagree with the following statements? (To make these statements clear for you, try to think of any coursework assignment or research project you might be currently working on or that you have worked on recently. No=1, Sometimes=2, Not Sure=3, Usually=4, and Yes=5)."

4.1.1 Intellectual Critical Thinking Standards

The intellectual standards were adopted from the Paul-Elder Critical Thinking Framework and consisted of nine standards that enable learners to assess the quality of their thinking according to their ability to apply these standards to the elements of thought

<table>
<tr><td colspan="2"><u>Critical Thinking Statements for Measuring the Perceived Critical Thinking in Research Projects Among third-Year Students</u></td></tr>
<tr><td>Pre-online questionnaire</td><td>Post-online questionnaire</td></tr>
<tr><td>Section one: Demographic information questions
What is your programme of study?</td><td>Section one:
Please provide your email you used in the experiment.</td></tr>
<tr><td colspan="2">Section two: Intellectual Critical Thinking Standards: Clarity, Accuracy, Precision, Significance, Relevance, Depth, Breadth, Logic and Fairness.
To what extent do you agree or disagree with the following statements? To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently. (No=1, Sometimes=2, Not Sure=3, Usually=4, Yes=5)
1) Clarity: When I write reports or essays, I express my thinking clearly in different ways and with multiple supporting examples.
2) Accuracy: I support my arguments by making sure that all information is correct and free from errors, based on reliable resources.
3) Precision: In writing, my words and data are specifically exact and no more details could be added to explain what I mean.
4) Significance: In my research work, I focus on the most important ideas and crucial facts that would help to make a meaningful point.
5) Relevance: In the literature review, everything included is important, each part makes a difference, and accordingly, I connect my arguments to any reliable relevant information.
6) Depth: My arguments are thorough, tending to explore the complexities of the research questions, which are addressed profoundly in my answers.
7) Breadth: I consider additional perspectives and different viewpoints when I think or write in my research work, to look at the problem from various ways.
8) Logic: My arguments are reasonable, such that the thinking is consistent and the conclusions follow from the evidence, where things make sense step-by-step.
9) Fairness: My arguments are balanced, objective and free from hidden biases by considering both positive and negative outcomes.
Section three: Elements of Thought: Purpose, Questions, Information, Inferences, Concepts, Assumptions, Point of view, and Implications.
To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently. (No=1, Sometimes=2, Not Sure=3, Usually=4, Yes=5)
10) Purpose: I think purposefully when I set my research objectives by trying to determine what the main goal of my work is and why it is important.
11) Questions: I use my research questions as guidance for my thinking, to figure out how to solve the research problems.
12) Information: The information I use is correct, accurate and relevant to the purpose and to the questions or issues I am addressing.
13) Inferences: The inferences and conclusions I make logically follow from the evidence, with no more or less than what is implied in the situation.
14) Concepts: I justifiably use concepts, ideas, theories, laws, principles, or hypotheses in thinking to make sense of things in my research work.
15) Assumptions: In assumptions, which are the beliefs I take for granted, either subconsciously or unconsciously, I make sure that they are justified by sound evidence.
16) Point of view: In my research work, I understand the limitations of my point of view and I fully consider other relevant reasonable viewpoints.
17) Implications: I am aware that the implications of my claims logically follow from other claims or truths, where implications follow from thoughts and consequences follow from actions.</td></tr>
<tr><td>Please provide your email to continue participating in the study.</td><td>Thanks for your participation.</td></tr>
</table>

Table 4.1: An Instrument for Measuring the Perceived Critical Thinking Skills of Students in Their Research Projects

(discussed in the next section). The intellectual standards are clarity, accuracy, precision, significance, relevance, depth, breadth, logic, and fairness. The following sections describe each standard, using the definitions provided by the authors (Paul and Elder 2013, 2008, 2006) of the framework and the definitions found in the literature.

4.1.1.1 Clarity

Clarity is one of the primary essential standards for measuring the quality of critical thinking. A clear argument denotes that the ideas are understandable and that the justifications have been well-explained and demonstrated clearly, within an exact context, leaving the reader with no further doubts (Paul and Elder 2013). Supporting examples and explanations, which should be easy to follow and be linked to the claims being made, aid clarity when presented with different examples. According to Butler (2012), clarity is a factor used by many standardised and non-standardised tests to assess critical thinking skills. Clarity was defined in the instrument, using the provided definition.

4.1.1.2 Accuracy

Accuracy refers to the ability to make clear, accurate, and specific arguments, which can be achieved by asking the proper questions to be answered. Accurate statements are strongly associated with evidence and with reliable resources that can be used to extract the information necessary to support any claims (Dwyer et al. 2014; Paul and Elder 2013; Celuch and Slama 2002). The information should be true, clear, relevant, and free from errors. The second statement in the instrument represents an accuracy standard.

4.1.1.3 Precision

Precision indicates that thinking is precise when approaching a problem. Precise arguments are clear, accurate, and relevant to the questions, and the information used to present ideas require no additional words (Paul and Elder 2013). Precision can connect separate parts of a single large picture by generating a primary purpose and identifying proper methods. Precision is represented in the third statement in the instrument.

4.1.1.4 Significance

According to Paul and Elder (2013), significance is the standard for specifying meaningful arguments. Significant statements hold essential, consistent, and meaningful claims that require important, clear, accurate and precise facts, which can be ascertained by asking questions or acquiring information and by considering both positive and negative results.

4.1.1.5 Relevance

Relevance represents the connections and relationships that can be established to identify similar patterns among questions, information, and methods (Paul and Elder 2013). Relevance indicates that each included part is centric and important. Relevant statements are presented based on related, clear, accurate, precise, and significant questions or information that are associated with a specific problem. Relevance is a crucial standard during analysis and evaluation, which are both necessary processes during research work (Al-Mubaid and Bettayeb 2017).

4.1.1.6 Depth

Depth indicates that complex and substantial ideas involve exploration (Paul and Elder 2013). Deep and intense arguments consider difficult problems and require sophisticated thinking to answer certain questions. Deep thinking can occasionally occur due to the nature of the problem; however, deep thinking can be achieved more generally by asking thorough questions and by exploring new and novel methods for creative problem solving.

4.1.1.7 Breadth

Breadth is a standard that refers to the wide variety of opinions and views that can be found for a specific problem (Paul and Elder 2013). Arguments with breadth show different points of view and diverse aspects, with respect to relevance and significance. Breadth can be achieved by considering whether an argument, question, or statement considers additional perspectives, various backgrounds or multiple viewpoints.

4.1.1.8 Logic

Logic refers to making sense of ideas. Logical arguments follow valid and reasonable principles that examine consistency and avoid logical fallacies (Paul and Elder 2013). Logical conclusions are based on evidence and facts when making an argument.

4.1.1.9 Fairness

Fairness requires balanced consideration when making an argument (Paul and Elder 2013). Fair judgements are objective and free from hidden biases. Fairness standards minimise the effects of uncontrolled emotional statements by considering both objectivity and subjectivity during evaluation and analysis.

4.1.2 Elements of Thoughts

The elements of thought form the second part of the adopted Paul-Elder Critical Thinking Framework and consist of eight elements that allow learners to apply intellectual standards to scientific steps during a research project. The elements of thought represent the scientific method when conducting a research project. The elements of thought are purpose, questions, information, inferences, concepts, assumptions, points of view, and implications. The following sections describe each element, using both the formal definitions described by the authors of the framework and definitions found in the literature.

4.1.2.1 Purpose

In research, the purpose is the aim of study, including motives, intentions and functions (Paul and Elder 2013). To clarify purpose in the context of critical thinking, concepts such as the primary goal of the study and the objectives underlying specific tasks should be considered, which can help to identify the purpose of a targeted task (Dos Santos and Cechinel 2019).

4.1.2.2 Questions

The best approach to solving a problem is to first identify the problem and then to ask the right questions (Dwyer et al. 2014; Paul and Elder 2013). This approach can be applied to tasks in daily life or to problems associated with research that require critical thinking. Determining what question must be addressed, why they must be addressed, and what types of questions should be asked are all aspects of thinking critically, as asking proper questions results in receiving contextually relevant answers.

4.1.2.3 Information

According to Paul and Elder (2013), information can be defined as the facts or data that emerge from evidence or as the experiences that are used to understand certain situations. Information can originate from different types of sources, which must be verified and examined. Critical thinking requires that targeted and gathered information be relevant to the questions being asked and to the purpose of the work.

4.1.2.4 Inferences

The interpretations or conclusions that result from critical thinking exercises are referred to as inferences (Paul and Elder 2013). Relevant inferences can be made by determining whether these inferences are supported by specific data, by identifying whether the processes used to infer conclusions were appropriate, and by examining how the data were interpreted. Inferences depend on many factors, such as the point of view and the question being asked, which can vary across situations.

4.1.2.5 Concepts

The concepts in any theoretical work refer to the thoughts, ideas, and methods that are applied to generate hypotheses and to the principles required to understand phenomena (Paul and Elder 2013; Ku 2009). Identifying the necessary concepts in a targeted task can be accomplished by identifying the ideas required during the process of thinking about a situation and examining why these ideas are important, by determining whether the theories or hypotheses used to support any ideas make sense for a specific issue, and by examining how the purpose, questions and targeted information support any ideas. All of these exercises can help to identify necessary concepts when thinking critically about a problem or issue.

4.1.2.6 Assumptions

According to Paul and Elder (2013), any beliefs that exist at the subconscious or unconscious level and are taken for granted are called assumptions. Awareness of any prior assumptions regarding issues or problems can be addressed by considering what ideas are presupposed regarding any issue or conclusion, by identifying how to test or examine existing assumptions, and by identifying what is taken for granted when considering certain issues and whether these factors can be changed (Nicholas and Raider-Roth 2016). These exercises can clarify assumptions and prevent incorrect assumptions from being made, during either research or daily tasks.

4.1.2.7 Point of view

The point of view is the position or perspective used to examine an issue (Paul and Elder 2013). When considering a problem, the point of view includes the background of the person and the angle from which a problem is being approached. The correct point of view from which to view a problem can be established by determining how best to approach a problem, considering whether other approaches should be examined, identifying which issues should reasonably be considered or focused on when thinking critically about an issue, identifying any issues a specific point of view neglects, and ascertaining whether the current viewpoints are difficult to agree with or challenging to believe. Addressing these issues can also help to identify the viewpoints of other authors (Niu et al. 2013).

4.1.2.8 Implications

According to Paul and Elder (2013), implications are truths or conclusions that logically follow other truths or conclusions. Implications follow thoughts, whereas consequences follow actions. Understanding the implications associated with any idea requires the determination of how specific decisions are made, the consequences of deciding against any specific decisions, and the determination of what can be inferred from specific actions. These exercises can support the ability of a critical thinker to understand the implications of a question being asked, the purpose of the work, and the information that must be gathered to logically infer the correct conclusions.

4.2 An Initial Survey to Asses Student Perceptions of Their Critical Thinking Skills and Their Preferences for Using Technology to Improve Critical Thinking Skills

The initial survey attempted to address one component of the first research question, which involved designing an instrument to measure student perceptions of their critical thinking skills (POCT). These perceptions were assessed by asking students to self-reflect on their critical thinking and research skills. Relationships between critical thinking skills and mobile use were also ascertained. The most effective educational techniques for improving the critical thinking skills of students were examined in this survey.

4.2.1 Participants

A total of thirty two undergraduate third-year students from the Electronics and Computer Science department (ECS) of the University of Southampton were targeted for participation in this survey. Participants were approached through email lists. The demographic information for the participants showed that almost all of the students owned smartphones and that they have been using smartphones for more than four times in daily basis, and for more than seven years, on average, for educational purposes.

4.2.2 Procedures

Invitation emails were sent to students, containing a brief description of the study and an online link for the initial survey hosted on the iSurvey website. The email explained that this survey was for experiment purposes and would not affect research project grades to encourage participants to reflect candidly on their skills. Participants were asked to reflect upon their skills as accurately as possible to receive feedback according to their reported deficiencies. These statements were designed to reduce any effects on the objectivity of their self-assessments. The initial survey consisted of three sections, as shown in Appendix A.

- The first section asked students to reflect upon statements regarding the intellectual standards of critical thinking.
- The second section asked students to reflect upon statements regarding research projects and the use of mobile technology to communicate with supervisors.
- The third section asked students to reflect upon their experiences using educational techniques to support critical thinking.

Using the instrument in the survey, students are asked to answer the following: "To what extent do you agree or disagree with the following statements? (To make these statements clear for you, try to think of any coursework assignment or research project you might be currently working on or that you have worked on recently. No=1, Sometimes=2, Not Sure=3, Usually=4, Yes=5)."

4.2.3 Data Collection and Analysis

Qualitative and quantitative data were collected from university students. The email addresses provided by participants were used to associate the relevant data with the individual participants. Data collection via the initial survey was approved by Ethics and Research Governance Online (ERGO, ethics number: 19224).

4.2.4 Results and Findings

A total of thirty two undergraduate students from the Electronics and Computer Science (ECS) department of the University of Southampton participated in the survey. The next sections describe the results for each segment of the initial survey: student self-reflections on critical thinking standards, research projects, and experiences with educational techniques to support critical thinking.

4.2.4.1 Student Reflections on Critical Thinking Standards

The analysis of the participant responses was divided into two components. The first component concerned student reflections of their critical thinking skills (POCT). The second component described student experiences with mobile technology for educational purposes. Students were asked about their previous experiences with the nine intellectual standards (Paul and Elder 2013): clarity, accuracy, precision, relevance, depth, breadth, logic, significance, and fairness (Figure 4.1). The results showed that most of the students responded either not sure or sometimes, indicating deficiencies in their critical thinking skills. The graph in Figure 4.1 shows that students find some critical thinking standards more difficult to perform than others. For example, students indicated a general perceived deficiency in precision, fairness, and logic skills, whereas they considered themselves to be more proficient at the relevance skill. Briefly, the results represent student self-reflections of their critical thinking abilities (POCT).

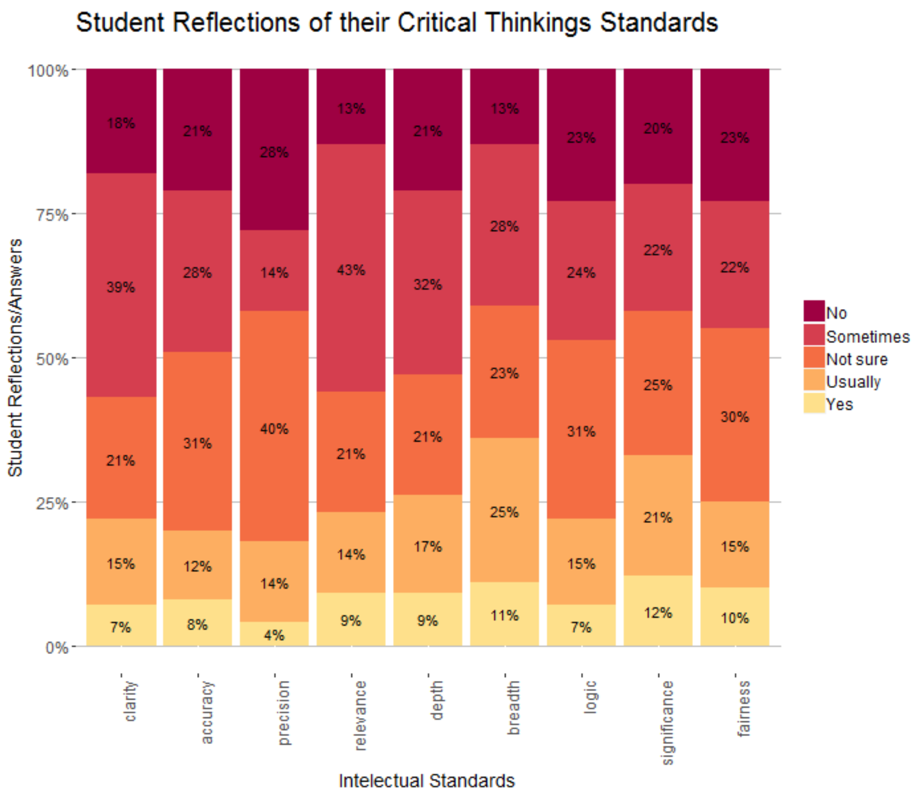

Figure 4.1: Student Reflections of Their Critical Thinking Standards

4.2.4.2 Research Project Issues

Generally, students self-reported having negative views of their critical thinking skills (POCT). In fact, most students reported feeling lost in the middle of the research projects. Moreover, students reported that they always experienced difficulty linking the introduction, hypothesis, and conclusion together. The students indicated that 'finding the research topic' of their projects was the most difficult component of their research process. The students expressed their beliefs that various critical thinking skills should be practised more to enhance them.

The results demonstrated that the majority of the participants found mobile technology to be a helpful tool for communicating effectively and quickly with others in terms of their research projects. Moreover, students indicated that smartphones might be helpful for changing their critical thinking behaviours due to their constant presence.

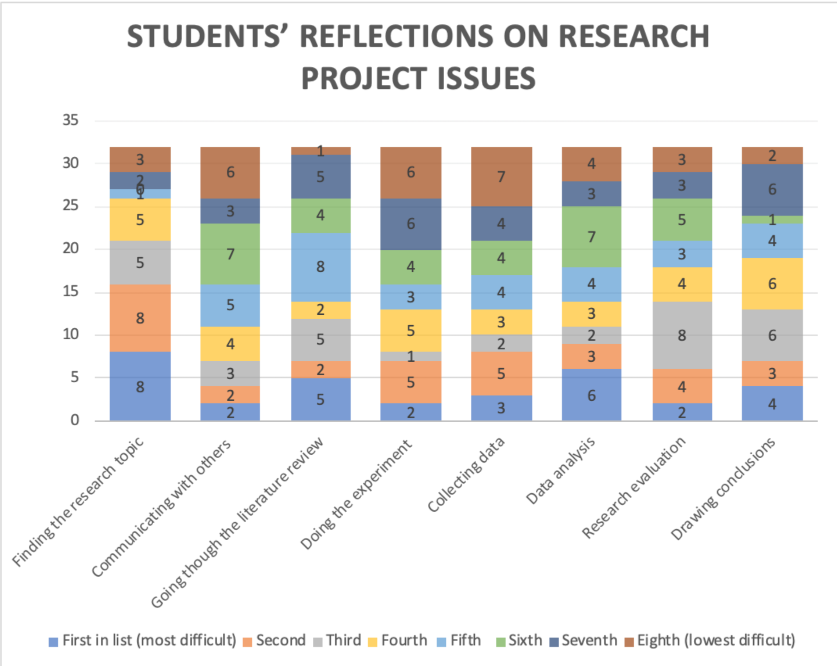

FIGURE 4.2: Students' Reflections on Research Project Issues

4.2.4.3 Student Experiences with Educational Techniques to Support Critical Thinking

The survey results also showed the students' experiences with different educational techniques (Figure 4.3). Students reported both negative and positive experiences with educational techniques. For example, students did not prefer using reflective journals or performing experiments. Students also reported that is always difficult to receive quick and useful feedback from others regarding their research inquiries. However, with regards to working on research activities, students preferred to collaborate with experts, to visualise their research projects, and to receive direct instructions from their supervisors during their research work.

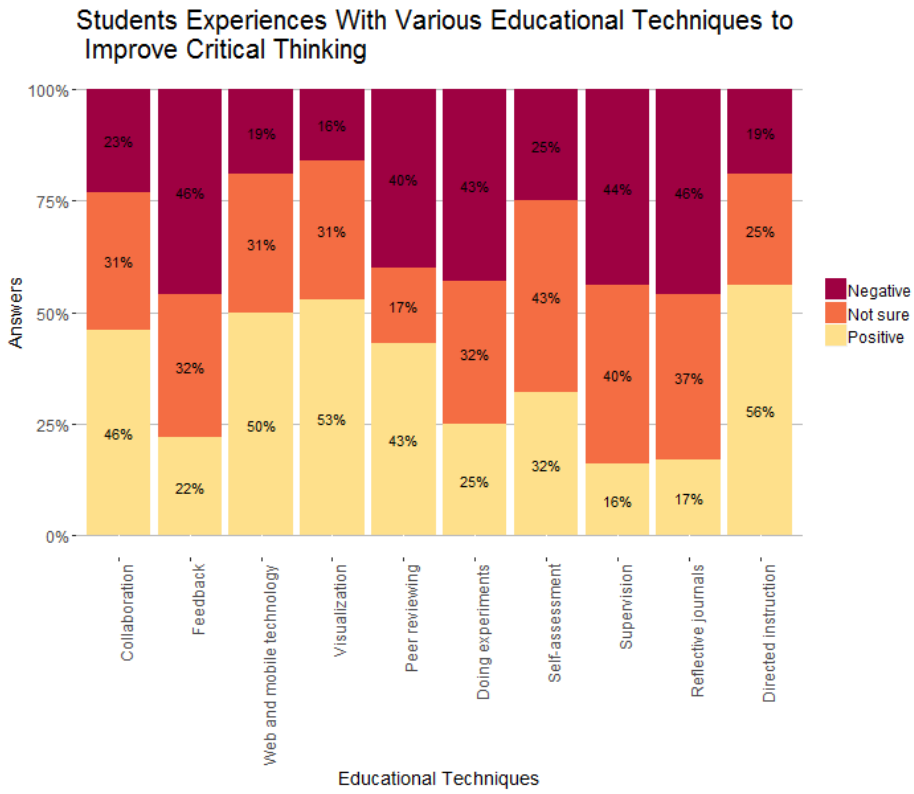

FIGURE 4.3: Student Experiences with Various Educational Techniques

Data from the survey showed that students preferred to use smartphone technologies for faster communication with supervisors. In general, mobile technology has been highly suggested by students to represent a preferred avenue for practising their critical thinking skills and for the improved management of their research projects.

4.2.5 Discussion

Students require a high level of guidance and support to develop critical thinking skills. Critical thinking is not an inherent ability; instead, it is a learned skill that requires both training and practice (Alnuaim et al. 2016) and requires more than simple student engagement. Critical thinking requires students to be actively engaged in the processes of conceptualising, applying, analysing, synthesising, evaluating, and communicating information (Behar-Horenstein et al. 2011). A significant number of students lack the problem-solving and critical thinking skills that are required for many college majors (Shaw et al. 2013).

Based on the results of this survey, students reported that they struggle with understanding how to be clear, accurate, precise and fair when they are working on research tasks. The students that responded to the survey reported that they do not understand how their work can be significant, logical, deep and relevant. Therefore, students likely require more rigorous support and assistance during research projects to be able to accurately evaluate improvements in their critical thinking skills. These survey results agree with those reported by previous research on critical thinking skills in college students. Several studies have indicated that students are weak in high-level thinking skills (Alnuaim et al. 2016; Holzer et al. 2015), which may be due to the traditional methods that most instructors use to teach critical thinking skills. Another possible explanation is the lack of available, well-designed technologies that enable the practice of critical thinking skills. According to Al-Emran et al. (2016), research studies should emphasise the importance of using technology to foster and evaluate critical thinking skills, after much careful design.

According to Lloyd and Bahr (2010), academics and students in higher education have essential similarities in defining and understanding critical thinking which is consistent with the extant literature. Lloyd and Bahr investigated how academics and students, in the Faculty of Education at an Australian University, define and understand critical thinking by simply conducting a survey that contains questions about critical thinking. The findings of this study show that students and academics have many similar ideas of what critical thinking is. However, students focus on the products and the outcomes of critical thinking while academics emphasize the perspective, dispositions and the process of critical thinking. In Lloyd and Bahr's study, students were asked to define critical thinking which might differ from applying what the students know about critical thinking. In the other hand, academics showed more capability in understanding critical thinking with slight differences. However, some academics in this Lloyd and Bahr's study indicated difficulty in understanding critical thinking as an instructor.

In the current survey, the majority of the students reported finding it difficult to receive useful feedback from their supervisors with regards to their research skills. Supervisors also report difficulty finding enough time to provide advice to each student. Most students have indicated that using mobile technology to communicate with their supervisors during the completion of research tasks would be a helpful form of support and would prompt critical thinking. The unique features of mobile technology can help both students and supervisors remain in contact with each other, with fewer limits on time or place.

Students can receive support for each step of their research projects through mobile interventions. Moreover, each step of their research can be treated separately. For example, in the survey results, students responded that identifying the topic is the most difficult step of their research projects. Each stage of a research project has its own requirements and necessary skills. Evaluating these research steps independently would provide both students and supervisors with insights regarding what assistance students require. Therefore, using this approach, students can practise critical thinking skills using the suggested interactive mBCI under the supervision of their supervisors. The features of the mobile intervention system can reduce the gaps between students and their supervisors that can occur between more traditional meetings.

In this study, the LifeGuide Toolbox open source software was used to help students with their critical thinking skills. The LifeGuide Toolbox software is designed to aid people with limited programming skills in the creation, evaluation and modification of Internet-delivered interventions. Based on the LifeGuide Toolbox software, an interactive mBCI was designed to overcome the issues that students reported experiencing during their research projects, in conjunction with an instrument that was designed to measure their perceived critical thinking skills. Engaging students in research projects is believed to be an effective way to allow students to explore the process of critical thinking, step-by-step (Paul and Elder 2013). Supervisors, using the mobile application, can deliver mobile interventions to assist students while they are working on their research projects. For example, the software allows supervisors to create interventions that provide tailored advice, with the capability of adding texts, images, audio and video, to support the critical thinking skills of students. Moreover, supervisors can design questionnaires and quizzes, using the intervention software, to evaluate the critical thinking skills of students.

In addition, the digital mBCI can help students to monitor their own research progress by allowing them to describe their project information, and set plans, reminders and goals. In addition, students and supervisors can communicate with each other through text messages, emails and discussion boards within the mobile intervention framework. Eventually, logs recording the student's use of the intervention can be analysed to determine which pages have been viewed, how long the pages were viewed, in what order the pages were viewed, and what information has been submitted to intervention pages. By using mobile technology in a well-designed approach, many issues can be resolved, such as difficulties organising meeting times between supervisors and students. Moreover, critical thinking skills should be practised and learned, with a focus on independent experiences. Students can evaluate what skills they lack and then ask for help as needed. By examining the usability and utility of the system, the most appropriate design for the promotion of critical thinking skills can be determined.

4.3 Interviews with Supervisors to Identify Requirements and Expectations for Measuring and Enhancing Critical Thinking Skills in Research Projects

Interviews were conducted to ascertain the views of supervisors regarding the instrument that was designed to measure critical thinking in research projects and regarding the use of digital mBCIs to foster the critical thinking skills of students. The aim of these interviews was to explore the perceived effectiveness and usefulness of a digital mBCI designed to enhance critical thinking skills. Research project supervisors were interviewed to validate the instrument for its ability to measure critical thinking skills and of the study design for its approach to critical thinking skills in higher education. During the interviews, supervisors were asked about their expectations and requirements for the use of digital mBCIs to enhance the critical thinking and research skills of their students. Later, ExpressScrib[1] software was used to transcribe the interviews. In addition, NVivo software was used to analyse the transcribed interviews.

4.3.1 Participants

In this study, five supervisors, from the fields of computer science, e-learning and human-computer interaction within the Electronic and Computer Science Department of the University of Southampton, were interviewed for approximately 30 to 60 minutes in their offices. This survey was approved by Ethics and Research Governance Online (ERGO, ethics number: 19224).

4.3.2 Procedure

Emails, containing short descriptions of the research topic and the aims of the interview, were sent prior to the interviews. Later, the audio recordings of the interviews were transcribed verbatim; this yielded 50 pages of text that were printed for the initial phases of the data analysis. To identify recurring patterns and themes within the data, thematic analysis, as proposed by Braun and Clarke (2006), was adopted.

These are the questions that were asked in the supervisor interviews, as shown in Appendix B:

- What are the possible ways to measure critical thinking skills?
- In your experience, what are the most effective strategies you have used to promote students' critical thinking?

[1] http://www.expressscribe.co.uk/

- Have you used web or mobile technologies to help students with their critical thinking and research work?
- What are the advantages and disadvantages? What are students strong and weak at in terms of critical thinking skills?
- How would you, specifically, use mobile technology to help students with their critical thinking and research skills?
- Are there any other suggestions to technologically improve the process of teaching critical thinking and research skills for both supervisors and students?
- In your opinion, what are the practical ways to improve the mobile *CriticalThinking* application that I am using for the experiment? Any suggestions?

4.3.3 Data Collection and Analysis

The primary objectives for supervisor interviews were as follows:

1. To validate the instrument that was designed to measure the perceived critical thinking skills and to understand the factors that might affect the use of mobile devices in critical thinking, such as flexibility, usage, connectivity, personalisation, and mobile affordance.
2. To study the requirements of supervisors with regards to the use of mBCIs designed to enhance the critical thinking skills of students in the context of research projects.
3. To evaluate the strengths and weaknesses of the critical thinking skills of students in the context of research projects.
4. To be aware of any usability issues prior to designing the *CriticalThinking* application-based intervention prototype (described in Chapter 5), by considering the effective technical methods that supervisors have previously used to promote the critical thinking skills of students.

4.3.4 Results and Findings from the Interviews

The data were codified, and a total of 22 codes were initially identified; 7 were classified as primary codes, while 15 were classified as sub-codes. The codes and corresponding labels are provided in Appendix B. The codes were refined into the following three themes:

First Theme: Defining and measuring critical thinking skills.

Second Theme: The requirements of supervisors for the digital behavioural learning environment.

Third Theme: Mobile interventions to change critical thinking behaviours.

The next sections will provide the analyses of each theme. In the following sections, the interviewed participants have been coded to differentiate between the participants in these interviews and the participants in the following interviews (with academics) regarding the validation. For example, the symbol (V1P01) is used to indicate the first participant in the supervisors' interviews.

4.3.5 First Theme: Defining and Measuring Critical Thinking

The definition of critical thinking became clearer, based on the views of the supervisors during these interviews, which demonstrate various perspectives on the definition of critical thinking and different requirements for the fulfilment of critical thinking tasks. Here are some examples that describe critical thinking skills:

> "*Critical thinking is about asking the right question: 'Why you have done that' or 'What does that mean' or 'What does this tell you about the big picture'. And these kinds of things [...] you have got some relevant literature and you have explained it, but what you have not done is explain how the literature is related and what the body of the work tells you about [your project]. So, I tend to do it in term of using examples at the beginning, setting expectations, and then kind of nudging as we go through.*" (V1P01)

Another consideration for measuring critical thinking skills when research-based work is required is to focus on the concept of evidence within the task. Critical thinking is a method for analysing ideas and evaluating arguments based on reasons and logic, which can be achieved by addressing questions through discussions or by using technical tools, such as mind mapping or writing. This process was described by supervisors during the interviews, and here are some examples of their views on the use of research projects to promote critical thinking:

> "*To understand that, when [students] undertake a project, they need to be able to evaluate and reflect on the value and credibility of evidence. The simplest way you can do that is through literature.*" (V1P03)
>
> "*Getting students to create texts, mind maps or concept maps, as an exercise, helps them to think about the information more critically and then to evaluate it. What you can also do is scaffold the learning by giving them clues as [...] to have them represent it and media it. I might do this as a paper exercise. You can transfer this paper exercise to computers.*" (V1P04)

Focusing on a literature review is the first step that might teach students to think critically. Supervisors tend to assign tasks such as reviewing other research work and critiquing the ideas within them and how they are presented. The primary goal is to enrich critical thinking by enabling students to identify gaps and hidden links between ideas.

> "*You can focus on how to do, for example, the literature review, not what they are going to write about it, and then how are you going to analyse it at the end. You can ask students, 'What is the purpose?', 'What is your concepts [...] in the literature review?', 'How they are going to do that', [...] 'What is the main point they solved and how [do] they relate [to other ideas]?', So, 'are they contradicting themselves or do they confirm this [idea]?'. That's the point of view, which is quite nice.*" (V1P05)

Supervisors had positive views of the instrument that was designed to measure the perceived critical thinking skills of students in this study. Supervisors indicated the effectiveness of using this instrument to measure the perceived critical thinking skills of students. However, they emphasised reducing the subjectivity of self-reflection by examining the students' work to determine whether the self-reports aligned with actual skills.

> "*You want to measure what they know now. You need to have some sets of metrics. And after doing this, how they have improved their critical thinking. I think the idea is nice and it will work.*" (V1P01)

> "*These are the actual questions that need to be asked, as a check-list.*" (V1P02)

Critical thinking can be assess by academics based on the requirements of the criteria and rubrics provided by the university for evaluating the research projects, which might require different methods to be employed to interpret the effectiveness of the intervention. When designing the prototype, various views of critical thinking assessments should be considered. Based on the assessments of critical thinking provided by the supervisors, several activities should be considered when critical thinking is required, such as preparing a targeted task for students, monitoring their progress, and scaffolding students by delivering well-timed feedback.

4.3.6 Second Theme: Digital Behavioural Learning Environment

All of the supervisors agreed that helping students maintain their critical thinking behaviours during research work is essential and that this can be achieved by sending digital content through various platforms. However, designing a specific platform to perform these tasks could be more useful than using existing platforms, according to the supervisors.

There are many reasons why students may require continuous support to develop their research and thinking skills. For example, according to the supervisors, some students are incapable of generalising their critical thinking skills to different areas. Lacking the confidence to apply critical thinking skills could be another reason why students are weak in some aspects of critical thinking.

> "*Critical thinking is a higher intellectual level and [students] can't engage easily in it.*" (V1P02)

> "*Sometimes, people have the ability to think critically in one sphere, but they have difficulty generalising that skill.*" (V1P03)

> "*You can nudge, nudge and nudge and push [students] in directions, and even giving [...] them a prescriptive piece of work to do [that] involves critically engaging with the topic, but they just will not do it because, it seems to me, that they don't see the importance of it.*" (V1P02)

Generally, students must be reminded to use their critical thinking tools, which can be accomplished by asking questions, such as why and how, or by setting examples for students to follow. Moreover, establishing, from the beginning, what students are expected to accomplish during their projects helps students to regularly criticise their work throughout the process.

> "*Students are so focused on building something that works and building something that looks nice, but they don't understand [that] that is actually the easiest part of the process, where the hard work is [...] what this actually tells us about a certain topic. How this is generalisable? How could you apply this to general areas? What does this tell us about the arguments in the literature? [Students] seem to be almost blind.*" (V1P04)

> "*The idea [is] that people can have the grown mind set and the restrictive one. But that is only an observation of people's approaches, but it is about, typically, the necessity. At the same time, the students who exhibit [a] degree of critical thinking usually have [a] wide range of life experiences.*" (V1P03)

The requirements for building a digital system to prompt the use of critical thinking skills by students must include both technical and theoretical issues. Among the technical issues, the assistance must be cost-effective and help both students and supervisors perform the tasks easily. The tool must be reusable and flexible, allowing changes to be made in the content. More specifically, the tool must be designed specifically for critical thinking activities, such as providing information regarding how a student can utilise critical thinking skills in their work. The supervisors agreed that the intervention components should include the following: short questions to help students think about their work, activities to allow students to practice critical thinking skills, the ability for students to set goals and make plans for their work, and the ability for students to write about their experiences.

> "*You just need to ask them, 'Have you thought about the questions you are going to use? Have you been in doubt?', these kinds of questions. You ask questions, you get them thinking. Many kinds of questions can be asked, for example, after you have done the questionnaire in your project. 'Have you looked back to the literature review?' and 'What could you do differently?' That is the types [...] of questions they need at the end.*" (V1P01)

The supervisors demonstrated their motivations for using smartphones to implement DBCIs for critical thinking and indicated the usefulness of using such a technique to reduce the time spent helping students with their thinking. The supervisors stated that using a mobile intervention could be beneficial because it would help them to automatically track their students' thinking progress. Data generated from using the system would show what their students are struggling with during their research projects.

4.3.7 Third Theme: Mobile Interventions to Change Critical Thinking Behaviours during Research Projects

Based on the opinions of the supervisors, mobile interventions could be useful techniques for both students and supervisors, offering flexible methods for supporting and communicating with students regarding their critical thinking skills:

> "*Some of the things you have talked about [intervention components and the CriticalThinking mobile application] have the value of being on the mobile device. So, I think that has some resonance. I manage my diaries on my smartphone device. Along with other things, this could be useful for students who are doing their projects, too.*" (V1P02)

Students can be helped with their thinking skills by providing them with scenarios and specific topics to think about and requiring them to explain why and how various actions were taken.

> "*We [as supervisors] give [students] scenarios, and we ask them to critique scenarios. And then [ask] what they [would] do [given a] number of options. And then we show them several kinds of experts' work and what they have said about this problem. We teach them [through this exercise] that there is no one right answer. We teach them the rationale way.*" (V1P01)

Based on the experiences that supervisors have described, students might not respond to the process and may require regular support while they work on research projects. A mobile intervention could help by providing feedback, practice activities, and the chance to reflect on experiences.

> "*Why tell [students] it is not enough to build something and test it. That is not going to tell you anything interesting. We help them to change the way they look at things. [...] It is about getting in their work plans and then nudging them as they go along.*" (V1P02)

According to the supervisors, critical thinking is not only a skill but is also a behaviour that must be monitored over time. Utilising smartphones, which are constantly available to students, has the potential to successfully deliver interventions that change how they think about their work. However, some challenges remain, such as connectedness and the small screen sizes of mobile devices, which can make reading or writing difficult. Based on the views of the supervisors, the mobile *CriticalThinking* application articulates the mBCI technique. The features of the mobile application can be constructive and useful, providing insights into the critical thinking performance of students during the research project period.

4.3.8 Discussion and Findings

In general, interviewees stated that students demand technological support for their critical thinking skills. As an example, an mBCI might facilitate communications between students and supervisors. Mobile applications would help supervisors create relevant content for the critical thinking skills that students require. In addition, supervisors could measure the critical thinking skills of their students by designing surveys or short questionnaires. Similarly, students might benefit from the mobile application by reflecting on questions posed by their supervisors. Students might also use other features that a mobile application could provide, such as a planner, a reminding feature, or a diary. Mobile interventions can be designed to accommodate timing preferences, student situations, and overall progress.

The results of the interviews generally encouraged the use of an mBCI to maintain student engagement with their research projects and to increase awareness of critical thinking skills during research projects. The supervisors stated that students require continuous support during research projects, including being providing with information regarding critical thinking skills. Regardless of the level of critical thinking that students demonstrate, they must regularly be reminded to think critically in the context of research projects.

According to supervisors, college students lack critical thinking skills at almost every step of research projects, from the literature review to forming conclusions. Supervisors might desire the ability to measure the critical thinking skills of their students through the use of surveys and short questionnaires or by providing relevant activities. Similarly, students might benefit from a mobile application by reflecting on questions posed by their supervisors. Students might also use the features that an mBCI could provide, such as a planner, a reminding feature, and a diary, combined with a notification system that can help maintain student engagement with the critical thinking process. The learning behaviours demonstrated by students during their approaches to critical thinking standards can be monitored and guided by digital interventions.

In conclusion, the second research question was answered by interviewing supervisors to identify their requirements and motivations for the use of DBCIs to promote critical thinking. Their encouraging and positive views regarding the instrument designed to measure critical thinking skills and the mobile application components, along with the Paul Elder Critical Thinking Framework, indicated that the implementation of this mBCI could potentially be successful for prompting the critical thinking of students in the context of research projects. However, some challenges might be encountered when conducting this experiment. Recruiting supervisors for the next study must occur during or after the experiment, which might increase the chances that the results are more objective and reflective. The busy schedules of both supervisors and students might also be an obstacle for future studies. Addressing these limitations from the beginning will help to identify methods that can carefully resolve them.

4.3.9 Summarising the Findings from the Previous Two Studies: Initial Survey and Interviews with Supervisors

The two previous studies showed that the instrument designed to measure the perceived critical thinking skills would enable the evaluation of critical thinking skills during research projects in the context of a DBCI. The components of the digital intervention included a project information page, activities and training, practise tasks, short questionnaires, setting goals and plans, notifications for engagement, inquiries and answers, and providing feedback and instructions. However, the previous interviews did not clearly validate the instrument; therefore, it was necessary to include more academics from different fields to confirm the instrument's effectiveness. New interviews were conducted, which will be described in detail in the next section, including the participants, methods, and results.

4.4 Validation of the Critical Thinking Instrument and the Mobile Intervention Components by Academics

The purposes of interviewing academics were as follows: 1) to validate and refine the instrument designed to measure the perceived critical thinking skills, presented in Table 4.1, and the content of the mobile intervention; 2) to explore different experiences among different fields in regards to the critical thinking skills and behaviours of students in the context of research projects; and 3) to review the design of the mBCI used in this study.

4.4.1 Participants

A total of new ten academics from the University of Southampton were approached individually by email to participate in the interviews. The academics were selected from different fields, with varying levels of experience and diverse backgrounds, to fully cover the spectrum of critical thinking, research projects and the use of mobile interventions to support the critical thinking of learners in the context of research projects. The interviews with the academics were approved by the Ethics and Research Governance Online (ERGO) at the University of Southampton (number: 30055).

4.4.2 Methods

The study began with semi-structured interviews of the participants (Figure 4.4). The semi-structured interview type was selected because it allows all of the different opinions and views on critical thinking to be considered. Moreover, the intervention components of the mobile intervention design required the use of open-ended questions to explore the various aspects of usability and the user experience. The interviews were not designed to make predictions or form generalisations but rather to understand the nature of the participants' experiences and to determine the requirements, suggestions, patterns, expectations and needs for this study.

4.4.3 Procedure

The first step was to identify academics with experience supervising students during research projects. Academics within the fields of human-computer interactions, education, and e-learning were desirable because this study includes usability and technical aspects, requiring interviewees who are familiar with these aspects. After identifying promising academics, emails were individually sent to each academic, based on information found on the university website regarding research interests and experience. In the emails, information regarding the experiment was provided. Agreement to participate in the study was denoted by returning a signed consent form or by replying to the email and expressing an interest in participation. Participants were also provided with the option of signing the consent form immediately prior to the interview session. Academics were interviewed for approximately 30-40 minutes, in their offices. All of the interviews were recorded and then transcribed. At the end of the interviews, academics were asked whether they were interested in continued participation through the evaluation of research reports submitted by students at the end of the mobile experiment.

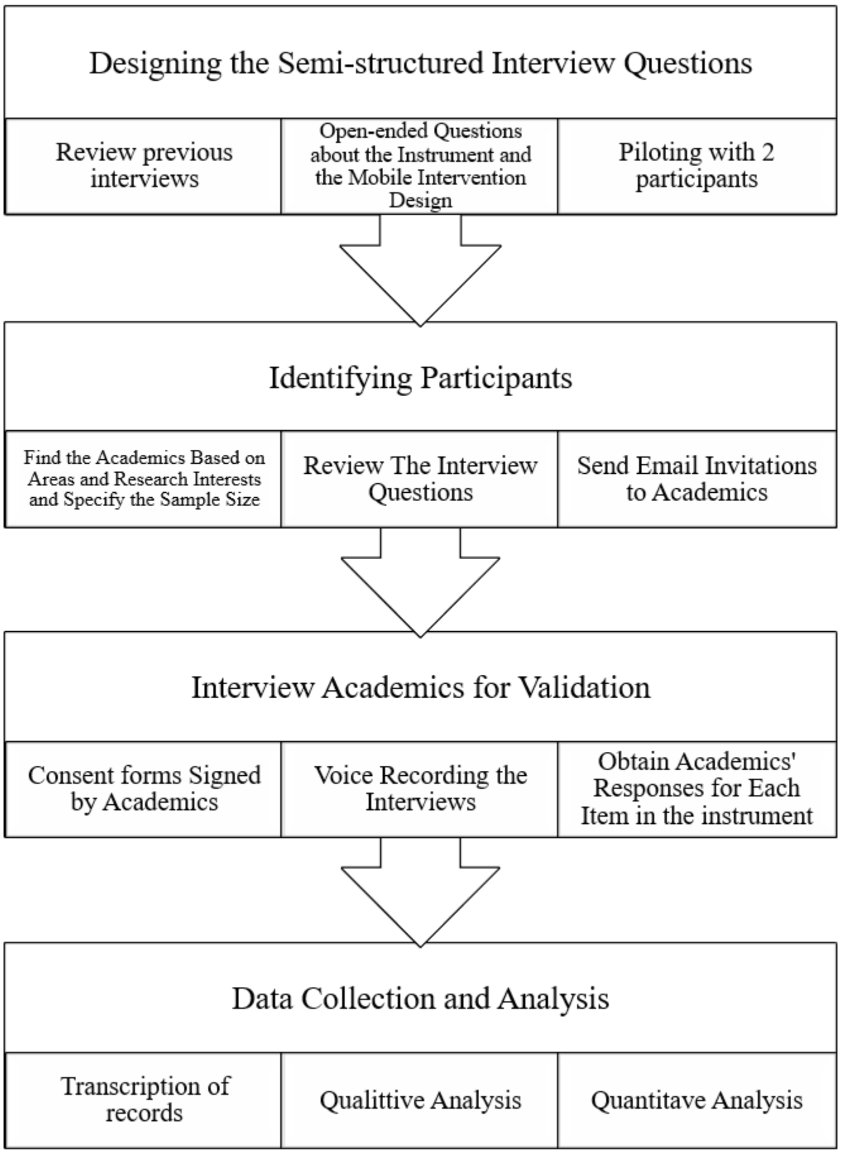

Figure 4.4: Procedures for Academics' Interviews

4.4.4 Data Collection

During the interviews, the interviewees were asked whether voice recording of the interview was permitted. The researcher provided a brief description of the study and described the primary purpose of the instrument. Then, the following steps were performed for each interviewee:

1. The participant was asked to fill out the survey (instrument), while the researcher took notes on any comments the participant made while filling out the survey. The validation process required the participant to answer the survey questions as if they were students.
2. After the participant finished the survey, discussion regarding the consistency and design of the survey, as well as the wording used in the survey occurred, covering the following questions:
   (a) What do you think of the survey?
   (b) Does it lead to an accurate measurement of the critical thinking skills of students in the context of research projects?
   (c) If there are any issues with the survey to reconsider, what are they?
3. Examples of the interfaces of the mobile *CriticalThinking* application were shown to the supervisor to illustrate how the intervention components and content would be implemented. Discussion was focused on the following intervention components:
   (a) Information about the student research projects.
   (b) Activities and tasks to practice critical thinking skills in the context of research projects
   (c) Goals and plans to improve the critical thinking skills of students.
   (d) Mini quizzes assessing the levels of critical thinking skills during the study, to enable supervisors to provide necessary advice and supportive information.
   (e) Inquiries allowing students to ask questions and make comments regarding the skills they need to improve.
   (f) Notification settings and features in the mBCI.

4.4.5 Data Analysis

All of the voice recordings were transcribed verbatim. The discussed issues were analysed by categorising the primary methods that have been previously used by academics. Qualitative and quantitative analyses were performed, as described in the analysis and results section. NVivo software was used to analyse the qualitative data. The audio recordings of the interviews were transcribed individually. To identify recurring patterns and themes from the data, the approach for thematic analysis, proposed by Braun and Clarke (2006), was adopted.

4.4.6 Results and Findings from Interviews with Academics

A total of new ten academics from the University of Southampton participated in this study. The participants were chosen based on the relevance of their academic interests to the topics of this study, such as experience with critical thinking while working with students for research projects. The participants specialised in the following areas: computer science (4 participants), education (5 participants), and psychology (1 participant). The data were codified, and a total of 25 codes were initially identified; 10 were classified as primary codes, and 15 were classified as sub-codes. The codes and corresponding labels are provided in Appendix F. The codes were refined into four themes, as follows:

First theme: Assessment of critical thinking and instrument validation.

Second them: Critical thinking as both a behaviour and a skill.

Third theme: Supervision and teaching of critical thinking through research projects.

Fourth theme: Design and content of the digital mBCI to support critical thinking.

The next sections will provide analyses of each theme. In the following sections, the interviewed participants have been coded to differentiate between the participants in these validation interviews and the participants in the previous interviews regarding requirements. For example, the symbol (V2P01) is used to indicate the first participant in this second interview.

4.4.6.1 First Theme: The Assessment of Critical Thinking and Instrument Validation

There was a consensus among the interviewed academics that assessing critical thinking is a difficult task. Attempts to assess critical thinking skills have led to a better understanding of the nature of the assessment. For instance, assessing critical thinking can be subjective, even if the assessor is experienced in the field, which was made clear in the interviews in the context of student assignments:

> "*I know that [academics] are biased in the way we mark assignments.*" (V2P03)

Assessment can be a burden to students in terms of evaluating critical thinking skills. Many standards and criteria used for academic assessments and evaluation can limit the ability of students to think critically due to overly rigid guidelines:

> "*I sometimes think, in this university, we do so much assessment of different sorts that it is like the students are constantly being told what they can and can't do, which means there is less time in learning how to do it better.*" (V2P06)

There are many methods of assessing critical thinking in the context of research projects. One method currently used by academics and supervisors to assess critical thinking is the use of specific criteria and standards to evaluate student work. For instance, students should provide a justification for choosing a specific topic. However, many aspects should be considered when assessing critical thinking, such as the ability to evaluate arguments, examine information and draw conclusions based on evidential synthesis, as mentioned by academics when describing the approaches they use to teach critical thinking skills to students who are working on research projects.

> "*We have our marking criteria. One of the important things in the workshop, the terminology I use, is that they are not allowed to say that they like somebody's work or don't like it. They have to say what is working or what is not working.*" (V2P07)

The instrument has been designed for academic purposes and can be used to assess progress in research projects, including intellectual standards and elements of thought. Moreover, the instrument can be used by students regardless of their critical thinking abilities. After viewing the instrument that was designed to assess the perceived critical thinking in research projects in the context of a DBCI, the academics agreed that the designed instrument could measure the critical thinking skills of students, which can be inferred from the following quotes extracted from the interviews:

> "*Just the whole concept of the questionnaire is good. I think the way you do it could be done [...] electronically or on paper.*" (V2P04)

> "*I say, sort of, almost like a self-check, so that people are looking to see if they have questioned their assumptions, if they have got something on assumptions. Are their questions clear? Is there any sort of bias in what they are doing? What else have you got here? You have got concepts. Are the concepts relevant to their research question? I think, all of that, produced as a sort of self-check. Yes, there could be some place for that to be done for the assessment.*" (V2P09)

The validation process for the instrument, which was designed to assess the perceived critical thinking, showed that a few issues needed to be addressed. For instance, the statements within the instrument were composed of long sentences that needed to be shortened. There were also some double-question statements in the instrument, which were avoided by rewriting the statements to combine the terms into one shortened statement for each standard or element.

> "*I think, the problem with people, respondents on an electronic survey. [...] Sometimes, they will not read everything, and you have got some very long sentences there.*" (V2P03)

Another point was raised regarding the tendency of respondents to be subjective during self-reflection. Although self-reflection has been used to assess pedagogical progress in education, students must be aware of being honest and careful when assessing themselves, and unreliable respondents should be removed. Another way to reduce the subjectivity is assess the work performed by participants in the mobile intervention experiment.

> "*I think all what it will lead to is that someone is indicating, either that they have the skill or not.*" (V2P04)

The assessment of critical thinking is inherently subjective, and there can always be disagreement regarding the assessment of a standard or element. For example, when assessing clarity, it can be difficult to determine whether the text written by a student is clear, depending on the intended audience of the text. Clarity in critical thinking is essential, as reported by different academics:

> "*There can always be a disparity, and then, who decides, you know, what actually is clear and what isn't clear [...] it could be a decade of disagreement.*" (V2P01)

The instrument appeared to evaluate the perceived critical thinking for the stages after a project has been chosen but not for stages prior to that point, which succeeded in accomplishing the aim of this instrument, which was to assess the perceived critical thinking of students during research projects.

> "*This is all, that it seems to me, to be at the stage of deciding what the research question is going to be [...] if you're setting out on a piece of research, then before you actually do that or in the course of doing that, you have to address all of these issues. Does this go further? And then you look at, when you're engaged in the research, what the critical thinking involves.*" (V2P04)

When the participants read the instrument, there appeared to be some similarities among the statements in the instrument. For instance, the statements for the standards of clarity and precision had similar meanings; however, when considering amending the instrument to remove similarities among the statements, it was necessary to maintain the definitions of the standards and elements described by the Paul-Elder Critical Thinking Framework. Moreover, it was determined that using word forms of the Likert scale (No, Sometimes, Not sure, Usually, Always) was not sufficient, and the addition of numbers next to the words (i.e., No = 1, Sometimes = 2, Not sure = 3, Usually = 4, Always = 5) was deemed necessary to help students more exactly self-reflect on their critical thinking abilities. All of the comments provided by the academics in the interviews to validate the instrument improved the instrument.

> "*The third question here, of this question three, the information I used is correct and accurate. It is very similar to the one of the questions of question two about the correctness of the information.*" (V2P03)

The primary concern regarding the assessment that the instrument provides was whether the assessment can help the assessors understand their abilities. In this study, the assessment of critical thinking was necessary not only to measure critical thinking before and after a controlled experiment (pre-test and post-test) to study the impact of the digital intervention but also to provide relevant interventions for weak critical thinking skills during the course of a research project. This necessity was indicated by a participant who recommended a critical thinking book written by Cottrell (2017) that contained activities similar to those in the designed instrument for the assessment of critical thinking based on standards and elements.

> "*This, what you are doing, reminds me of things that she does in her book because it is a critical thinking skills book, which is very accessible to students. So, she puts in things like of surveys and questionnaires, and she calls them a sort of self-help, self-evaluation section, and she'll have 20 questions. And you have to answer not just in terms of using [words]. She'll do it in terms of numbering. And then, you have to add up your scores.*" (V2P09)

4.4.6.2 Second Theme: Critical Thinking as Both a Behaviour and a Skill

On the question of whether critical thinking is a skill or a behaviour, there was agreement that critical thinking can be both a behaviour and skill that can be practised and changed. Critical thinking can also become a daily activity that is not only applied to academic tasks but also to tasks in normal life. Many factors can influence the ability to think critically, such as social experiences, families and friends, and culture.

> "*That's an excellent question. I mean, I think it's both because I also think that a lot of what we call critical thinking in an academic context doesn't exist only in an academic context. So, perhaps in my normal life, I'm doing sort of these types of things anyway. And then perhaps, just different individuals, perhaps, [it's] almost a personality sometimes, just about any of it, like a character.*" (V2P01)

The participant V2P06 added:

> "*I even think yes, habit, training, perhaps. Also, just sort of part of your upbringing and your social experience and some families, some people's friends, perhaps, are just more often [critical thinkers]. So you sort of easily become more like them. I mean another possible issue is culture.*"

There was an emphasis on critical thinking being a behaviour because this would allow critical thinking to be treated as a habit that can be supported and improved with practice and reminders.

> "*I think that's a very good point actually. I think thinking about treating it as a sort of behaviour is a very good way to think about it. But my experience is that many students don't have that behaviour. And maybe what they need to learn, the skill they need to learn, is the behaviour. So then it becomes sort of second nature, but they naturally would engage with text in a sort of critical way.*" (V2P08)

To form a habit, it is important to understand the skills that need to be supported as a behaviour:

> "*But also, look, part of learning that behaviour is learning what critical thinking involves, what it actually means. So there's a whole range of different things that might be involved in critical thinking. But I think ultimately, yes, you want to achieve a sort of behaviour, so that somebody is naturally, as soon as they start reading the text, they start thinking in certain ways and it becomes a natural thing to do.*" (V2P05)

> "*I think when you say behaviour, I think it can also become a habit. I think it can actually become a bad habit, sometimes, as well as a good one.*" (V2P10)

> "*About that behaviour, I think that certain people have a disposition towards being accurate and precise, and it's not necessarily [...] but it is opposing different ways.*" (V2P03)

4.4.6.3 Third Theme: Supervision and Teaching Critical Thinking in the Context of Research Projects

Teaching critical thinking to students is one of the primary tasks that supervisors focus on when supervising students during research projects. Supervisors use many methods to teach critical thinking during research projects, such as asking questions and conducting meetings to directly instruct their students. Students are intended to learn and use different critical thinking skills in their research work, such as asking the right questions, gathering evidence, and drawing conclusions.

> "*The students don't do any research for me till semester two. They do, basically, this sort of thing as an institute, so they have questions to research about, sort of, to gather evidence. They have to assess the evidence. They have to sort of try and reach conclusions. In semester one, it's more what are the, sort of, I suppose you might say, the micro skills.*" (V2P06)

> "*[Critical thinking is] making decisions, finding information. I think that's probably the biggest thing and that students assume that it's something that they've done, too, and then assume it's something that they can't do, which I think, it just isn't true.*" (V2P01)

> "*Looking at things from, I think, precisely that sort of [perspective of] relating ideas to each other. I think looking at things very discreetly, so they look at maybe one or two items but don't look broadly enough, don't relate things to each other so often, people think that they have to [...] You'll know that there's a distinction. With a lot of the students that I see, it's a master's level.*" (V2P09)

Students must demonstrate a deep knowledge and understanding of the topic they are researching, which might include synthesising the contradictions in different arguments within the area they are studying in their research projects:

> "*It's getting a good understanding of the field that you're working in. Really getting sorts of broad reading[s]. I know that you've grasp[ed] what the conversation is, and then, sort of using people against each other. All the dispute, you know, that the critical stuff is on forward and done for, and out of that, you begin to form some of your own ideas from doing that. And that's a distinction between that and the [...] realm where you want [...] doing something so you're looking at the whole field, absorbing everything, understanding conversations. But ultimately, what you're looking at things is going to be something unique with [...]. Master's level. You are going to be sort of doing good stuff that other people avoid.*" (V2P09)

Another important element of good critical thinking is creativity, which is an essential element for critical thinking. Imagination can boost the ability to thinking critically because it allows the learners to think freely about certain issues. However, using logical arguments is necessary when utilising the imagination in free and critical thinking. Creativity as a component of critical thinking has also been addressed in these interviews, as well as the freedom to apply creativity:

> "*It's what it gets going between those two. You really do need that critical thinking. But you need to allow the creative work to come through you. I think critical thinking also must be creative.*" (V2P02)

> "*I think critical thinking has to go between creative thinking and being free, allowing your imagination to take over and sometimes your subconscious to lead you, followed by critical thinking about what you've just done, whether what you've just done is working., And they need to have a combination of creative and critical thinking to work out problems, so I think it's very much going between trying to get rid of your editor, so that you're creating and being a bit more instinctive and allowing the work to lead you, and then coming in as the editor and saying, "This doesn't work here. This doesn't work there." And you really do have to use almost the logic in doing that. At the same time, there's also a bit of creativity in that as well.*" (V2P02)

Several methods have been introduced to train students to be critical thinkers:

> "*I teach things, like how do you decide, how do you decide which sources may be more reliable than others or what problems might that be with one source as opposed to another's. So, things like credibility, things like bias, things like interest, even things like recognising. You've mentioned that somewhere, so recognising, like the limitation, conclusions, try to recognise if someone's perhaps overgeneralising or something. I guess you're making me think now, I could be doing a lot more of those things in terms of sort of tasks, sort of gaining new tasks.*" (V2P05)

Workshops have been used by some supervisors to teach critical thinking:

> "*I think, well, for their creative writing? I do have something in creative writing. Kind of important, that's very common, and it's called the workshop.*" (V2P02)

The approaches used to teach critical thinking vary based on the goals and objectives the instructors desire for their students. For example, asking students to find similarities among concepts is one method of teaching critical thinking:

> "*I sometimes wonder, should we do something kind of a bit more discreet, like saying [that] critical thinking skills or tests [are] sort of a more integrated part of their reading, more integrated with their research, more integrated with their writing? I don't know. I guess you can do either.*" (V2P06)

> "*To be able to do so I make it from an article, and I want them to identify strengths and weaknesses in terms of credibility.*" (V2P06)

Other academics use a model to teach any skill, including critical thinking. For example, four factors must be considered when teach a skill: knowledge, understanding, social aspects, and attitude:

> "*It's where the balance lies. It's not [that] any one activity is one thing, but any one activity, like teaching critical thinking, is a mixture [...] The actual skills are providing sentences that are concise and precise, accurate, and that's the skill. But there's also a knowledge about what is accurate, you know. They've got to have the knowledge to know what is the truth in something. So there's an element of knowledge about it. There's an element of understanding. They have to understand that you want a lot of things, like the concepts or the morals or ethics, or you have to understand the concept of - You have to understand this concept of criticality. So, there's an understanding to it, and of course, the whole thing because it's predicated by their attitude to it. It's guiding, it's core attitude, and it won't worry them and they won't do anything about it. Also, if they're very sensitive, [their] attitude towards criticality, their skills might not be great, but they'll do quite a lot towards it so that they'll possess internal motivated [...] to the critical.*" (V2P03)

Students often struggle with or misunderstand critical thinking. For example, looking for the wrong information, assuming that critical thinking is identifying negative points, and losing the balance between practising critical thinking as both a behaviour and skill. These issues were identified by the participants in the interviews.

> "*And sometimes, the problem is, they sort of learn the skill things. Or I sometimes think, are they learning the skills to criticise something or are they just simply learning that it's okay to say it? And then, I think the problem is, once they realise it is okay to think this way, actually, they do it too much. So usually, the first task I give them when I have to assess, like, all sorts of information, they may find like 20 things, to go back -okay and nothing looks good.*" (V2P09)

> "*Is being positive [...] also critical thinking? I'm not just saying that's bad because I don't believe that, but that's true or that's good evidence.*" (V2P06)

Another problem that students face when becoming critical thinkers in the context of research projects was articulated as follows:

> "*Everyone thinks the main point of that is you get feedback on your own work, but I, actually, I think the main point is you're learning to hone your critical eye by looking at other people's work. You could be more objective about what they were thinking. And eventually, you [are] then able to use those skills to apply it to your own writing. So that's one way that we - I try to, you know, hone their critical eye. In terms of their critical writing, I try to break it down. Then, to have a very clear thesis and to have examples from creative works [that] they [can] draw upon, and also critical works, and to apply that. So, I try to be - break it down for them in[to] a series of points that they need to do.*" (V2P04)

> "*I think some of it is because they think it's new to them and because they think it's sort of, it is academic. I've tried to sort of make it more of a part of teaching in the context of real life. Thinking can be something, as you said, linked with personality, with culture.*" (V2P01)

4.4.6.4 Fourth Theme: The Design and Content of the Digital mBCI to Support Critical Thinking

Academics encouraged the use of technology to promote independent skills, such as critical thinking and research skills. However, it is important to pay considerable attention to the challenges faced when technology is integrated with a learning environment.

> "*I think [the mobile application] is going to be useful, whether it helps critical thinking or it helps manage students' time and effort in going through a large project [...] it's a project management tool.*" (V2P08)

> "*Whether [...] this app [will improve] critical thinking, I think the answer will always certainly going to [...] be yes [be]cause [...] it's drawing attention to it.*" (V2P03)

Discussion within the interviews pertained to the contents of the mBCI. The participants generally supported the components of the mobile intervention, indicating that it would help improve critical thinking skills in students.

> "*Well, this is actually quite a good exercise. It's given me an idea of where you think your strengths are and where you think your weaknesses are, and it looks like when it comes to sort of - what was this question? When I set my research objectives, are [you] trying to answer the main goal? Why it's important? And maybe you're sort of not doing that as well as you could, what can we do? How can we try and improve on that, helping you? So, I think as far as that goes, yes you could do that, sort of, in terms of technology, could then lead onto [...] conversation.*" (V2P04)

The suggested *LifeGuide Toolbox* package for designing digital intervention components in the mobile application could also allow supervisors with minimal programming backgrounds to assist students in their research projects:

> "*It could be a [...] for a tutor to actually say, 'I want you to complete this in a very honest way, so that we can then discuss what we've come up [with]'. But I think, I'm not sure how it would work off the bat and actually engage in the research, and you're actually doing it. You don't need somebody to be reading your own research. You've got to then see whether all these sorts of relations, things that I'm talking about, are being done. And you can only do that by the person's sort of meeting.*" (V2P04)

However, academics might have less experience with using technology for critical thinking or in general:

> "*I would say, I know very little about mobile apps, so that's part of why I'm actually meeting because that's something I should know more.*" (V2P06)

Technology also is seen as a distracting tool for learners:

> "*Technology for creative writers [...] it just interrupts.*" (V2P02)

4.4.7 Discussion

The academics all emphasised the importance of critical thinking for university students, especially in the context of research projects. According to the academics, there are three major elements to consider when discussing critical thinking. First, the definition of critical thinking and how it differs from normal thinking. Second, the effective techniques for teaching critical thinking, considering the most common models or frameworks for promoting and enhancing critical thinking skills. Third, the assessment of critical thinking, which depends on the context.

The instrument that was designed for this study has been validated and confirmed by academics who have experience in research supervision. The academics encouraged the use of the instrument to assess the perceived critical thinking in the context of research projects. The validation process confirmed that the current intellectual standards (clarity, accuracy, precision, significance, relevance, depth, breadth, logic, and fairness) and the elements of thought (purpose, questions, information, inferences, concepts, assumptions, points of view, and implications) should be included in the instrument to assess the perceived critical thinking skills in research projects when DBCI methods are used.

To determine a comprehensive definition and an appropriate method for the assessment of critical thinking, we must further scrutinise the different perspectives of critical thinking provided by academics. There is no one definition for critical thinking, according to academics. However, the primary components of critical thinking are similar across all definitions. For instance, evaluating an argument by asking what tools will be used to accurately evaluate the argument and how these tools will be used is a common component of the definition. One academic has described critical thinking as the ability to analyse and examine an idea with relevant information. There were common concepts introduced by academics in the interviews with regards to critical thinking definition. For instance, when academics were asked to define critical thinking, these aspects were used generally by the academics to define critical thinking: 1) the ability to analysis and evaluate and arguments with evidence, 2) using logical reasoning, and 3) examining claims with facts and truths.

Changes were made to improve the instrument, without changing the primary definitions of the adopted Paul-Elder Critical Thinking Framework. For instance, changes were made to shorten long statements and to avoid double-question statements. One of the interviewees, who specialises in creative writing, discussed the level of thinking in both scientific and humanitarian methods. Research emphasises the idea that collaboration is an effective way to enhance critical thinking (Novakovich 2016; Styron 2014; MacKnight 2000). Science, in particular, is not something you can work on alone but requires collaboration with others. Approaching critical thinking as both a behaviour and skill will enable the use of DBCI methods to improve critical thinking in the context of research projects. In addition, as argued by academics and recent research studies (Al-Mubaid and Bettayeb 2017; Asiri et al. 2018), behaviours are related to the daily life activities; therefore, approaching critical thinking as a behaviour enables the mobile application to be more successful at enhancing critical thinking habits, as DBCI can be used to address behaviours that require continuous support.

Many effective approaches have been used to teach students critical thinking skills during research supervision. Using research papers to train students is one of the most common methods for teaching students to understand the process of critical thinking. Research papers use complex topics and questions, examine how people criticise each other, and demonstrate how to present knowledge using evidence. These concepts were addressed in the literature, in studies where students focused on the background of a topic or studied the introductions of research papers (Dos Santos and Cechinel 2019; Clear 2014; Bakar et al. 2011). Another method for teaching critical thinking skills to students is direct instruction or providing them with different examples and scenarios that demonstrate the application of critical thinking skill.

There are a few general comments can be identified from the interviews about the students' critical thinking based on the interviewees' experiences. Students make many common mistakes when applying critical thinking skills during their research projects. For instance, students tend to collect relevant information but fail to synthesise ideas. Students appear to misunderstand the literature review as a way of initially finding the problem. During research work, students tend to think directly about building tools rather than thinking about theories and frameworks. Students gravitate towards building something rather than investigating or exploring ideas. Students succeed in recognising the definition of each standard but still struggle to apply them to their work. Students incorrectly believe that critical thinkers do not make mistakes. Students tend to view solutions in terms of right or wrong approaches. Students think that critical thinking skills are steps that can be followed exactly, but instead, critical thinking skills are tools than can be used to create one's own ideas. Students tend to understand the critical thinking skills of others but not their own skills or how to apply them to their own ideas. Students tend to avoid simplicity because they think it refers to weak statements. As people become accustomed to getting immediate answers, they do less digging for information themselves. Students consider results more important than methodology.

All of the intervention components in the mBCI were reviewed and supported by the academics, such as the project information page, activities and training, practise tasks, short questionnaires, setting goals and plans setting, notifications for engagement, inquiries and answers, and providing feedback and instructions.

4.4.8 Summary

This chapter details the data analysis performed for the first phase of this study. This chapter answers the first and second research questions, which concern how to measure the critical thinking skills of university students in the context of research projects and the technical methods for teaching critical thinking skills. This chapter also describes the instrument that was designed to measure the perceived critical thinking skills. This chapter describes the investigation of how students and supervisors perceive the benefits of using mobile technology and DBCIs to measure and improve critical thinking skills in research projects. This chapter provides an understanding of the data that was collected from students through a comprehensive survey, requiring them to reflect on their thinking skills. This chapter also describes the qualitative data that was gathered by interviewing supervisors and academics regarding their needs and expectations for the instrument and for the use of DBCIs to promote critical thinking skills. The aims of the interviews were to identify the requirements of supervisors and academics for the use of digital interventions to promote critical thinking skills during research projects and to validate the designed instrument and intervention components.

Chapter 5

Design and Implementation of Digital mBCI Components to Support Critical Thinking Skills During Research Projects

This chapter addresses the third research question in this study, which identifies the principles necessary for designing and implementing digital mobile-based behaviour change interventions (mBCIs) to foster the critical thinking skills of students in the context of research projects. This chapter describes the designs and implementations of the technical tools used in the experiments performed in this study, followed by a detailed description of the pilot study that was conducted to examine the impact of using a digital mBCI to support critical thinking skills during research projects. After the initial survey results, and based on interviews with supervisors regarding the effectiveness of using an mBCI to foster critical thinking and research skills, the need for such a tool became obvious. Supervisors were convinced that DBCIs could have an impact on the critical thinking skills of students and their abilities to perform independent study, in general. Therefore, to identify an appropriate implementation protocol, the experimental design was prototyped to study the usability and utility of the tool based on user feedback. The data generated by participants using the system were analysed and studied to determine a practical implementation protocol for the tools used in this study.

5.1 Digital Behaviour Change Interventions (DBCIs)

As discussed in Chapter 2, DBCIs are techniques used to provide continuous support and tailored advice to learners, with the goal of changing undesirable behaviours through interactions with web- and mobile-based platforms (Michie et al. 2017; Yardley et al. 2016). A digital intervention consists of three factors, as illustrated in Figure 5.1. First, the intervention builders provide the tools necessary for intervention experts and users to digitally interact with each other through web- or mobile-based platforms. Second, the intervention experts, who might lack programming skills, can design interventions that positively change the behaviours of users. Third, the intervention users receive the interventions from experts by using the mobile- or web-based intervention. A gap in the current *LifeGuide Toolbox* framework was identified, which was the inability of intervention builders to communicate with intervention users. In this study, this gap was bridged, making the *LifeGuide Toolbox* more interactive, providing specific intervention components that can provide notifications or feedback to users and that can receive inquiries from users, accompanied by a web-based admin panel to monitor the interactions between the users and the mobile intervention.

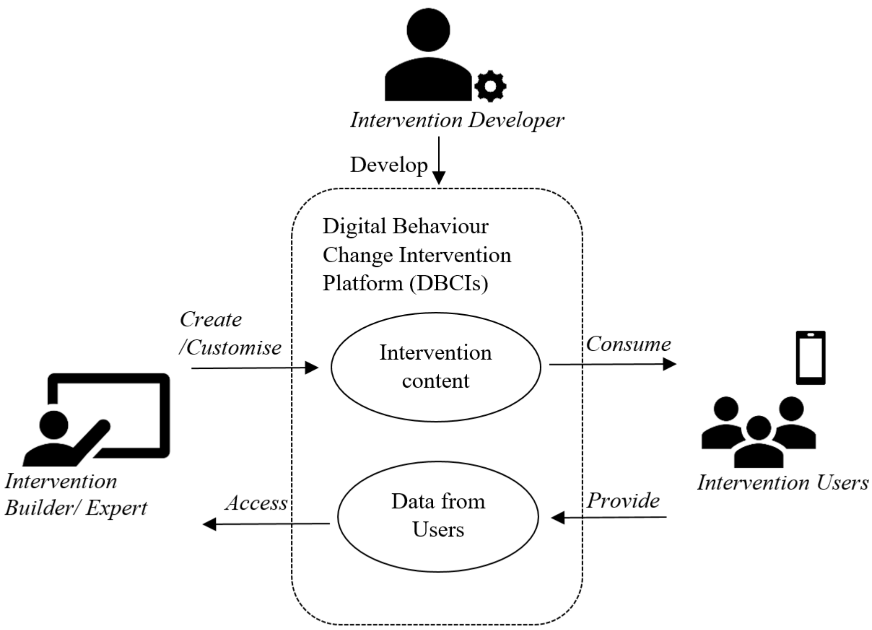

Figure 5.1: Main Factors in Digital Behaviour Change Intervention System

The design and implementation of the DBCI used in this study contained two primary parts. First, a web-based authoring tool (Figure 5.4) was used to design a mobile intervention with the goal of changing behaviours, such as supporting the critical thinking skills of students in the context of research projects, supported by an existing *LifeGuide Toolbox* software tool (under development) that was adjusted and extended to run the initial DBCI experiments. Second, a mobile, application-based intervention, named the *CriticalThinking* mobile application (Figure 5.9), was designed using the tools mentioned above, included a web-based admin panel that enables the intervention creators to interact with users by visualising and tracking their work. The web-based admin panel

(Figure 5.6) was designed to help the intervention creators monitor user data and manage communications through notifications, the delivery of supportive information and feedback, answering questions, and sending short questionnaires to evaluate progress. Detailed descriptions of these various tools are presented in the following sections.

5.2 Intervention Components

The intervention components comprise the primary digital elements that enable users to interact with the mobile intervention content. The components were identified based on a literature review (Chapter 2) and on interviews with supervisors and academics (Chapter 4). The specified components were selected because they were considered to be more effective for the promotion of critical thinking as a behaviour in the context of research projects. The intervention components used in this study were as follows: project information, activities and training, practise tasks, short questionnaires, setting goals and plans, notifications for engagement, inquiries and answers, and providing feedback and instructions. A detailed discussion regarding the implementation of the intervention components and their contents can be found in the following sections.

Activities and feedback required users to read the content provided in the intervention, while the other components required the user to choose from a list of options (short questionnaires) or to provide a text-based response (tasks, inquiries, plans and goals, and project information). These components were used within the mobile intervention to assess the responses of the users, both before and after the implementation of the mobile intervention to promote critical thinking skills. The intervention components were linked to the previously described intellectual standards and elements of thought to further understand which components contribute to the enhancement of specific critical thinking skills. Measuring how much time the users spent with each component and assessing the responses to those components allowed the effectiveness of the mobile intervention to be assessed in this study. Each component is briefly described below.

5.2.1 Project Information

The project information page contained a set of basic questions that allowed students to consider the primary aspects of their research projects, based on the elements of thought. Students were asked to describe aspects of their research projects, such as the purpose, the questions being asked, the types of information gathered, the inferences being made, the concepts being examined, the assumptions being made, the points of view being examined, and the implications of the research projects. As an intervention component, students were asked, both before and after entering their project information, to examine how this component helped them with their critical thinking processes. Students were asked to reflect on following statement, in both the pre- and post-intervention surveys: "Writing my research project information can be helpful to rethink about my critical thinking and research skills during the research project." (Appendix H).

5.2.2 Activities and Trainings

Providing activities that contain content designed to improve critical thinking skills is considered to be an effective method for enhancing the critical thinking skills of students (Cavus and Uzunboylu 2009). In this study, many activities designed to enable students to use intellectual standards were provided. These activities were supported with descriptions of the intellectual standards and how to apply them in the context of research projects. Students were asked to reflect on the following statement, in both the pre- and post-intervention surveys: "I tend to try thinking about activities or trainings in my mobile device (using any application or web) to improve my critical thinking and research skills."

5.2.3 Practise Tasks

Practise tasks were comprised of activities designed to allow students to think specifically about their research projects. Using challenging tasks to practise critical thinking skills is considered to be an effective approach for improving critical thinking by changing how students tend to approach their research projects (Haghparast et al. 2014). The tasks were provided by supervisors for each student and were directly associated with each student's research project. These tasks can be provided to allow students to apply what they had learned during the activities component to their research projects. Students were asked to reflect on the following statement, in both the pre- and post-intervention surveys: "Working on simple critical thinking tasks (using text editor) in my mobile device helps to improve my critical thinking and research skills for my research work".

5.2.4 Short Questionnaires/Polls

For DBCIs, using short questionnaires is considered to be a practical method for measuring the progress being made by users during the intervention (Zheng et al. 2016), which allows intervention creators to determine the optimal timing for interventions. Moreover, intervention creators require data regarding why users require an intervention and how users interact with the intervention, which can be acquired by asking simple questions during the intervention that enable users to self-reflect on their progress with regards to the intervention goal; in this study, the intervention goal was the enhancement of critical thinking skills. Students were asked to reflect on the following statement, in both the pre- and post-intervention surveys: "Short surveys during the research project period to test the progress of my critical thinking skills helps to self-reflect on my work".

5.2.5 Setting Goals and Plans

Setting goals and plans is considered to be another effective strategy for changing behaviours (Henningsen et al. 2011). Students were allowed to set goals and plans with regards to their research projects and with regards to improving their critical thinking skills. Students were asked to reflect on the following statement, in both the pre- and post-intervention surveys: "According to my goals and plans written in my mobile device, I succeed to make positive behaviours to improve my critical thinking and research skills".

5.2.6 Notifications for Engagement

Notifications, such as nudges and triggers, can be used to maintain user engagement with an intervention (Weston et al. 2015); in this study, notifications were used to maintain student engagement with critical thinking skills in the context of research projects. Students were able to customise their notification preferences, using time settings and forms. The notification feature was used as an intervention component because it is an effective technique for promoting intervention engagement by providing students with tailored information and materials relevant to critical thinking skills on a daily or weekly basis during their research projects. Students were asked to reflect on the following statement, in both the pre- and post-intervention surveys: "The mobile notifications help me to stay engaged in the mobile application content and therefore to help me to stay engaged in my critical thinking and the research work".

5.2.7 Inquiries and Answers

Enabling users to ask questions and make suggestions during the intervention is important (Thaiposri and Wannapiroon 2015). This component provides both students and supervisors with the ability to communicate and interact with each other to promote critical thinking skills. Students regularly have questions regarding their research projects, and this component is an effective method for providing them with the answers and the support they require. In addition, supervisors can anticipate common questions and assess the weaknesses in the critical thinking skills of their students, allowing the supervisors to deliver constructive and prepared answers. Students were asked to reflect on the following statement, in both the pre- and post-intervention surveys: "Asking questions about my critical thinking skills helps me to improve my research work".

5.2.8 Feedback and Instructions

Feedback is a useful technique to scaffold learning and support learners with the knowledge they require (Hermsen et al. 2016). Feedback is an intervention component that allows experts, instructors, and in this case, supervisors to provide students with comments regarding their work. Students were asked to reflect on the following statement, in both the pre- and post-intervention surveys: "Receiving feedback and direct instructions through the mobile application is a fixable way to improve my knowledge and behaviour in critical thinking and research skills".

5.3 *LifeGuide Toolbox* and Authoring Web-based Tool

An existing *LifeGuide Toolbox* software tool was adjusted to run the initial experiment using DBCIs to foster the critical thinking skills of students. The *LifeGuide Toolbox* is an open-source framework that enables intervention creators to design and generate DBCIs in the form of mobile applications. The *LifeGuide Toolbox* allows experts with no programming skills to generate web- and mobile-based applications for various purposes. The *LifeGuide Toolbox* was developed as part of the LifeGuide project[1], which aims to promote cross-disciplinary research by studying the use of DBCIs delivered through web- and mobile-based platforms (Hargood et al. 2012)..

According to Osmond et al. (2009), the following factors make the *LifeGuide* unique and different from other tools, such as HTML editors, which can be used to design internet-based interventions:

- The *LifeGuide* is designed for the creation of complex interventions and interactive web pages that change their contents depending on the conditions.
- The *LifeGuide* creates pages that will record data generated by participants, without requiring the browsing of server logs.
- The *LifeGuide* offers the ability to randomise and stratify participants or to use the data gathered by users, which authors may use to deliver statements.
- The *LifeGuide* is designed with a framework for running trials and allowing repeat visits, a necessary feature for many interventions.
- The logic editor is the most crucial component of the authoring tool and is what sets *LifeGuide* apart from standard HTML editing software, allowing an intervention to be more than a series of static web pages and enabling authors to express logic naturally, without requiring special training.

[1]LifeGuide Project Website: `www.lifeguideonline.org/`

- The *LifeGuide* allows the use of a graphical interface for the suggested logic, with pages in the intervention being represented as nodes and links between pages being represented as arrows, demonstrating the ability to move from one page to another.

In addition to the above capabilities, the *LifeGuide Toolbox* framework was adopted in this study for more relevant reasons. First, it was free to use the software tool because my primary supervisor is one of the co-founders of the project. Second, the *LifeGuide Toolbox* has been successfully used in similar studies, primarily in the field of healthcare education, using DBCI techniques (Weston et al. 2015). Third, the *LifeGuide Toolbox* framework supports the integration of the other frameworks and models that have been used in this study, including the Paul-Elder Critical Thinking Framework, the five-step model to enhance critical thinking, and the Theory of Planned Behaviour. The *LifeGuide Toolbox* captures the primary stages of DBCIs, such as preparing and designing interventions, user learning, user reflection, and monitoring performance, and allows feedback and interventions to be delivered to users based on the collected data.

In this study, the *LifeGuide Toolbox* framework was used to create an mBCI. The *CriticalThinking* mBCI was created using the accompanying authoring tool available with the framework (Figure 5.4), which did not require much in the way of computer programming knowledge. However, generating the mobile applications used in this study required extra work to make them suitable for the experiment; e.g., the tool was adjusted to accommodate both iOS users and Android users, which required deep knowledge of Java, JavaScript, NodeJS, and Ionic frameworks. Moreover, the backend of the mobile application was not fully supported by the *LifeGuide Toolbox* software tool, requiring further extra effort to make it suitable for the experiment.

5.4 Digital Intervention Design

The system consisted of a client side and a server side, along with an intervention configuration file. This section is structured as follows. First, the overall architectural diagram for the prototype will described. Second, the primary components that were implemented will be described in more detail. Finally, the screen layout designs will be presented. Implementing the *LifeGuide Toolbox* for this study resulted in four primary developments: an extension of the *LifeGuide Toolbox*; the addition of features to the authoring tool; an mBCI with critical thinking content; and a supportive admin panel for communicating with the user and monitoring user interactions with the mobile intervention.

5.4.1 System Architecture

The system architecture represents the primary components of the *LifeGuide Toolbox* framework (Figure 5.2). The system starts with the intervention builders, or the intervention researchers, who create an intervention configuration file using the intervention web-based authoring tool. On the sever side, the intervention configuration JSON (JavaScript Object Notation) file is uploaded manually to the server through a web-based interface. The server stores intervention configuration files in a database, along with other intervention-related data. The database is queried by the server, either upon request from clients or periodically. On the client side, the user requests specific intervention configurations from the server through the internet when using their devices. The server responds to requests from clients through the Internet, such as available interventions, intervention configurations, tools usage, and data logging. The interventions configuration is saved locally as a JSON file (in the phone's internal memory). The Application Controller uses the intervention configurations to call other appropriate Activity Controllers. The Activity Controller loads the appropriate activity onto the phone's screen. Data collected from different activities are passed to the Data Logging file. Whenever an appropriate type of connection is available, pending data transfers are undertaken.

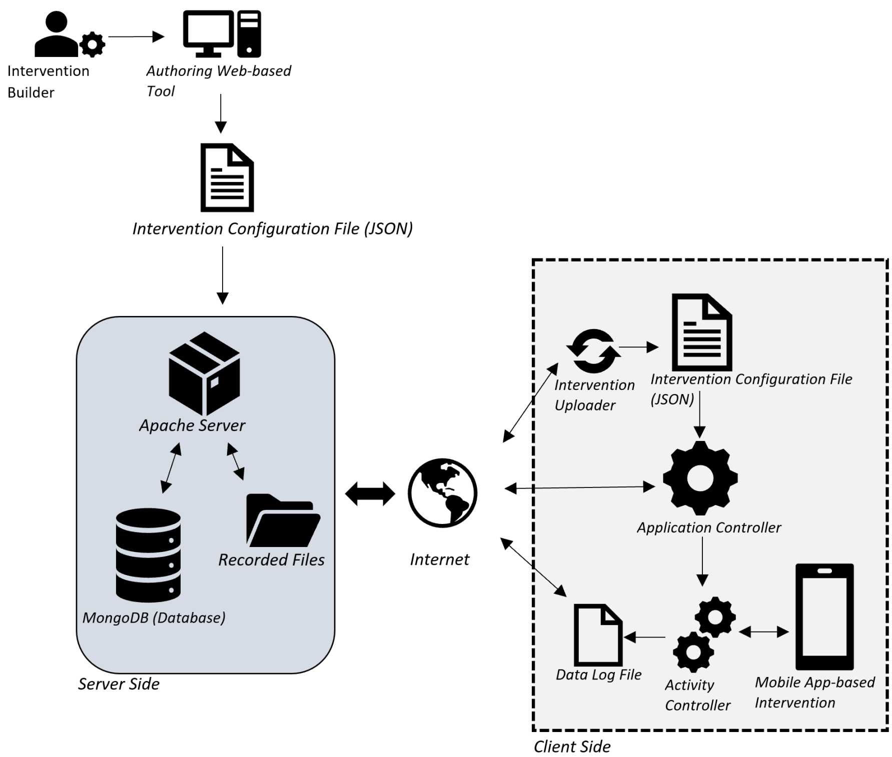

FIGURE 5.2: *LifeGuide Toolbox* Framework Architectural Diagram

As shown in Figure 5.3, the *LifeGuide Toolbox* framework was modified to be suitable for this study. The modified system architecture uses the same processes for the primary components of the *LifeGuide Toolbox* framework. However, the modified framework has notification features that allowed users to be nudged and triggered during the experiment, as illustrated in red. Additionally, the admin panel was added to facilitate communications and to monitor user interactions with the mobile intervention, based on the data stored in the database.

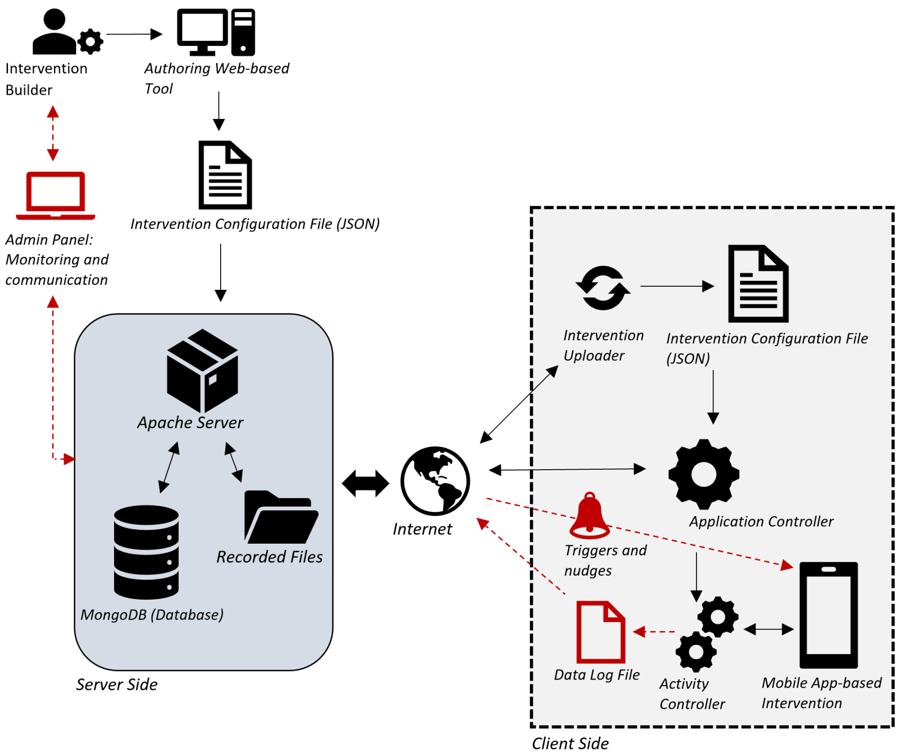

FIGURE 5.3: Extended *LifeGuide Toolbox* Framework Architectural Diagram

5.4.2 Primary Components

The primary components of the *LifeGuide Toolbox* framework, including both the server side and the client side, are described in the next sections.

5.4.3 Server Side

For the server side, the script has been modified to query user data, such as emails, answers to surveys and activities, text from tasks, plans and goals, and questions or suggestions. Accordingly, all data are securely stored within a database that is linked to both the mobile application and the admin panel. A local database was used in this study. A web-based admin panel was developed to allow the visualisation of the data stored in the server; the panel also enables developers to download log files, send notifications to the mobile application, according to user defined preferences, answer questions, deliver tailored information, and motivate users to use the mobile application. The database stores all data generated by using the mobile application, such as user names for participants, time spent using the mobile application, answers to activities and surveys, and the text from goals, diaries, and plans.

5.4.3.1 Authoring Tool: Intervention Configuration File

Authoring tools are web-based pages that enable users to create web documents using specific software or tools. Authoring tools offer graphical user interfaces to help users more easily navigate HTML and web pages (Osmond et al. 2009). Currently, there is a web-based authoring tool that has been developed to accompany the *LifeGuide Toolbox*. This authoring tool was used to design the mobile intervention used in this study, which automatically generates an Intervention Configuration file containing all of the necessary configurations and settings for the intervention in a JSON format. The configuration file can be edited using a text-editor and is used by the mobile application for the customisation of the intervention. The primary information contained in Intervention Configuration files includes the intervention ID, the intervention components that end-users can be assigned to, and the content for the intervention.

As shown in Figure 5.4, the web-based authoring tool provides a set of features that enables intervention builders to design mobile interventions. The authoring tool contains a set of options that facilitate the design of short surveys, text boxes for plan and goals, and exercises with logical sequences. After the mobile functions are designed, the tool generates a configuration file (JSON files) when the 'Save' icon is selected. Accordingly, JSON files can be run on the Ionic framework by using the *LifeGuide Toolbox*.

The primary interface of the authoring tool consists of three sections (Figure 5.4). First, the intervention settings offer a set of options that allow the intervention creator to provide information for the mobile application interface, such as the name of the application, the order of the activities shown, and the logo for the application. Second, in the middle of the page, the creation section of the authoring tool contains a set of features that enable the intervention builder to design the desirable intervention, using text, media, and images. This section contains ten tabs, including menu, survey, diary, information, media, settings, sequence, planner, and review. Last, on the right side, the modification section allows content to be added to the interface. For instance, Figure 5.5 illustrates how the authoring tool can be used by intervention creators to design short quizzes for the intervention.

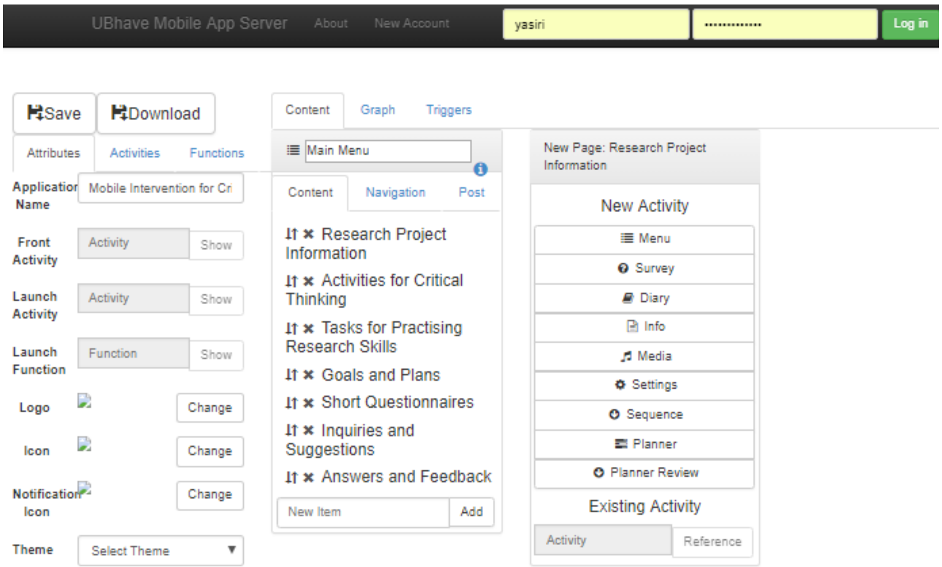

FIGURE 5.4: UBhave Authoring Web-based Tool

5.4.3.2 A Tracking, Web-Based, Admin Panel

The control panel or administrator's panel in the web-based admin panel contains a representation of the data generated by users and controls features of the intervention. In the content management system (CMS), the admin panel provides the administrator with the opportunity to create and manage content for users. The admin panel used in this study (Figure 5.6) was designed and added to the *LifeGuide Toolbox* to control and track the users of the mobile intervention and consists of the following three sections:

- Imported data, which downloads user-logged data individually from the server to a local device.
- Notifications, where triggers and nudges can be sent to all users or to specific users, containing specific content.
- Inquiries and answers, where administrators can reply to user submitted questions and is capable of differentiating between answered and pending inquiries.

5.4.4 mBCI (Client)

In this study, the mBCI, named the *CriticalThinking* mobile application, utilised the authoring tool of the underdeveloped *LifeGuide Toolbox* framework, which provides a set of core functionalities for DBCIs. *CriticalThinking* contains many features that support the development of critical thinking skills for users and provides useful information regarding critical thinking, instructions for how to use the mobile application, and an explanation of the purpose of the mobile application. *CriticalThinking* was designed

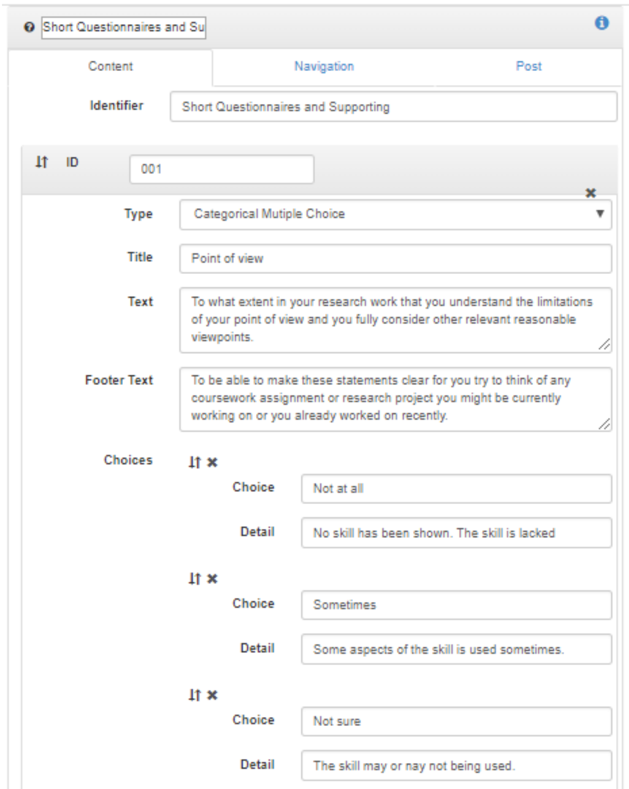

FIGURE 5.5: Short Questionnaire for the Mobile Intervention

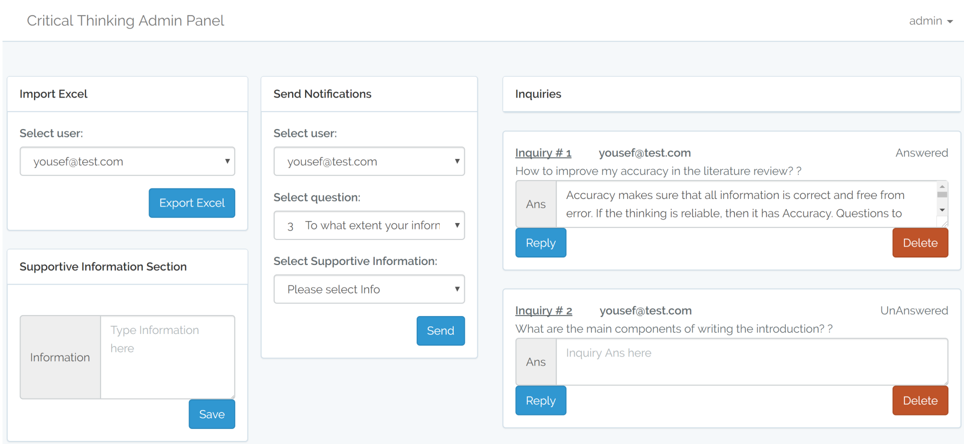

FIGURE 5.6: A Web-based Admin Panel

to study how students interact with digital interventions, how they self-reflect on their critical thinking skills during the process of working on research projects, and how they respond to the intervention components to improve their critical thinking skills. The graphical user interface for the prototype uses different screens, as illustrated in the figures below.

As shown in Figure 5.7, the mBCI was developed to provide several supporting tools, including project information, activities, tasks, short quizzes, goals and plans, inquiries and answers, and feedback, designed to act as intervention components to support critical thinking in research projects. These components were necessary to study the behaviours and performance of the users, as well as their interactions with the mobile application. The data generated by the mBCI are securely stored in a database, for the expressed purpose of analysing user performance. Based on activity within the mobile application, users received notifications and feedback to maintain engagement with the intervention and to provide them with relevant information.

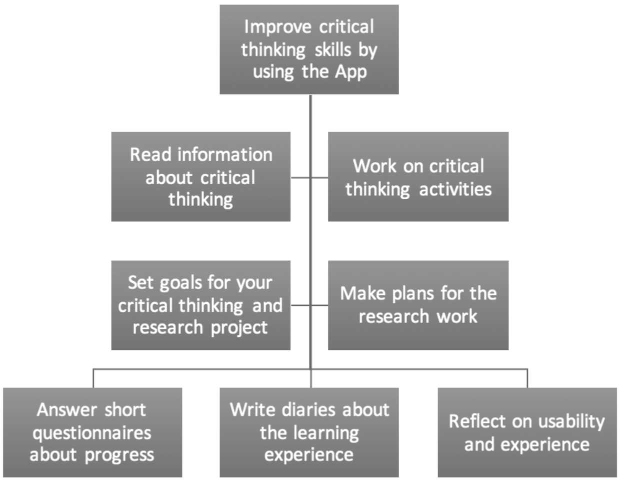

Figure 5.7: *CriticlaThinking* Mobile Intervention Scenario for The Users

The aim of the activities and tasks was to allow users to practice critical thinking skills, which was supported by a project information page that enabled users to reflect on their research project by answering basic questions regarding the process of conducting research. Short quizzes, with a notification feature, were included to examine user performance on critical thinking tasks during the experiment. Pages for setting goals and planning were provided to allow users to organise their learning experience and improve critical thinking skills. Inquiry pages were added to allow users to ask questions or to suggest improvements for the mobile intervention, which the intervention creator was able to respond to during the experiment. The intervention creator, in this case the researcher, provided feedback during the experiment based on the on-going analysis of the content created by users, which was visible to the intervention creator through the web-based admin panel.

5.5 Implementation Approach

The implementation utilised a bottom-up approach for the various components of the mBCI features. The primary reason for using this approach was that the *LifeGuide Toolbox* framework provided a basic platform for the integration of different components, with a well-tested code and an agile process (Table 5.1). The implementation was intended to be integrated with the provided framework, which was necessary to utilise the available programming languages, software and tools within the *LifeGuide Toolbox*, which have been demonstrated to be efficient and reliable. The Ionic platform was used to convert the code for use on smartphone operating systems (iOS and Android). The intervention configuration file (Appendix D) used JavaScript Object Notation (JSON) as a data-interchange format. While this prototype demonstrated how DBCI components could be integrated into the *LifeGuide Toolbox* framework, there remain several areas that could be improved to provide increased flexibility and scalability for the mobile intervention features. This prototype was evaluated in terms of its usability, perceived usefulness, and impact potential when integrated within DBCIs.

Stakeholder	Platform	Software and frameworks	Description and Content	Developed by
Intervention designer	LifeGuide Toolbox	Java, NodeJS, JavaScript, Cordova, MongoDB, and Apache HTTP Server scripted in PHP and Slim framework	Server and client sides scripted to fully provide tools to design digital intervention.	LifeGuide development team but adjusted partially by the researcher
Intervention creator or expert	Authoring web-based tool	JavaScript and JSON files	A web-based page to enable users to create web documents using a list of intervention components.	LifeGuide development team
Intervention creator or expert	Web-based admin panel	Laravel: PHP web framework	Download Excel files, Send notification, and monitor performance.	The researcher
Intervention end-user	Mobile application-based intervention	Ionic framework, Android or iOS operating system	Interfaces that enable users to interact with the mobile intervention.	The researcher

TABLE 5.1: Software tools Used in the Implementation

A technical improvement was made in the *LifeGuide Toolbox*, as shown in Figure 5.8. The framework was extended to be suitable for this study. The framework was supported by a (Model−view−controller) (MVC) on the client side, to illustrate the process of designing and implementing the mobile intervention. The intervention builders created the digital intervention by using the authoring tool, which allowed the intervention to be designed despite a lack of background in programming (Table 5.1). The intervention was generated using JSON files created by the authoring tool, which can be used on the server side of the *LifeGuide Toolbox* and stored in the database.

On the client side, users can request the intervention from the server, which can be downloaded over the Internet to the user's device, when authorised. The user runs the mBCI and stores it on their mobile device, which requires the application controller and the item controller to manage and interact with the intervention components. The mobile intervention components utilise the model components to send or receive updates from the server. For instance, the notification component was added to enable the intervention creator and the intervention user to exchange data, such as the delivery of feedback from the intervention creator and the sending of inquiries by the intervention user. Another example of the model components are the data collector and the connectivity service, which are responsible for connecting the devices to the internet, requesting updates from the server and downloading or uploading data from the server.

5.6 Mobile Intervention Content and Screen Layouts

As discussed, the *CriticalThinking* mBCI contained many features to support the critical thinking and research skills of users. The home page consisted of the following options: project information, activities, tasks, short quizzes, goals and plans, inquiries and answers, and feedback. The graphical user interfaces were represented by different screens, as illustrated in the figures below.

As shown in Figure 5.9, the home page contained six icons that represented the intervention components, with a notification tab at the bottom of the page. Each icon included a figure that illustrated the content of the component. The project information and actives for critical thinking pages were located in the first row of icons on the home page. The order of the components on the home page was designed to facilitate the learning experience for users; however, the user was able to navigate the pages in any order once he or she became familiar with the components of the intervention.

Figure 5.10 shows sample pages of the tasks and inquiries with answers components. The user was able to answer the critical thinking tasks by inputting text into the empty boxes associated with each task. The tasks were designed to reinforce critical thinking standards, which are explained in detail in Chapter 6. The inquiries page displayed a

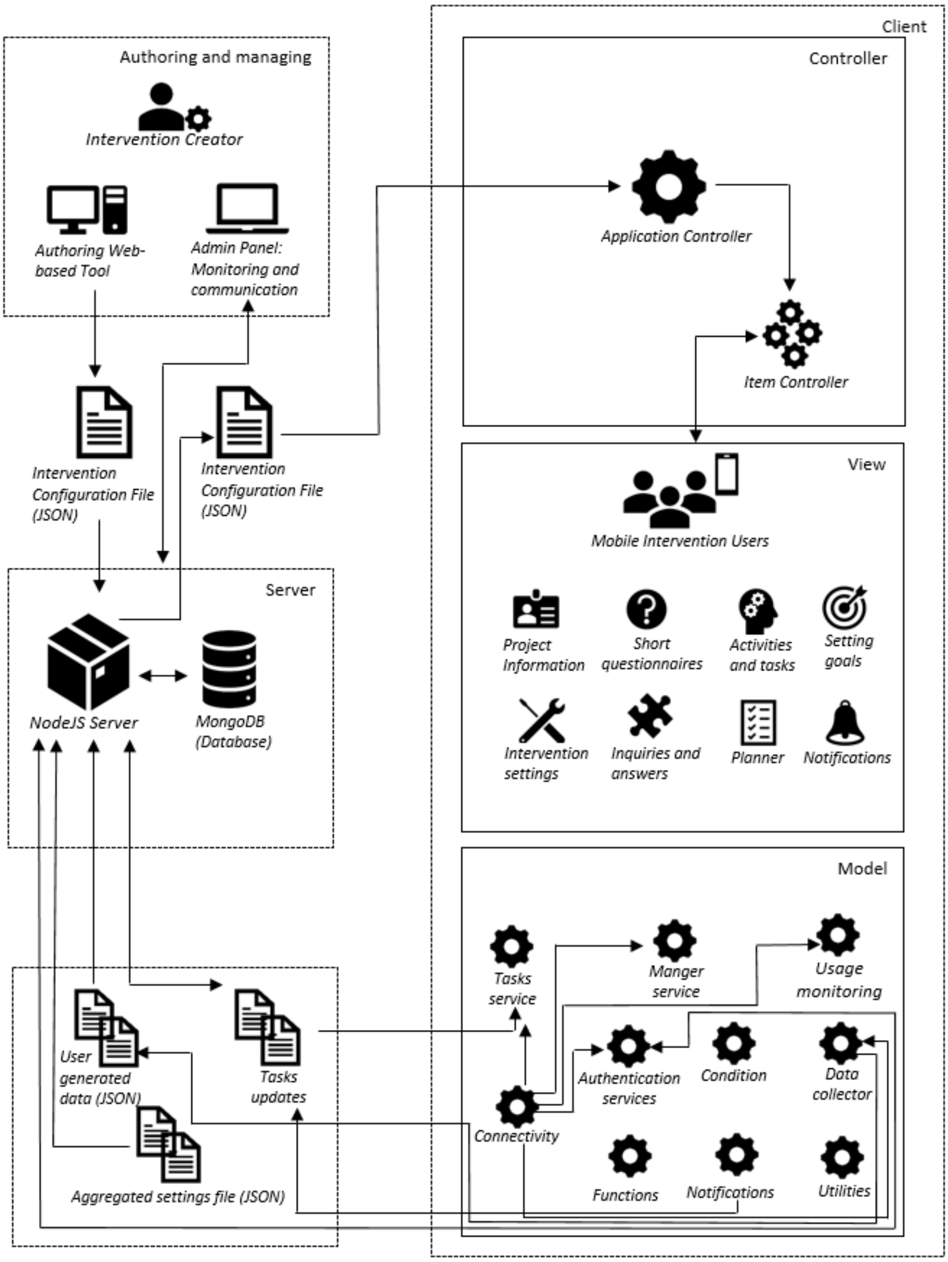

Figure 5.8: Remodelled Generic Framework Architecture

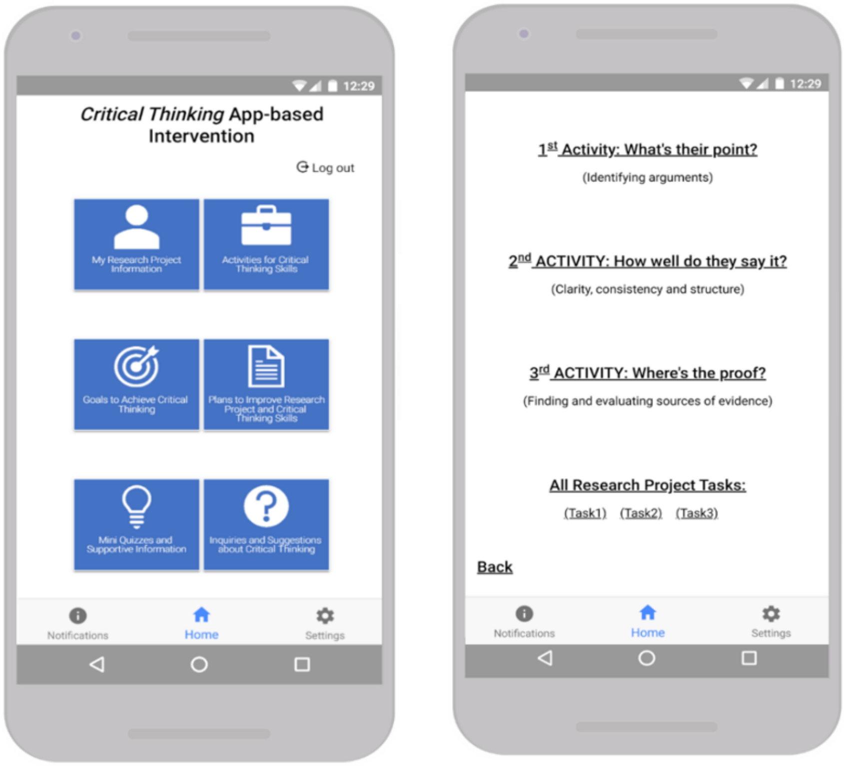

FIGURE 5.9: Home and Activity interfaces in The Mobile App-based Intervention

text box where users could input questions for the intervention creators to answer and displayed whether the inquiry was pending or had been answered.

Similarly, Figure 5.11 shows a sample of the short polls that could be sent to users, which users could answer on a 1 to 5 scale, indicating the critical thinking progress of the users during the experiment. The answers to the polls can then be used to develop relevant feedback for each user, based on his or her answers.

5.6.1 Content for the Mobile Application-based Intervention (mBCI)

The critical thinking activities in this experiment were developed by adopting the theories presented in two recent books on critical thinking: Cottrell (2017) and Paul and Elder (2013). Each activity contained seven sections, associated with different icons to indicate their purposes (Table 5.2):

- ***Title***: The name of the critical thinking activity within the mobile application.
- ***Learning outcomes***: The objectives of the activity, describing the skills students should learn by the end of the activity.

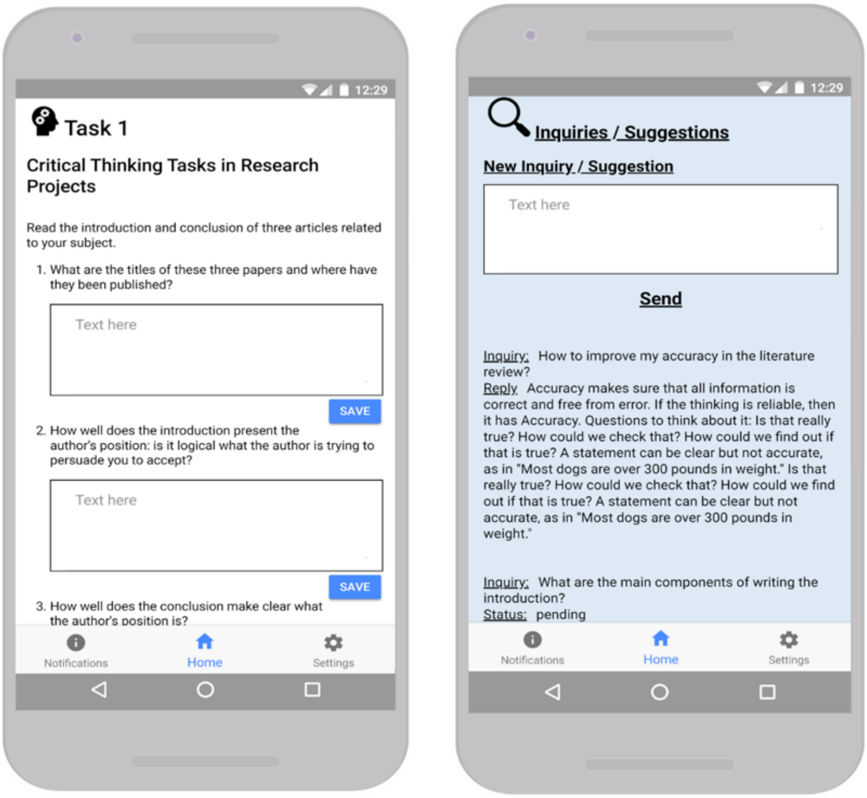

FIGURE 5.10: Tasks and Inquires in The Mobile Application-based Intervention

- ***Critical thinking Standard***: The nine intellectual standards of critical thinking, clarity, accuracy, precision, relevance, depth, breadth, significance, logic, and fairness, divided into three standards per activity.
- ***Estimated time to finish the activity***: The estimated time to complete each activity was generally ten minutes. However, this time could vary based on individual experiences with critical thinking and research skills. The activities were not required to be completed in a single session, and participants were free to stop and continue as needed.
- ***Critical thinking concepts with examples***: The activity began by introducing the critical thinking concept to the participant, with examples.
- ***Activities for the critical thinking skills***: A few passages are provided to trigger participants to consider basic scenarios associated with different topics. These passages helped participants to understand the concepts in context. The passages presented in the activities have been adopted from Cottrell (2017).
- ***Critical thinking tasks to practice in research projects***: Participants were asked questions that allowed them to practice the critical thinking skills that they had learned in the context of their research projects. The text provided by the participants were assessed by the intervention creators and then participants were

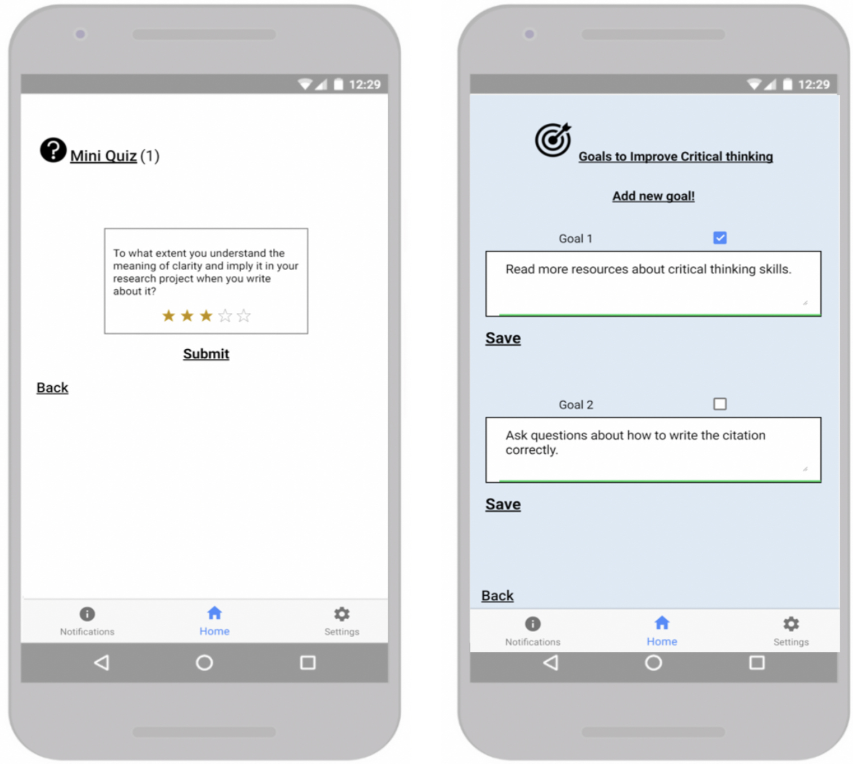

FIGURE 5.11: Short Quizzes and Setting Goals and Plans Pages

provided with relevant information, as described in Chapter 6. There were three activities that covered the nine intellectual standards (clarity, accuracy, precision, relevance, significance, depth, breadth, logic, and fairness). The three activities focused on those concepts of critical thinking that learners must be aware of when working on research projects. All activities influenced each other and could be used alongside the critical thinking standards to enhance critical thinking skills. The following activities were included.

The mBCI included three primary activities that were designed cover the nine intellectual standards (clarity, accuracy, precision, relevance, significance, depth, breadth, logic, and fairness). The three activities focused on those concepts of critical thinking that learners needed to be aware of while working in research projects. Each activity was able to influence all other activities. Learners were able to use the activities associated with the different critical thinking standards to enhance their critical thinking skills. The tasks were listed as follows:

Stands for	Example
Training	The app provides introductions for users to think about general topics in critical thinking. Example from the app: "The author's position."
Practice	The app provides simple passages for users to practice some critical thinking concepts. For example, "PRACTICE 1: Capturing the author's position: Read through the following passages and identify the author's position."
Task	The tasks are provided to think specifically about students' research projects. Students will be asked to link what they learn in the app with their research topics. Example, "Read the introduction and conclusion of three articles in your subject and answer the following".
Goals	Set goals to improve certain intellectual standards. For example, improving clarity and significance in writing.
Plans	Set up plans for improving certain critical thinking skills. For example, identifying books for this month or meetings with a supervisor.
Polls	Students will be asked to answer mini quizzes in the app during their research work time. For example, "Have you read about the difference between the conference paper and journal paper as sources of information?"
Notification	Notification will be delivered to students through the app to help them with relevant information in critical thinking skills.
Settings	Setting day and time for receiving notifications.
Inquires	Participants can ask questions or provide feedback on any problem they face in their critical thinking skills. Questions will be answered by the intervention researcher.

Table 5.2: Content in the Mobile Intervention

First Activity: What's Their Point? Identifying Arguments

This activity presented information regarding how to identify arguments and identified the different types of arguments, with examples. This activity included passages that were relevant to the critical thinking skills being trained by this activity, which included the standards of depth, breadth, and logic. At the end of the activity, there were tasks for the participants to perform, based on their own research projects. This activity provided users with the opportunity to apply their critical thinking skills to their actual research topics. Additional activities are shown in Appendix E.

Second Activity: How Well Do They Say It? Clarity, Consistency and Structure

This activity helped learners to understand what it means to be clear, consistent, and structured. Concepts, terms and examples were provided to help learners understand the activity, which focused on the standards of clarity, precision, and accuracy. At the end of the activity, there were tasks for participants to perform, based on their

Tasks (1) for 'what's their point? Identifying arguments'	**Tasks (2) 'for how well do they say it? Clarity, consistency and structure'**	**Tasks (3) 'where's the proof? Finding and evaluating sources of evidence'**
Read the introduction and conclusion of three articles related to your subject.	*Find a paper which criticises another paper in your area/topic.*	*Use the following questions in your research projects.*
1. What are the titles of these three papers and where have they been published?	1. How clear and accurate the arguments are in the paper?	1. What makes you think your topic is significant/important?
2. How well does the introduction present the author's position: is it logical what the author is trying to persuade you to accept?	2. Are ideas connected with each other? How?	2. If you had the chance to do your project in a different context, would you do it differently? How?
3. How well does the conclusion make clear what the author's position is?	3. To what extent the data used in the paper is reliable?	3. What data you will rely on in your research? Is it reliable?
4. Can you capture the arguments that the authors provided?	4. Why do you agree (or disagree) with criticism in the paper?	4. What were the conferences/journals for most of the papers in you are citing in your research? Do you know their impact factors? What the impact factors tell you about them?
5. Do you think the arguments considered all the perspectives? How?	5. What would you add or change to the criticism to make the argument in the paper more precise?	5. Do you have any assumptions that your results will be insignificant? Why?
6. Which of these three papers are holding deep or simple arguments? Why?	6. How would write about both papers in your literature review section?	6. What kind of evidence you are using in your research project?

Table 5.3: Critical Thinking Tasks in the Mobile Intervention for Research Projects

research projects. This activity provided users with the opportunity to apply their critical thinking skills to their actual research topics.

Third Activity: Where's The Proof? Finding and Evaluating Sources of Evidence

This activity focused on evidence and sources, teaching learners what evidence is and how to support evidence with valid sources. Training, examples and explanations were presented to explain this activity, which focused on the standards of significance, relevance, and fairness. At the end of the activity, there were tasks for participants to perform based on their research projects. This activity provided users with the opportunity to apply their critical thinking skills to their actual research topics.

The tasks for the activities described above were mapped onto the specific critical thinking standards that were supported by each activity. A summary of the tasks provided in the *CriticalThinking* mBCI is presented in Table 6.10.

5.7 Summary

This chapter addresses the third research question in this study, which was to identify the necessary principles for designing and implementing DBCIs to foster the critical thinking skills of students in the context of research projects. This chapter describes the design and implementation of the technical tools used in this study. The intervention components of the mBCI were identified and examined, and the design principles for implementing DBCIs to promote the critical thinking skills of students were described. Further improvements to the design of these tools were made during subsequent experiments.

Chapter 6

Evaluating the Use of Digital Mobile-based Behavioural Change Interventions (mBCIs) to Measure and Promote the Critical Thinking Skills of Students in the Context of Research Projects

This chapter presents a study that was conducted to evaluate the use of a digital mobile-based behavioural change intervention (mBCI) to measure self-reported (POCT) and improve critical thinking skills during a research project period. This study addressed the fourth research question, which examines how a digital mBCI could help students improve their critical thinking skills in the context of research projects. After a pilot study was performed, an experimental study was conducted in two stages. First, new interviews were conducted with academics from different fields who have experience supervising students during research projects to validate and confirm the instrument, the intervention components, and the critical thinking content (this phase was presented and discussed in Chapter 4). Second, two groups of participants were recruited and the impacts of the digital mBCI on their critical thinking skills were evaluated over a two-month period. The experimental trial examined the usability and the effectiveness of the mBCI that was designed for this study, and formal assessments of the participants' work were made by academics. The results of this study are presented and discussed in Chapter 7.

6.1 A Pilot Study

The purpose of this experiment was to study the impact of using an mBCI on the critical thinking skills of students during their research projects. This study has been published (Asiri et al. 2018). The study consisted of online pre- and post-intervention surveys. The aim of these surveys was to measure and examine the students' perceptions of their critical thinking skills (POCT), based on the self-reflections of participants, both before and after using the *CriticalThinking* application-based intervention, which was developed for use in this study based on the design principles discussed in Chapter 5. In this study, the instrument (discussed in Chapter 4) designed to measure the perceived critical thinking was used in both the pre- and post-intervention surveys.

This experimental study was designed based on the results of the previous two studies (see Chapter 4). In this pilot experiment, students were asked to use an mBCI, with email notifications, during their third-year research projects. The aim of the study was to investigate how the mBCI impacts the critical thinking skills of the students when used during the two-month research project period. Quantitative data were gathered from pre- and post-intervention online surveys to examine the students' perceived progress of their critical thinking skills and to study the influence of using the mBCI. In addition, qualitative data from the mBCI was gathered and analysed.

6.1.1 Participants and Procedure

A total of thirty undergraduate students in their third-year from the Electronics and Computer Science Department at the University of Southampton were targeted. An email invitation, which included the title of the experiment, a description of the experimental purpose, and the purpose of the pre-intervention survey, was sent to these students, as shown in Appendix C. During the pre-intervention survey, students were asked to input their email addresses to continue participating in the mBCI experiment and in the post-intervention survey. These email addresses were required to create mobile application accounts. Later, the post-intervention survey was sent to the email addresses that the students provided. Each email address was linked to relevant data in the mBCI and in the pre- and post-intervention surveys to examine the progress of each participant and to ensure that all data were analysed consistently.

During the study, email notifications were sent to students based on their performances in the activities and based on their answers to the short questionnaires in the mobile intervention. Through these email notifications, students received supportive information and advice relevant to critical thinking skills. Email notifications were manually sent to participants according to their performances in the mobile intervention. Evaluations of users' performances were performed based on their answers to the short surveys and activities.

Email interventions were sent to participants throughout the two months of the study, timed to avoid distractions. The following are examples of email notifications:

- Notification 1: Try to identify the weakest and strongest critical thinking skills by writing in your diary through the application.
- Notification 2: Have you noticed any improvement in your thinking skills? Use the application to work on activities to enhance your skills. Think about these questions while you are working: Could you elaborate further? How could we check on that? How could we find out if that is true? How could we verify or test that? Could you give me an example? Could you illustrate what you mean?
- Notification 3: Setting plans for your research work can promote your thinking skills. Use the tool to state your goals.
- Notification 4: Polls are an effective way to measure your thinking progress. Try to answer some of the questions in the application to reflect on your research skills. Meanwhile, think about these questions for your work: Could you be more specific? Could you give me more details? Could you be more exact?

6.1.2 Data Collection and Analysis

This experiment was conducted for two months. This experiment began in October 2016 and ended in December 2016. Qualitative and quantitative data were collected during the study, both from surveys and from the mobile application. The quantitative data from the surveys were analysed, both before and after using the mobile intervention. Application usage data were analysed to evaluate the performances of participants. Participants were asked to answer survey questions using the Likert scale (Yes, Usually, Not sure, Sometimes, No), which was associated with a 1-5 scale, where a 5 represented 'Yes' answers and a 1 represented 'No' answers. Answers of 'Yes' and 'Usually' were considered to be positive, while 'Not sure' was considered to be neutral, and 'No', and 'Sometimes' were considered to be negative. This study was approved by Ethics and Research Governance Online (ERGO, ethics number: 23503).

6.1.3 Results of the Pre- and Post-intervention Surveys

A total of thirty undergraduate students in their third-year from the Electronics and Computer Science Department of the University of Southampton participated in the pre-intervention survey, the mobile intervention, and the post-intervention survey. The results are shown in Tables 6.1 and 6.2 and demonstrate the differences in the perceived critical thinking skills of some students before and after using the mBCI technique. The student responses to the pre-intervention survey showed a general lack of critical thinking skills.

Indeed, the pre-intervention survey results for this experiment are in line with the results of the initial survey that was performed at the beginning of this study (see Chapter 4).

Pre-test	No	Sometimes	Not sure	Usually	Yes
Clarity	18%	25%	38%	18%	1%
Precision	16%	23%	23%	30%	8%
Relevance	41%	20%	36%	2%	1%
Significance	45%	19%	28%	5%	3%
Depth	26%	15%	26%	18%	15%
Breadth	17%	10%	36%	18%	19%
Logic	25%	23%	28%	18%	5%
accuracy	10%	28%	35%	15%	12%
Fairness	41%	15%	28%	3%	13%

Table 6.1: Participants' Reflections of Their Abilities to Apply Critical Thinking Standards Before Using the *CriticalThinking* mBCI

In this study, the focus was only on the first two stages of the students' research projects. For instance, the application activities addressed how to think critically during the steps associated with identifying a research question and performing a literature review. In addition, the evaluation of student skills primarily occurred during the first two months of their third-year projects. This focus was indirectly reflected by the critical thinking performance of the students for almost every standard. As shown in Table 6.2, the post-intervention survey results demonstrated that students still lacked certain perceived critical thinking skills, such as significance, depth, breadth, and accuracy. In contrast, slight perceived improvements could be observed for the other critical thinking standards of clarity, precision, logic, relevance, and fairness, which increased after using the mobile app-based intervention and receiving email notifications.

Post-test	No	Sometimes	Not sure	Usually	Yes
Clarity	16%	23%	23%	30%	8%
Precision	18%	29%	25%	21%	7%
Relevance	40%	18%	35%	6%	1%
Significance	41%	15%	33%	10%	1%
Depth	28%	11%	21%	15%	25%
Breadth	15%	13%	25%	23%	24%
Logic	21%	16%	33%	18%	12%
accuracy	11%	21%	30%	27%	11%
Fairness	38%	13%	28%	9%	12%

Table 6.2: Participants' Reflections of Their Abilities to Apply Critical Thinking Standards after Using the *CriticalThinking* mBCI

The instrument used to evaluate the perceived critical thinking skills of students is based on the Paul-Elder Critical Thinking Framework. Each standard includes criteria that can be assessed by asking certain questions. For example, clarity requires clear answers that include further elaboration, examples and meaningful illustrations. Similarly, accuracy requires testable ideas, and being specific requires exact details that can be verified.

	Descriptive Statistics					
	N	Min	Max	Sum	Mean	Std. Dev
Total_scores_pretest	30	17.00	30.00	675.50	22.516	2.957
Total_socres_posttest	30	19.00	31.50	716.50	23.883	2.686

Table 6.3: Mean Values and Standard Deviation for CT Standards for Pre- and Post-tests

All of these standards must be related to the problem and be associated with the particular issue being addressed. In addition, critical thinking skills should cover the depth and breadth of the problem by considering factors that make the problem difficult and more complicated, which may require other perspectives or consideration from different points of view. However, being clear, accurate, and relevant, with depth and breadth of perspective, still does not cover all of the metrics that can be used to assess critical thinking. For example, logical evidence is necessary when considering solutions, which must also be significant and focus on the most important aspects of the problem. In addition, fairness is one of the most commonly neglected standards of critical thinking, and unfairness can often arise by dealing sympathetically with a problem and ignoring hidden biases.

6.1.3.1 Statistical Analysis

A paired sample Student's t-test was conducted to investigate differences between the average values before and after using the mBCI for the participants' responses to questions regarding the nine critical thinking standards. Figure 6.1 shows a comparison between the pre- and post-intervention means for all nine perceived critical thinking standards. The results showed statistically significant differences for the five perceived critical thinking standards of clarity, precision, logic, relevance, and fairness when comparing pre- and post-intervention survey answers ($p < 0.05$). The chart in Figure 6.1 shows the mean values from the pre- and post-intervention survey data, where the darker bars indicate high confidence that the respondents possess a given skill. In general, students' reflections regarding their perceived critical thinking and research skills showed a positive impact of using the mBCI.

After using the statistical techniques to analyse the data, the results showed statistically significant perceived differences in the pre- and post-intervention mean values for some critical thinking standards. Thus, by examining both the t-values and the *p*-values, the overall results of the post-intervention survey showed significant differences from the pre-intervention survey for the questions associated with clarity, precision, logic, relevance, and fairness. Students' reflections on their perceived critical thinking and research skills (POCT) showed the positive impact of using the mBCI.

CT Standards		Overall Scores Pretest	Overall Scores Posttest
Clarity	Q1	73	96
	Q2	81	76
Precision	Q3	64	90
	Q4	77	70
Relevance	Q5	69	53
	Q6	50	72
Significance	Q7	64	45
	Q8	51	66
Depth	Q9	89	84
	Q10	80	92
Breadth	Q11	106	85
	Q12	83	111
Logic	Q13	85	79
	Q14	68	88
Accuracy	Q15	97	79
	Q16	77	102
Fairness	Q17	65	76
	Q18	72	69
Total		1351	1433

TABLE 6.4: Overall Scores in CT Standards for Pre- and Post-tests

In Tables 6.3 and 6.4, the overall scores in CT Standards for pre- and post-tests are presented. The overall scores in the pre-intervention survey (M = 22.5, SD = 2.95) was 1351 and in the post-intervention-survey (M = 23.8, SD = 2.68) was 1433 which indicates the total scores has increased in the post-intervention survey with 82 points. Each standard has two questions in the pre- and post-intervention surveys. The results showed that some standards increased in some questions after the mobile intervention such clarity (Q1), precision (Q1), relevance (Q2), significance (Q2), depth (Q2), breadth (Q2), logic (Q2), accuracy (Q2), fairness (Q1). However, the results showed that some standards decreased in some questions after the mobile intervention such clarity (Q2), precision (Q2), relevance (Q1), significance (Q1), depth (Q1), breadth (Q1), logic (Q1), accuracy (Q1), fairness (Q2). Mean values and standard deviation for the CT standards in the t-test Results are presented in Table 6.5.

As shown in Table 6.5, based on the t-test analysis, the participant's perceptions of their perceived critical thinking skills before and after using the tool shows some perceived abilities of students to think critically during their third-year research projects in the standards: clarity, precision, logic, relevance, and fairness.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre.Clarity - Post.Clarity	-0.30	0.60	0.11	-0.52	-0.08	-2.76	29	0.01
Pair 2	Pre.Precision - Post.Precision	-0.32	0.70	0.13	-0.58	-0.05	-2.48	29	0.019
Pair 3	Pre.Relevance - Post.Relevance	-0.10	0.20	0.04	-0.18	-0.02	-2.69	29	0.012
Pair 4	Pre.Significance - Post.Significance	0.07	0.41	0.07	-0.09	0.22	0.89	29	0.38
Pair 5	Pre.Depth - Post.Depth	-0.12	0.58	0.11	-0.33	0.10	-1.10	29	0.282
Pair 6	Pre.Breadth - Post.Breadth	-0.12	0.77	0.14	-0.41	0.17	-0.83	29	0.415
Pair 7	Pre.Logic - Post.Logic	-0.23	0.54	0.10	-0.43	-0.03	-2.38	29	0.024
Pair 8	Pre.Accuracy - Post.Accuracy	-0.12	0.47	0.09	-0.29	0.06	-1.37	29	0.182
Pair 9	Pre.Fairness - Post.Fairness	-0.13	0.29	0.05	-0.24	-0.02	-2.50	29	0.018

TABLE 6.5: A Paired Sample Student's t-test Results for The Pre- and Post-Intervention Surveys

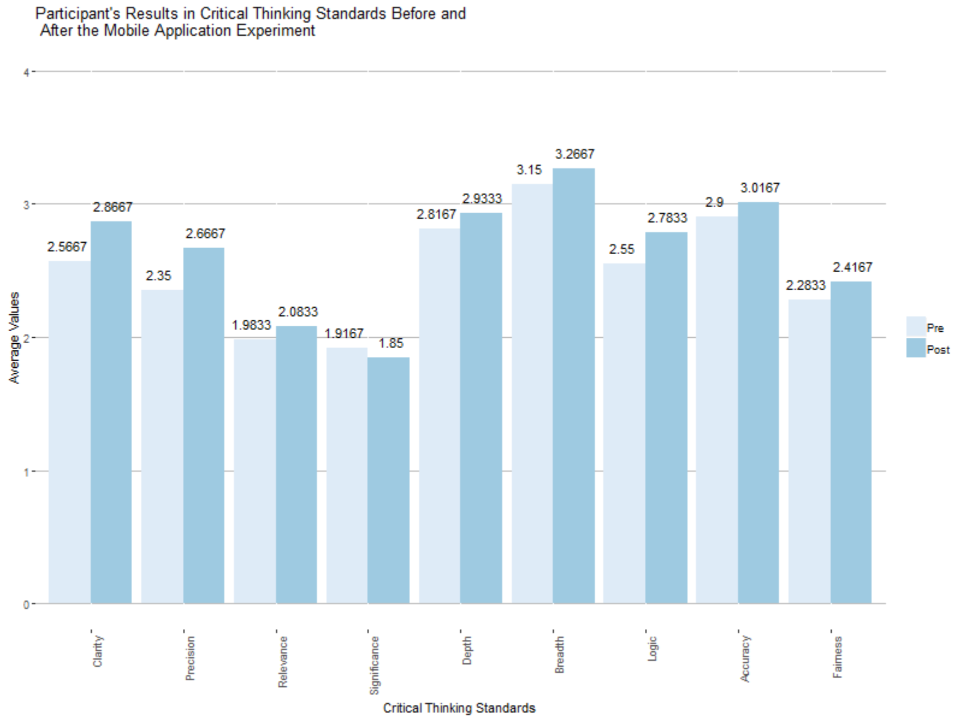

FIGURE 6.1: Mean Values for Each Critical Thinking Standard in Pre- and Post-Surveys

The results of the reliability test (Cronbach's Alpha) for scale items at all testing times is (0.56) which shows low reliability. However, there are some significant correlation in pre- and post-intervention between the overall CT scores and some standards. In Table 6.6, the correlations among overall CT and standards at pre-intervention and post-intervention are presented. There was a significant correlation in pre-intervention between the overall CT scores ($r = 0.59$, $p < 0.01$) and depth standard, the overall scores ($r = 0.36$, $p < 0.05$) and logic standard, the overall scores ($r = 0.38$, $p < 0.01$) and fairness standard, and the overall scores ($r = 0.60$, $p < 0.01$) and fairness standard. There was a significant correlation in post-intervention between the overall CT scores ($r = 0.38$, $p < 0.01$) and significance standard, the overall CT scores ($r = 0.38$, $p < 0.05$) and significance standard, the overall CT scores ($r = 0.49$, $p < 0.01$) and depth standard, the overall CT scores ($r = 0.51$, $p < 0.01$) and accuracy standard, and the overall CT scores ($r = 0.63$, $p < 0.01$) and fairness standard.

6.1.3.2 Mobile Application-based Intervention: Usage and Short Polls

The primary purpose of the mobile intervention surveys was to allow researchers (intervention builders) to track student progress during research projects. In addition, interventions were provided based on student reflections during research tasks. Therefore, measuring the students' reflections of their perceived critical thinking skills during

Correlations	1	2	3	4	5	6	7	8	9	10
1.Overall CT scores	.904**	.250	.234	.228	.382*	.498**	-.195	.183	.510**	.633**
2. Clarity	.220	.680**	-.079	-.018	.055	.144	-.280	.088	.294	-.091
3.Precision	.221	.086	.547**	.085	.095	-.105	-.102	.096	.135	.060
4.Relevance	.265	-.054	.059	.918**	.371*	.188	-.235	-.199	-.076	.253
5.Significance	.314	.038	.040	.519**	.839**	.117	-.389*	.036	.140	.165
6.Depth	.590**	.254	.178	.184	.035	.898**	-.198	-.038	.052	.136
7.Breadth	.029	-.144	.000	-.310	-.310	-.050	.738**	-.029	-.183	-.056
8.Logic	.365*	-.099	.127	-.239	.190	.099	-.040	.823**	.012	.116
8.Accuracy	.388*	.212	.054	-.164	.004	.009	-.083	-.178	.829**	.460*
10.Fairness	.604**	.015	-.058	.248	.309	.167	-.316	-.022	.539**	.967**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

TABLE 6.6: Correlations Among Overall CT Standards at Pre-testing (below diagonal) and Post-testing (above diagonal)

the research project might help students to obtain the necessary critical thinking skills. The participants' performances in the mobile intervention are shown in Table 6.7.

Four short polls were designed to measure the perceived critical thinking progress of students during the experiment. Moreover, the polls were provided to evaluate the usability of the mobile intervention system by users. The first poll assessed the perceived progress made in critical thinking skills by users. The second poll measured the degree to which students asked for help. The third poll evaluated the level of supervision received by students, as one factor that might affect critical thinking performance. In the fourth poll, students were asked to provide feedback on the mobile intervention, which might help the researcher evaluate and reconsider the intervention delivery. Each poll included a text box for additional comments or suggestions regarding the design or the system in general.

The results from the short polls in the mobile intervention (Figures 6.2 and 6.3) showed that students found the mobile intervention to be an effective method for improving their critical thinking skills. The results also showed that the percentage of students who desired help during research projects was high, indicating that students require interventions during their research work. In addition, students also reported struggling with the supervision process. Students reported that they get less time to discuss their projects with supervisors in traditional face-to-face meetings, which might be resolved by using the mBCI, as was suggested by most of the participants in this study. When using the activities within the mobile application, students were able to go back and forth between exercises, including five mobile activities developed to address performing a literature review and developing research questions for their research projects. Some students were able to answer these questions correctly, while some continued to have difficulty answering these questions.

Intervention components	**Description**	**Number of participants completed the task**	**Participants performance in the task**
Answering short questionnaires	Participants reflect on 4 short questionnaires from 5 (highest) to 1 (lowest) during the experiment about the perceived progress in critical thinking, help needed, supervision, and mobile intervention.	30 participants	All participants were able to complete all short questionnaires.
Working on activities	Participants are provided 4 simple activities in the app to answers multiple choices questions to practice their critical thinking in writing their research questions and literature review.	30 participants	All participants were able to answer correctly the critical thinking activities.
Making plans	Participants use text boxes for writing plans regarding their research project.	11 participants	Some participants have made plans for the first month but not for the second month of the experiment. The main themes of the plans are: reading and summarising papers and meeting supervisors.
Setting goals	Participants create lists of goals for their critical thinking and research skills to achieve during their research project.	9 participants	Only 10% of the goals from the lists have been marked as achieved goals. Examples of the goals: “Identify research questions”, “Submit report on time”, “Improve research skills”.
Writing diary	Long text boxes for writing diaries about their critical thinking and their research experience during the experiment.	3 participants	A few participants wrote a few diaries about the research difficulties, reading findings and meetings.

Table 6.7: Participants’ Performance in The Mobile *CriticalThinking* App

6.1.4 Discussion and Challenges

The perceived critical thinking and research skills (POCT) of some students were improved by using the mBCI. However, the perceived critical thinking skills were improved during the study, but the students had supervision and were carrying out a research task that also have been improving their critical thinking skills through practice so the mBCI is not the only factor involved. The thinking skills of students were practised and enhanced while using the mBCI, through the use of tasks, diaries, and plans. The system helped students remain engaged in the process of critical thinking and research work. The evaluations of students’ performances and their self-reflections indicated that the

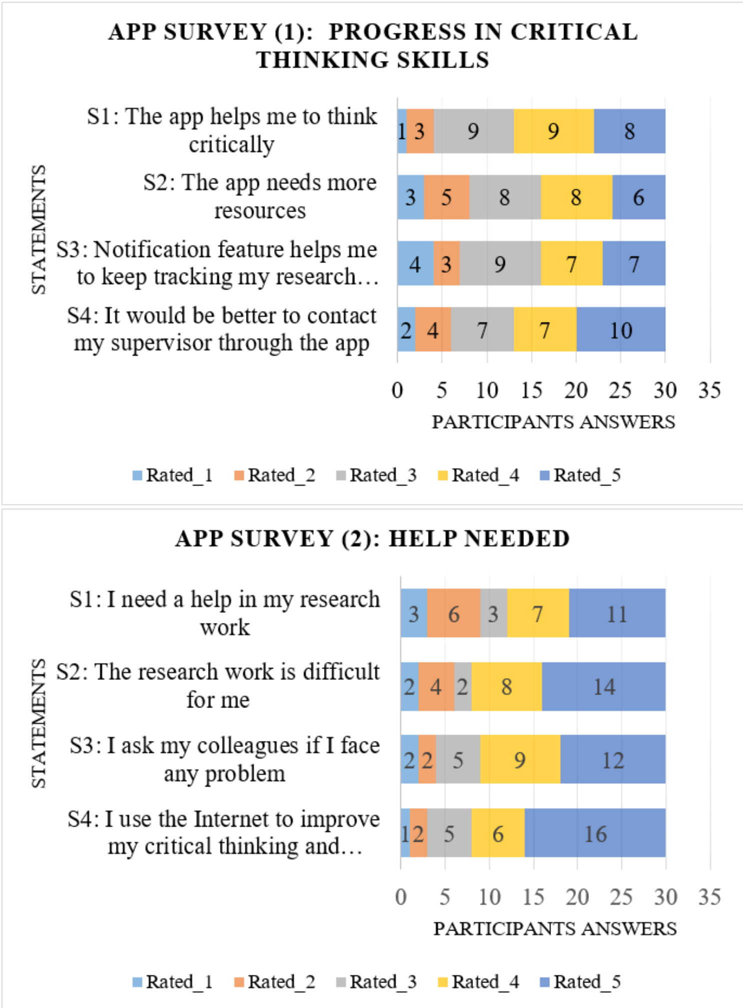

FIGURE 6.2: Results from The First and Second Short Questionnaires in the *Critical-Thinking* mBCI

system could have the potential to be successfully applied to other disciplines. This study examines the usefulness of using digital mBCIs in critical thinking situations where independent study can be effective.

The study attempted to address key components of a successful behavioural learning experience, with regards to the critical thinking skills of university students, and developed a more practical method for supervisors to support the development of critical thinking and research skills in students through the use of mobile technology. This study also explored the challenges of using mobile technology to promote critical thinking skills in a research context, highlighting the major challenges to behavioural learning when critical thinking is required. However, when using such a system with real supervisors, challenges can arise due to the busy schedules of supervisors and the difficulties engaging supervisors to build mobile interventions components, as well as potential technical

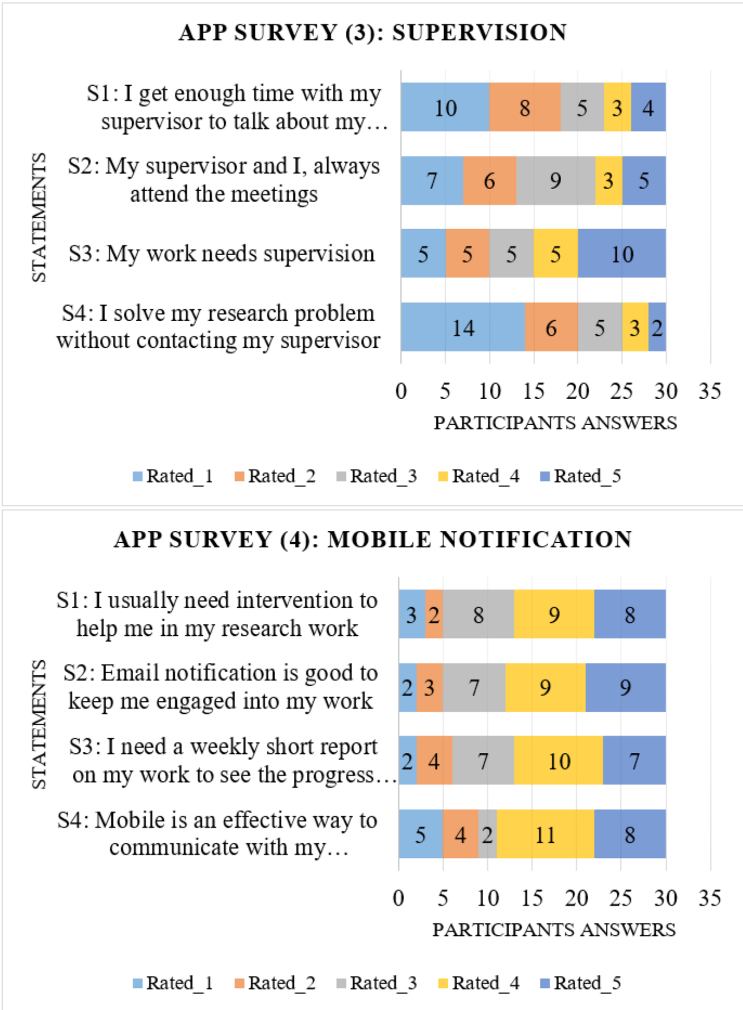

FIGURE 6.3: Results from The Third and Fourth Short Questionnaires in the *Critical-Thinking* mBCI

difficulties. Moreover, a longer time frame must be used to determine the impact of a mobile intervention that is limited by the level of participant engagement, which will need to be examined in future studies. Further evaluation designs should be considered, such as implementing flexible software engineering methods to ensure the functionality of the software tools. Additionally, the designs of the surveys and interviews must consider specific issues, such as focusing on one or two research steps, with deep analysis techniques for the gathered data.

6.2 An mBCI Experimental Study

The digital mBCI in this study has two stakeholders: the intervention creator and the intervention user. Each stakeholder must accomplish certain tasks to fulfil the digital mBCI requirements. As shown in Figure 6.4, the intervention creator is responsible for four steps (darker rectangles): measuring the level of user skill, designing the intervention, supporting the user, and evaluating user work and providing feedback for the user. The intervention users are also responsible for four steps: reflecting on their own skills, interacting with the intervention components, engaging with the intervention, and positively changing their behaviours. The results of the experiments conducted at the beginning of this study showed positive and encouraging outcomes when using an mBCI for the promotion of critical thinking skills, showing that mBCIs have the potential to be effective tools, based on the literature review, the initial survey, supervisors interviews (Chapter 4) and the pilot study described at the beginning of this chapter.

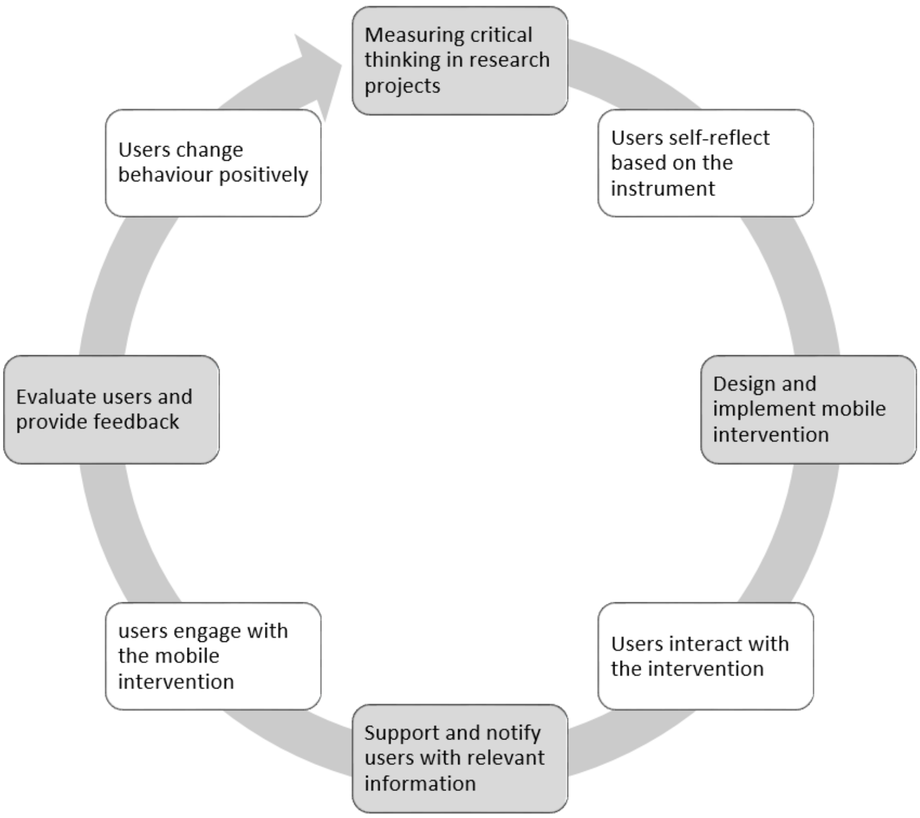

Figure 6.4: The Digital Intervention Life-cycle

In light of the previous experiments conducted in this study, many changes were made to enhance the evaluation of using an mBCI to promote critical thinking skills. These changes are described in the following sections.

6.2.1 New Changes for This Experiment

The previous experiments described in this study did not include any comprehensive methods for studying various factors that could potentially affect the outputs of using digital mBCI. Alterations have been made to the design of this study to include a more rigorous methodology and to include better tools to accurately evaluate the factors that might affect critical thinking behaviours in research project-based areas when an mBCI is used. As shown in Table 6.8 and Table 6.8, the changes have primarily occurred in two areas, which are described in detail below.

6.2.1.1 Improvement in The Methodology

In this section, the improvements made to the methodology of studying the use of mBCIs to promote critical thinking are discussed. For instance, the previous experiment lacked a control group, which should be included in any human-computer interaction study, to control for potential external factors (McLean 2005). Therefore, a control group was included in this study to evaluate whether any observed improvements could be reasonably attributed to the mobile intervention tools. In the previous experiment, self-reflections (POCT) were the only inputs considered when evaluating the perceived improvements in critical thinking, which may have resulted in subjective assessments, as addressed by Alnuaim et al. (2016). In this experiment, academics were also asked to assess the critical thinking skills displayed by participants in the submitted work (research reports and mobile texts).

6.2.1.2 Improvements in Intervention Design

New intervention components were added and mapped onto suitable learning content designed to support critical thinking and research skills. Moreover, as this study evolved, additional datasets were collected for the evaluation of other aspects, such as the level of engagement with the mobile intervention, which was assessed by considering the time spent on the application and the frequency of access according to mobile log files. Engagement is considered to be a key factor when examining the level of DBCI participation (Weston et al. 2015). The current experiment more carefully designed intervention components that mapped directly to critical thinking standards and the elements of thought, which allowed the evaluation of which specific intervention components were responsible for improvements and which areas of critical thinking were improved. Among the intervention group, it was essential to determine whether there were any correlations between mobile intervention use and improvements in critical thinking. These results are presented in the next chapter (Chapter 7).

The methodology of the study	Pilot Study	Experimental Study
Aims and objectives	To examine the perceived impact of using mobile intervention on students' critical thinking in research projects.	To evaluate the effectiveness of using mobile intervention to improve students' critical thinking in research projects. Also, to study the engagement with the mobile intervention.
Number of participants for the mobile application-based intervention	Only 30 third-year undergraduate students from Electronics and Computer Science Faculty, University of Southampton.	A total number of new 60 third-year undergraduate students from Electronics and Computer Science Faculty, University of Southampton. A control group involves 30 students and the other 30 students for the experimental group.
Academics interviews	Supervisors from the Human-computer Interaction and Computer Science areas were interviewed. The interviews were mostly general when discussing the requirements.	New academics from various fields were included in the interviews such as Education, Psychology, Human-computer Interaction, and Computer Science areas. The interviews were mostly specific when validating the instrument and discussing the requirements.
Instrument statements	Statements of the instrument to measure the perceived critical thinking were reviewed and accordingly reformed.	New statements were included in the instrument for the Element of Thought section as explained in (Chapter 4). Statements of the instrument to measure the perceived critical thinking were reviewed and confirmed to be valid.
Assessment for participants' work	The pilot study did not include formal assessment from the academics. Participants' work was assessed by self-reflection.	Academics assessment was included at the end of the study to fairly objectively participants' work and reduce the subjectivity in participants' reflection. The formal assessment covered the participants' research reports and the mobile texts.
Methods to analysis	The analysis included examining participants' reflections before and after the study. Also, participants' texts and answers to the notifications were studied.	The mobile app-based intervention was redesigned to be consistent to measure the progress which can be linked before, during, and after the study. New attributes were included in the analysis such as time spent in each intervention component, engagement (frequency of access) in the mobile application, correlation between intellectual standards, elements of thought, and intervention components.

TABLE 6.8: Improvement Made in the Methodology of the Studies

The design of digital intervention tools	Pilot Study	Experimental Study
Mobile app-based intervention	The mobile app-based intervention contains information about critical thinking, plans, goals, diaries, and short questionnaires.	The mobile app-based intervention contains information about participants' research work, plans, goals, critical thinking takes, activities, trainings, practices, and short questionnaires, setting for time to intervene, pages for inquiries and suggestions, and notification page. The design of the mobile app-based intervention was entirely enhanced with notification features and informative icons. Interfaces of the mobile learning application were redesigned based on the previous experiment. New scripts for the server were added to be linked with the admin panel.
Content for the intervention	Simple content to practice critical thinking skills.	New critical thinking and research skills content and material for the mobile app-based intervention was added. The content was provided carefully to serve the analysis process. Critical thinking tasks were designed to help participants in their research projects.
Admin web-based panel	Data were downloaded directly from the database.	Admin panel was designed for the researcher for two reasons: 1) to keep track of the participants' performance, and 2) to manage and download well-formatted log files. The web-based admin panel page contains sections with icons to send tailored information and supportive advice to easily distribute texts to users.

Table 6.9: Improvements in the Design of Digital Intervention Tools

6.3 Methods

The methods used in this study will be discussed in the following sections. First, the design of the experiment will be described, as well as the procedures used to target participants and conduct the study. The methods used to collect data before, during, and after the study are also discussed, step-by-step. The processes used to analyse quantitative and qualitative data are also explained, including the measures used to evaluate the results.

6.3.1 Study Design

A two-group experimental study was performed to measure the perceived critical thinking skills before and after using an mBCI in the context of third-year research projects. As shown in Figure 6.5, prior to this experiment, the requirements for conducting this experiment were ascertained, including designing the pre- and post-intervention surveys (Chapter 4) to measure the perceived critical thinking in the context of a mBCI. The final version of the instrument was improved based on the results of previous studies. However, the reliability test of the instrument was low. In addition, the mBCI was redesigned based on feedback from academics provided during the interviews. The iSurvey website was used to design the pre- and post-intervention surveys. The functionality and usability of the mobile application used in this experiment was verified during a three-day pilot using independent participants. Participants were recruited for the study by sending invitation emails containing consent forms. Data were collected and analysed, including formal assessments by academics. No critical thinking training or classes were provided by the researcher prior to the intervention study.

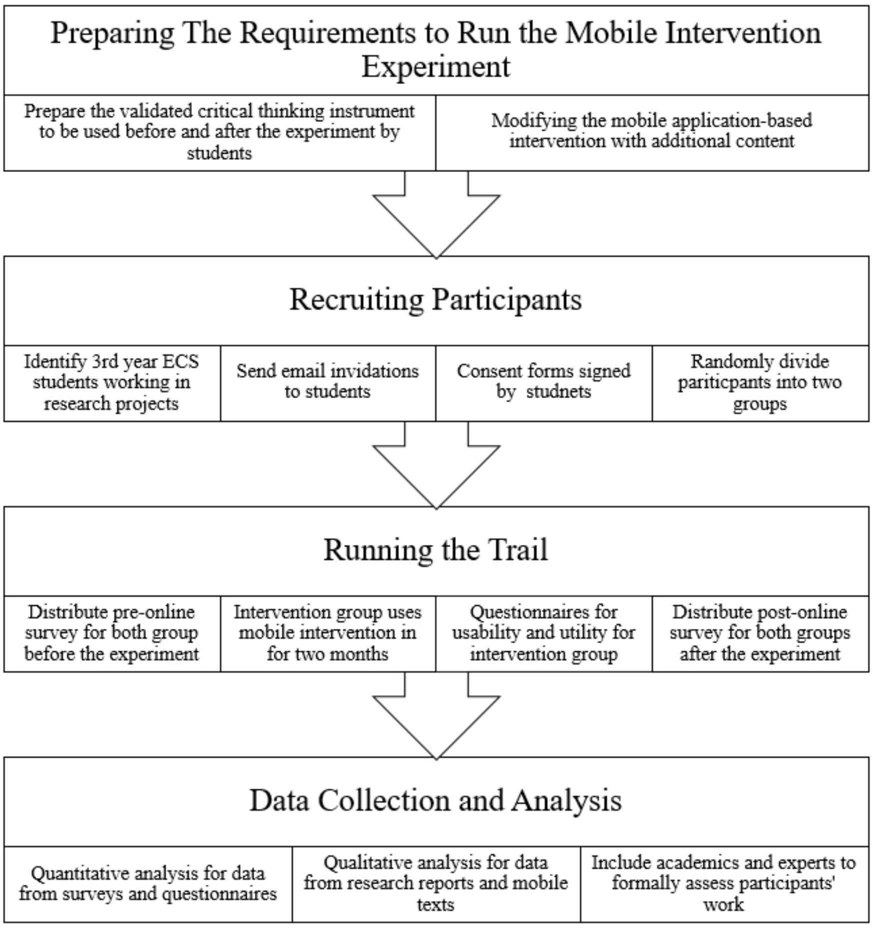

Figure 6.5: Procedures of The Experiment

6.3.2 Participants

Three types of participants were recruited for this study. First, a total of sixty third-year undergraduate students from the Electronics and Computer Science (ECS) department at the University of Southampton, who were chosen due to the researcher's familiarity with research topics in this department, were approached using the snowball sampling technique (Marshall 1996), which targets potential participants through already enrolled participants. Second, a total of three academics were purposefully targeted from the Electronics and Computer Science and Education faculties at the University of Southampton to assess the participating students' work (research reports). Third, two post-doctoral fellows within the ECS at the University of Southampton were recruited to act as academics and to assess the work of students (mobile texts).

6.3.3 Procedures

This section details the procedures that were performed before, during and after the experiment:

6.3.3.1 Before the Mobile Intervention Experiment

The recruitment process specifically involved the identification of the third-year ECS undergraduate students who were engaged in third-year research projects at the University of Southampton. Undergraduate research projects generally occur over a one-year period of time. This study focused only on the first semester of the research projects. As previously mentioned, students were targeted through specific email lists of third-year undergraduate students in the ECS department of the University of Southampton. The use of university emails lists is restricted and can only be accessed by the research project leader. Emails, including the title of the study, the study purpose and the pre-intervention survey, were sent to research project leaders of third-year ECS undergraduate students for distribution to the targeted students. The pre-intervention survey included a participant information sheet (Appendix H). At the end of the pre-intervention survey, a text box was provided for interested participants to enter their email addresses.

Participants were randomly divided in two equal groups: the first group received the intervention, and the second group was the control group. The randomisation process involves simply labelling the provided emails with different unique numbers associated to the participants who completed the pre-intervention survey anonymously in order. After that, the researcher divided the total number of participants into two equal numbers. Lastly, the researcher chose from the list of the numbered participants randomly for the intervention group and the rest were in the control group.

The intervention group received a welcome email asking them to continue participating in the mobile intervention experiment by downloading a mobile application from the Apple AppStore or Google Play, according to the smartphone being used. The intervention group completed the participation in the pre-intervention survey, the mBCI experiment, during two months of the research project period, and the post-intervention survey. In contrast, the control group completed the participation in the pre- and post-intervention surveys. Both groups were asked to provide their research reports for assessment at the end of the experiment. The pre- and post-intervention surveys were the instruments that were designed for this study (Appendix I). The surveys consisted of two sections, the intellectual standard statements and elements of thought statements. The participants were asked to self-reflect on their critical thinking skills based on these statements, using the following 5-point Likert scale: No=1, Sometimes=2, Not sure=3, Usually=4, and Always=5. Empty text boxes were provided to allow participants to provide explanations and comments at the end of each survey.

6.3.3.2 The Mobile Intervention Experiment

During the experiment, participants from the mobile intervention group received mobile notifications, which varied based on the intervention required and included reminders for goals or plans, corrections, supportive information, or feedback, as described below. The study occurred over a two-month period, which was divided into ten weeks. During the last week of the experiment, participants from the intervention group were asked to respond to questionnaires to evaluate the usability of the mobile intervention (Appendix H). Notifications were sent to participants (intervention group) during the experiment twice a week, in the form of nudges and feedback. Nudges were designed as reminders to maintain participant engagement with the intervention components, while feedback referred to the users' critical thinking skills and was based on participants' performances in the mobile tasks. The researcher read and assessed the work performed in the mobile intervention determine relevant information for the feedback. Emails were also sent to participants who disengaged for a long period of time to increase engagement. Details regarding notification contents can be found in Appendix G.

6.3.3.3 After The Mobile Intervention Experiment

When the experiment was completed, the previously interviewed academics were invited to assess the participants' reports. Emails were sent to the academics, which included the title of the study and the purpose of the assessment. After the academics agreed to participate in the assessment, a Google form was sent to the assessors (Appendix I). In addition, Linguistic Inquiry and Word Count (LIWC)[1] software was used to analyse the

[1]Website: http://liwc.wpengine.com/

reports. LIWC software is a text-analysis tool with a built-in dictionary that can be used for scientific content or everyday language. New academics (post-doctoral fellows from the ECS at the University of Southampton) were also asked to evaluate the text inputs provided by participants in the mobile application during the experiment. Another set of Google form were sent to the academics for the evaluation of the mobile application texts.

6.3.4 Data Collection

A mixed-methods approach was used to collect both qualitative and quantitative data for this experiment, as mentioned in Chapter 3. Data were gathered throughout the two months of the study, which took place from October 2017 through the beginning of December 2017. The section of this study that included assessments by academics was approved by ERGO (Ethics and Research Governance Online at the University of Southampton, number: 30055). The section of this study that included academics' reviews was performed later and was approved by ERGO (Ethics and Research Governance Online at the University of Southampton, number: 46528).

Three types of data were collected from students, academics, as described below:

- Responses to both pre- and post-intervention questionnaires, as quantitative data.
- Data from log files generated by participants using the mobile application, such as time spent on each page, the dates the mobile application was used, texts entered by users, and answers to the short questionnaires.
- The third-year progress reports of participants. For the mobile intervention group, data were individually collected by gathering answers from the pre- and post-intervention surveys, log files showing mobile application usage, and progress reports. For the control group, data were individually collected by gathering only the answers to the pre- and post-intervention surveys and progress reports.
- The assessments, performed by academics, of the participants' work, which included both qualitative data and quantitative data. Academics rated the work using a 5-point Likert scale, ranging from strongly disagree to strongly agree that using the mBCI improved the critical thinking skills of the students in the context of research projects.

6.3.5 Data Analysis and Measures

Four primary factors were used to analyse the collected data and to examine the impact of the mBCI on the critical thinking and research skills of the participants based on the evaluation methods mentioned in Chapter 2. First, data from the surveys were analysed to identify evidence of perceived improvement (POCT), if any, in the critical thinking standards and the elements of thought for both groups. Second, data from the mobile application log files were analysed to identify correlations between improvement, time spent in the intervention, and usage patterns and to determine whether the level of weekly engagement was affected by mobile notifications. Third, research progress reports submitted by participants were analysed to determine potential differences between the two groups, which could indicate the effectiveness of the mBCI technique. Fourth, data from the System Usability Scale (SUS) test were analysed to examine the usability of the mobile intervention with regards to improving critical thinking skills in the context of research-based projects.

The gathered data were analysed using both descriptive and statistical methods. Categories such as content, time, and progress after using the mobile intervention were analysed statistically, to measure the differences between the two groups before and after two months of using the mBCI, whereas other data required descriptive analyses. The software used to analyse the data included NVivo, for qualitative data, and R, SPSS and Excel, for quantitative data. Data were analysed to determine the following aspects, which are linked to the proposed research questions in this study and evaluate the effectiveness of using the mBCI:

1. Examine the perceived improvements in critical thinking skills for the participants (POCT) in both groups by determining what significant differences (with p-values < 0.05), if any, exist between the two groups before and after the experiment, including comparisons of self-evaluation ratings and formal assessments by academics with regards to critical thinking skills.
2. For the intervention group, identify correlations, if any, between critical thinking improvements and the time spent in the mobile intervention.
3. Identify which intervention components improved which intellectual standards or elements of thought by identifying correlations between the time spent using specific intervention components designed to improve certain standards or elements, as illustrated in Table 6.10, and performance on those standards or elements.
4. Measure the level of engagement that could be attributed to notifications by calculating the time spent before and after the notification each week.
5. Analyse the usability of the mBCI, based on user evaluations reported through the SUS test survey. The SUS test is a reliable questionnaire (with alpha=0.91) for evaluating the usability of a product or system, created by Brooke (1996). The SUS test was used in this experiment to measure the usability of the mobile intervention designed to promote critical thinking in the context of research projects. The SUS test provides ten statements, associated with a 5-point scale that ranges from strongly disagree to strongly agree (Appendix H).

Intervention component	Description	Standards and elements mapped to component
Project information	This page contains questions such: What is the research project, RQs, why, hypotheses, how, and what to expect.	Concepts, Questions, Purpose, Assumptions, point of view, Information Implication, inferences
First activity and task 1	What's their point? Identifying arguments. For all activities and tasks in the mobile intervention (See section 5.6.1)	Depth, Breadth, And Logic
Second activity and task 2	How well do they say it? Clarity, consistency and structure	Clarity, Precision, And Accuracy
Third activity and tasks 3	Where's the evidence? Finding and evaluating sources of evidence	Significance, Relevance, And Fairness

Table 6.10: Mapping Intervention Components and Content into Critical Thinking Standards and Elements

6.4 Summary

This chapter details the process of designing the final experimental study. A pilot study was performed to examine the effectiveness of using a digital mBCI to support critical thinking. The instrument for measuring the perceived critical thinking skills was verified and experimentally tested in a mBCI context. The intervention components for the mBCI were identified and examined. The design principles for implementing mBCIs to promoting the critical thinking skills of students were described and developed to practically study the impacts of the using mBCIs during actual critical thinking situations. Further improvements in the designs of the mBCI and of the study were also made. This chapter details the sampling used during the different phases, as well as the procedures used for data collection and analysis. The next chapter examines the results and findings from the experiment by providing discussion and evidence regarding the impact of using mBCIs for critical thinking in research projects.

Chapter 7

Data Analysis and Results of the Mobile Behavioural Change Intervention (mBCI) Experiment

In the previous chapter, the methods and procedures used for the final mobile intervention experiment were described in detail (Chapter 6). This chapter presents the results of the experiment, which was conducted to evaluate the impact of using digital behaviour change intervention (DBCI) technique to promote the critical thinking skills of students in the context of research projects. The aim of this chapter is to provide evidence that addresses the fourth research question of this study, which concerned how a digital mBCI could be used to enhance the critical thinking skills of students during their third-year research projects. This study investigated whether the critical thinking skills of students improved as a result of using mBCI and identified which specific intervention components, which were based on the Paul-Elder Critical Thinking Framework, contributed to these improvements. This chapter details the data analyses performed during this experiment, including mBCI usage, student behaviours with regards to the mBCI, student engagement with the mBCI, and the usability of the mBCI.

This chapter starts by reporting the results of the participants' perceived levels of critical thinking skills (POCT) in the context of real research projects prior to the experiment. Participants were divided into a control group and an intervention group. Then, a separate section details the resulting changes observed for the intervention group, after interacting with the mBCI for two months to support their critical thinking while working on third-year research projects. A comparison between the two groups was performed after the experiment, to examine whether improvements in critical thinking skills could be attributed to the mBCI, and included both quantitative and qualitative analyses of the gathered data. This chapter also discusses the assessments made by academics regarding the research reports and mobile texts submitted by participants.

7.1 The Level of Critical Thinking Skills before the Experiment

A total of sixty participants completed the pre-intervention survey prior to the mBCI experiment, and participants were randomly divided into intervention and control groups containing thirty participants each. As described in the previous chapter, an independent Student's t-test was used to identify significant differences between the two groups. Participants responded to the pre-intervention survey using a 5-point Likert scale to assess their perceived abilities to perform critical thinking skills (POCT) associated with the following variables: the intellectual standards, including clarity, accuracy, precision, relevance, significance, depth, breadth, logic, and fairness; and the elements of thought, including purpose, questions, information, inferences, concepts, assumptions, point of view, and implications. Tables 7.1 and 7.2 present the results of these variables for the control group and the intervention group, respectively.

7.1.1 Pre-intervention Surveys for both Groups

As shown in Table 7.1, for most of the intellectual standards and elements of thought, the majority of participants (29%) answered 'Not sure'. Answers of 'Sometimes' (25%) and 'Usually' (17%) occurred at higher frequencies than answers of 'Always' (13%) and 'No' (16%). The variable with the highest percentage of similar answers was the element of thought point of view, where 40% of the control group answered 'Sometimes' to the statement that they understand the limitations of their point of view and they fully consider other relevant reasonable viewpoints in their research work. The lowest percentages of similar answers within the control group (7%) were observed for the answers 'Always' and 'No', across multiple variables, including for the element of thought assumption, where 7% of the control group answered 'Always' to the statement "in assumptions, which are the beliefs I take for granted subconsciously or unconsciously, I make sure that they are justified by sound evidence". Details of the statements presented in the survey can be found in Chapter 4, section 4.1.

The intellectual standard of accuracy, which received a total score of 99 in the control group, was the standard most participants believed they were capable of applying prior to the experiment. The lowest score of 77 was reported for both of the intellectual standards logic and fairness, indicating that these standards were perceived to be difficult to apply by participants in the control group.

Similarly, for the intervention group, 'Not sure' was answered by participants more than any of the other answers, representing 31% of all answers, as demonstrated in Table 7.2. In contrast, the answers reported at the lowest frequencies among the intervention group were 'No' and 'Always', at 13% and 14%, respectively. The answers 'Usually' and

PreControl	**No**	**Sometimes**	**Not sure**	**Usually**	**Always**	Mean values
Clarity	20% (N=6)	27% (N=8)	23% (N=7)	13% (N=4)	17% (N=5)	2.8
Accuracy	10% (N=3)	13% (N=4)	33% (N=10)	23% (N=7)	20% (N=6)	3.3
Precision	7% (N=2)	27% (N=8)	37% (N=11)	13% (N=4)	17% (N=5)	3.03
Relevance	17% (N=5)	33% (N=10)	27% (N=8)	13% (N=4)	10% (N=3)	2.66
Significance	23% (N=7)	30% (N=9)	20% (N=6)	17% (N=5)	10% (N=3)	2.6
Depth	17% (N=5)	10% (N=3)	33% (N=10)	17% (N=5)	23% (N=7)	3.2
Breadth	20% (N=6)	20% (N=6)	20% (N=6)	27% (N=8)	13% (N=4)	2.93
Logic	23% (N=7)	30% (N=9)	23% (N=7)	13% (N=4)	10% (N=3)	2.56
Fairness	17% (N=5)	37% (N=11)	27% (N=8)	13% (N=4)	7% (N=2)	2.55
Purpose	10% (N=3)	20% (N=6)	33% (N=10)	17% (N=5)	20% (N=6)	3.16
Questions	20% (N=6)	27% (N=8)	30% (N=9)	17% (N=5)	7% (N=2)	2.63
Information	17% (N=5)	17% (N=5)	37% (N=11)	20% (N=6)	10% (N=3)	2.9
Inferences	10% (N=3)	33% (N=10)	23% (N=7)	17% (N=5)	17% (N=5)	2.96
Concepts	13% (N=4)	27% (N=8)	30% (N=9)	20% (N=6)	10% (N=3)	2.86
Assumptions	23% (N=7)	20% (N=6)	37% (N=11)	13% (N=4)	7% (N=2)	2.6
Point_of_view	10% (N=3)	40% (N=12)	27% (N=8)	10% (N=3)	13% (N=4)	2.76
Implications	17% (N=5)	23% (N=7)	27% (N=8)	23% (N=7)	10% (N=3)	2.86

Table 7.1: Pre-online Survey Results: Control Group

'Sometimes' were recorded at a frequency of 21% for both among the intervention group. The variable with the highest percentage of similar answers among the intervention group was the element of thought assumptions, where 43% of participants answered 'Not sure' to the statement "in assumptions, which are the beliefs I take for granted subconsciously or unconsciously, I make sure that they are justified by sound evidence in their research work". The lowest percentages of similar answers among the intervention group (7%) were observed for the answers 'Always' and 'No', including for the element of thought implications, where 7% of the intervention group answered 'No' to the statement: "I am aware that the implications of my claims logically follow from other claims or truths, where implications follow from thoughts and consequences follow from actions".

In the intervention group, the intellectual standard precision received the highest score

PreInterv	**No**	**Sometimes**	**Not sure**	**Usually**	**Always**	Mean values
Clarity	13% (N=4)	27% (N=8)	27% (N=8)	23% (N=7)	10% (N=3)	2.9
Accuracy	13% (N=4)	23% (N=7)	30% (N=9)	20% (N=6)	13% (N=4)	2.96
Precision	10% (N=3)	7% (N=2)	33% (N=10)	33% (N=10)	17% (N=5)	3.4
Relevance	10% (N=3)	23% (N=7)	27% (N=8)	20% (N=6)	20% (N=6)	3.16
Significance	13% (N=4)	30% (N=9)	23% (N=7)	20% (N=6)	13% (N=4)	2.9
Depth	20% (N=6)	13% (N=4)	27% (N=8)	23% (N=7)	17% (N=5)	3.03
Breadth	7% (N=2)	20% (N=6)	33% (N=10)	23% (N=7)	17% (N=5)	3.23
Logic	13% (N=4)	33% (N=10)	33% (N=10)	10% (N=3)	10% (N=3)	2.7
Fairness	17% (N=5)	30% (N=9)	23% (N=7)	20% (N=6)	10% (N=3)	2.76
Purpose	13% (N=4)	20% (N=6)	30% (N=9)	23% (N=7)	13% (N=4)	3.03
Questions	17% (N=5)	27% (N=8)	20% (N=6)	20% (N=6)	17% (N=5)	2.93
Information	17% (N=5)	10% (N=3)	40% (N=12)	17% (N=5)	17% (N=5)	3.06
Inferences	20% (N=6)	23% (N=7)	27% (N=8)	17% (N=5)	13% (N=4)	2.8
Concepts	10% (N=3)	13% (N=4)	37% (N=11)	23% (N=7)	17% (N=5)	3.23
Assumptions	10% (N=3)	17% (N=5)	43% (N=13)	20% (N=6)	10% (N=3)	3.03
Point_of_view	17% (N=5)	17% (N=5)	40% (N=12)	20% (N=6)	7% (N=2)	2.83
Implications	7% (N=2)	23% (N=7)	27% (N=8)	30% (N=9)	13% (N=4)	3.2

TABLE 7.2: Pre-online Survey Results: Intervention Group

among the list of intellectual standards, with a total score of 102. The lowest score, 81, was observed for the intellectual standard logic, indicating that this element was perceived as difficult to apply by participants in the intervention group.

7.1.2 Comparison of Pre-intervention Surveys Between Groups

The results of the independent Student's t-tests comparing the mean values for each intellectual standard and element of thought showed that there were no statistically significant differences ($p<0.05$) between the two groups for any of the intellectual standards or elements of thought prior to the mBCI experiment, indicating that participants in both groups had similar perceived levels of critical thinking skills (POCT). The details of the independent Student's t-tests performed for each variable are provided in Appendix H.

7.2 Interaction with the mBCI: Intervention Group

As mentioned in the previous chapter, the aim of this study was to evaluate the ability of the designed mBCI to positively affect the behaviours of the users. The study analysed user engagement with the mBCI by allowing them to answer questions, navigate content, set goals, and input text-based responses for tasks during the research project period. Data from log files, which recorded all interactions between the mBCI and the users, was used to assess mBCI usage, as explained in detail in Chapter 6, section 6.3.4. This section reports the usage times and patterns of participant interaction with the mBCI during the two-month experimental period, which illustrates the users' behaviours when an mBCI was used to enhance critical thinking.

7.2.1 Time Spent in the mBCI

The thirty students who had already participated in the pre-intervention survey were randomly assigned to the mBCI experiment. The results showing the amount of time spent in the mBCI are presented in Figure 7.1, which illustrates that the time spent in the mBCI varied depending on which component were being interacted with, including project information, activities, tasks, short quizzes, goals and plans, inquiries and answers, and feedback.

The results showed that participants spent more time reading content than entering text in the mobile application. The results indicated that most of the time spent in the mBCI was spent engaging with the different critical thinking activities designed to increase the user's understanding and knowledge of critical thinking concepts in the context of research projects. The tasks designed to offer students practice using critical thinking components, which were directly related to the research of each participant, were second in terms of time spent in the mBCI. More time was spent on the activities and tasks components than on the other components, possibly because there were three activities and three tasks. For example, the time spent on the first activity was 136 minutes, the time spent on the second activity was 96 minutes, and the time spent on the third activity was 115 minutes. Similarly, the time spent on the first task was 82 minutes, the time spent on the second task was 97 minutes, and the time spent on the third task was 69 minutes. Participants spent 66 minutes on the research project page answering basic questions regarding their research topics, while 92 minutes were spent on the feedback section. Participants spent 45 minutes on short quizzes and 49 minutes on inquiries and reading feedback. The lowest amount of time spent in the mBCI by

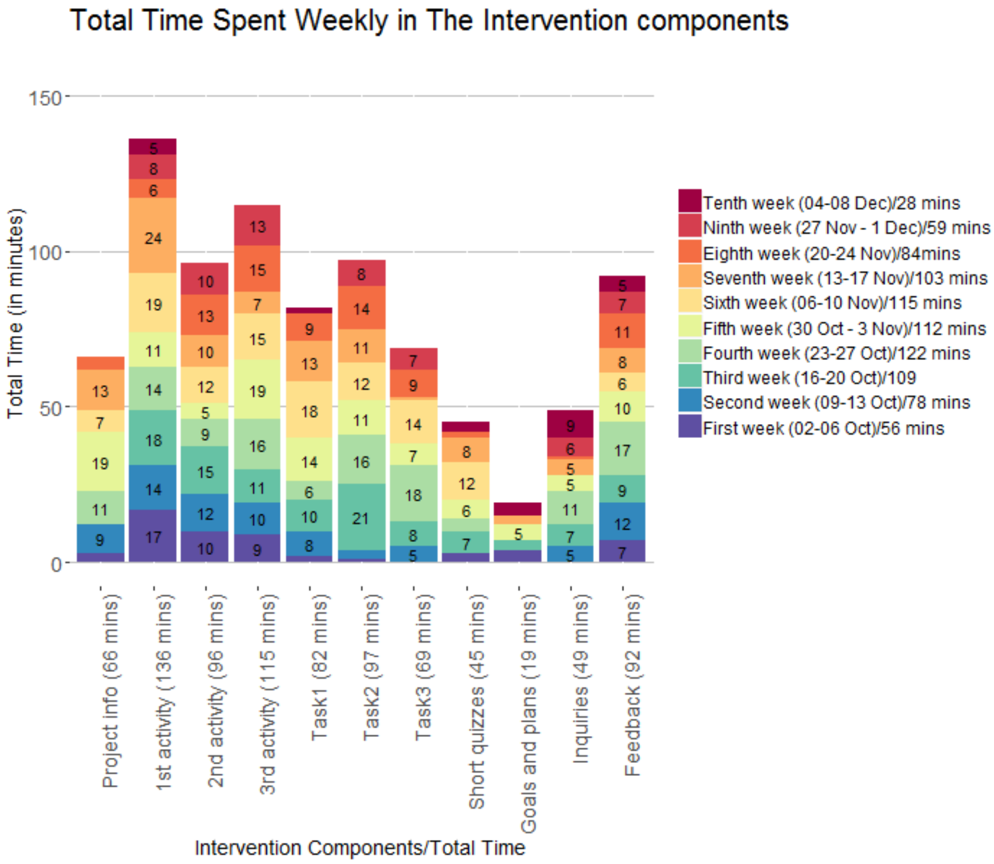

FIGURE 7.1: Total Time Spent in each Intervention Components by Participants

participants was in the goals and plans section, where only 19 minutes were spent during the course of the experiment.

The Figure 7.2 demonstrates the total time spent in the intervention components by each participant. The results showed differences in the amount of time spent in the mBCI depending on the need to engage with the intervention. For instance, the activities and feedback components required participants to read the content provided, while other components required either choosing from a list of options (short questionnaires) or typing and entering texts (tasks, inquiries, plans and goals, and project information). The different amounts of time spent (in minutes) on the intervention components by participants illustrate different levels of engagement with the mBCI. The average amount of time spent in the mBCI was 28 minutes. The highest amount of time was 45 minutes, recorded by the participants P20 and P27. The lowest amount of time was recorded by the participant P29, at 8 minutes.

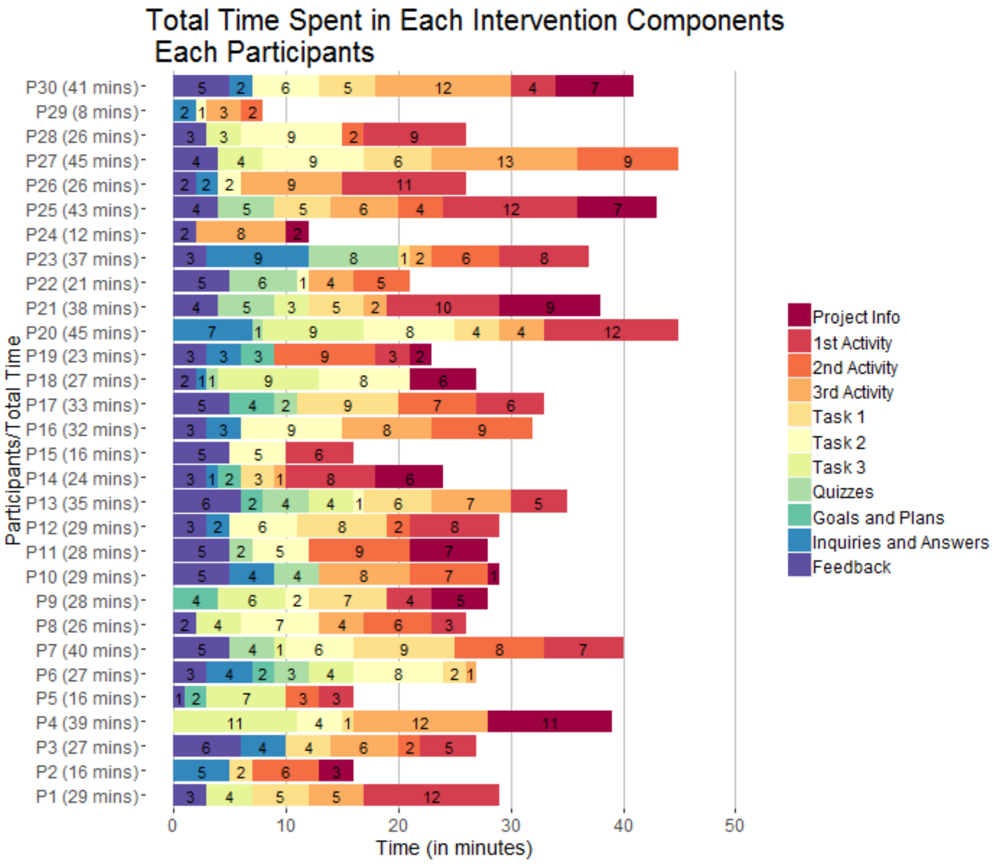

FIGURE 7.2: Total Time Spent in Each Intervention Component by Participants

7.2.2 Weekly and Daily Engagement with the mBCI

Engagement is a key factor for DBCIs, as it determines the level of participation with the intervention. The results show that engagement with the mBCI varied depending on how participants responded to notifications. Participants showed different responses to the notifications they received during the experiment. The notifications were sent on the second and fourth days of each week (See Appendix G). The first notification generally reminded participants to participate in the intervention component. The first notification generally reminded participants to participate in the intervention components, while the second notification contained answers to questions or feedback regarding the performance of participants on the critical thinking tasks and inquiries. The total time spent in the mBCI by all participants was approximately 855 minutes over the course of the experiment. The total time spent during each week varied among the ten weeks of the experiment.

The results (Figure 7.3) showed that participants spent their time in the mBCI differently each week. During the first week, participants spent only 56 minutes with the

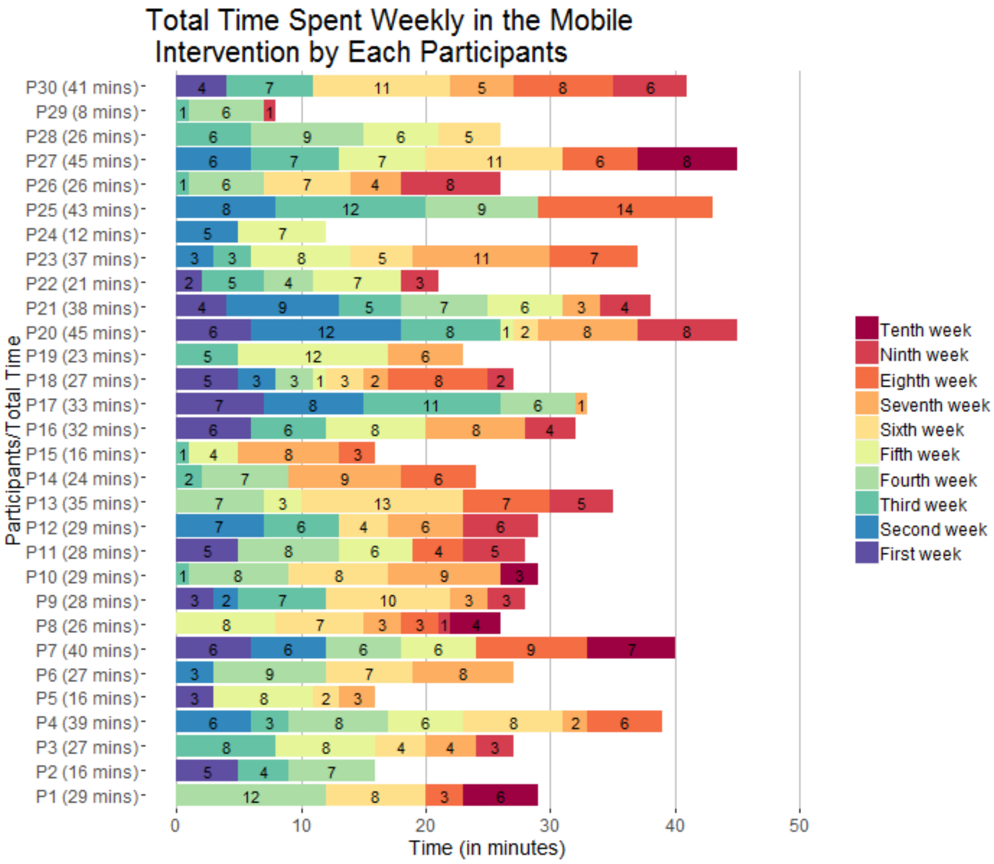

FIGURE 7.3: Total Time Spent in Intervention Components for Each Participant

mBCI, indicating a low level of initial engagement with the intervention. During week 2, participants increased their engagement with the mBCI by 22 minutes, demonstrating increased participation with the components. Using notifications as nudges to maintain participant engagement with the mBCI increased the level of engagement with the intervention. This result can be determined by evaluating the time spent in week 3, which was 109 minutes, and in week 4, which was 122 minutes. In week 5, engagement with the mBCI decreased to 112 minutes. Participants were sent notifications regularly, in the form of feedback and nudges during the experiment. Accordingly, the impact of notifications again increased the level of engagement in week 6 to 115 minutes. However, in week 7, the level of engagement with the mBCI decreased by 12 minutes. Similarly, in week 8, only 84 minutes was spent, showing a further decrease in engagement with the mBCI. In week 9, only one hour was spent, and approximately half an hour was spent in the last week in the mBCI, indicating a continuous decrease in engagement, starting in week 7.

Figure 7.4 shows the total time spent daily by participants during the experiment.

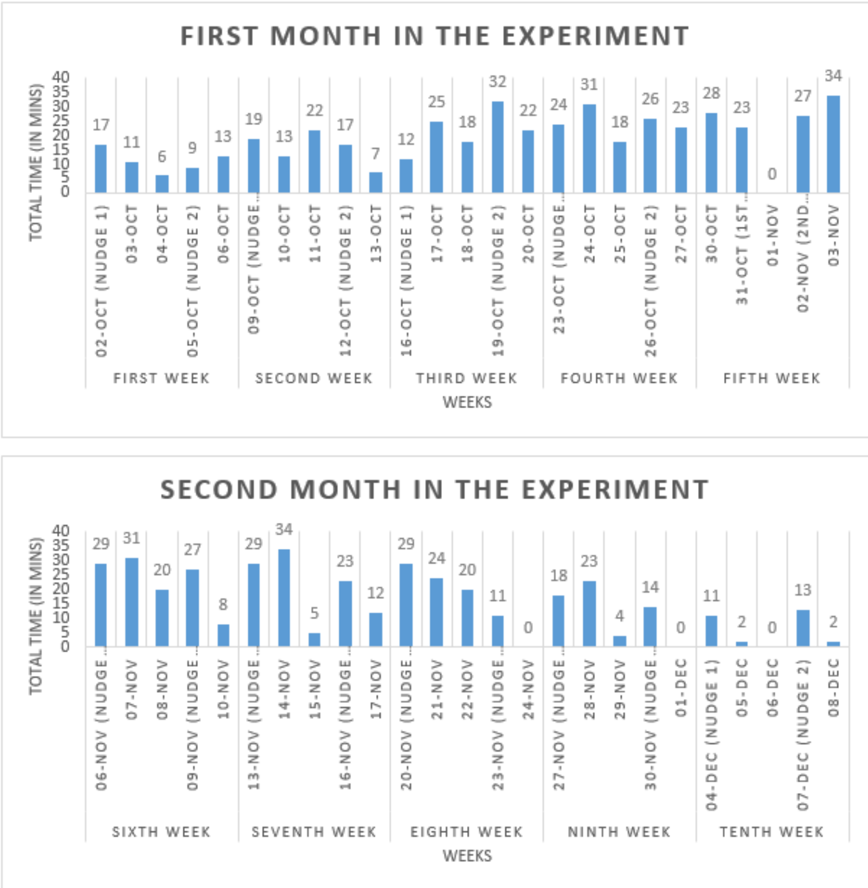

FIGURE 7.4: Daily Interactions of the Intervention Group with the mBCI

The first month of the experiment shows regular engagement with the mBCI. However, the second month of the experiment shows reduced levels of engagement, with more fluctuations. On average, 10 participants engaged with the mBCI on any given day. The highest amount of time spent with the mBCI by participants was 32 minutes. Some days show complete disengagement, which indicated that no time was spent with the mBCI by any participant, including day three in the fifth week, day five in the eighth week, day five in the ninth week, and one day in the last week. On days when participants received notifications, the relative level of engagement increased, indicating the positive impact of the notification on the level of engagement with the mBCI. In the next section, the influence of notification contents on the enhancement of the critical thinking skills of participants will be presented.

Figure 7.5 shows that the time spent in each component was different each day. During the first month, the participants tended to engage more with the activities, while during the second month, the participants tended to engage more with inquires and feedback. As described in the previous chapter (section 6.3), each week, participants were notified

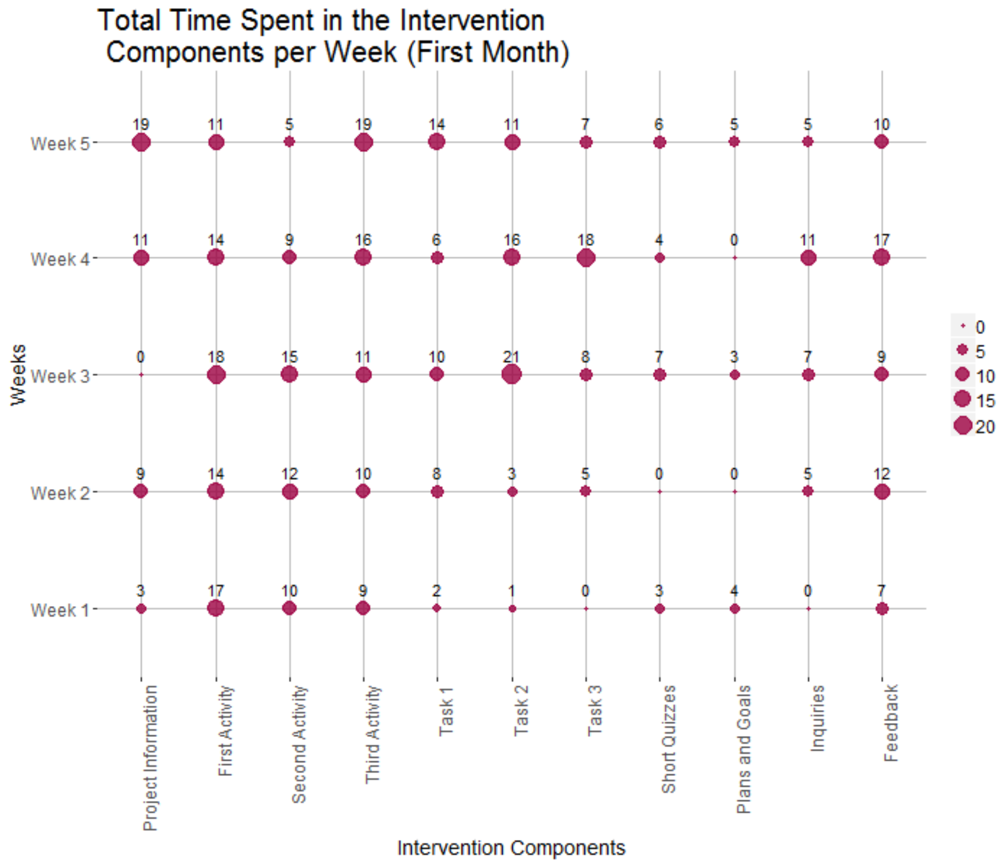

FIGURE 7.5: Time Spent Weekly in the mBCI Components

about specific intervention components. No link was found between the components referred to in these notifications and the amount of time spent in those components, indicating that the contents of the notifications did not affect how participants engaged with the components.

7.3 Usability Tests for the mBCI

The same thirty participants from the intervention group were used to assess the usability of the mBCI, using two surveys. The first survey was designed to allow users to self-reflect on the intervention components and was included at the end of the post-intervention survey. This survey can be found in Appendix H. The second survey, a System Usability Scale (SUS), was used to evaluate the usability of the mBCI by the participants, after using it for the two months of the experiment.

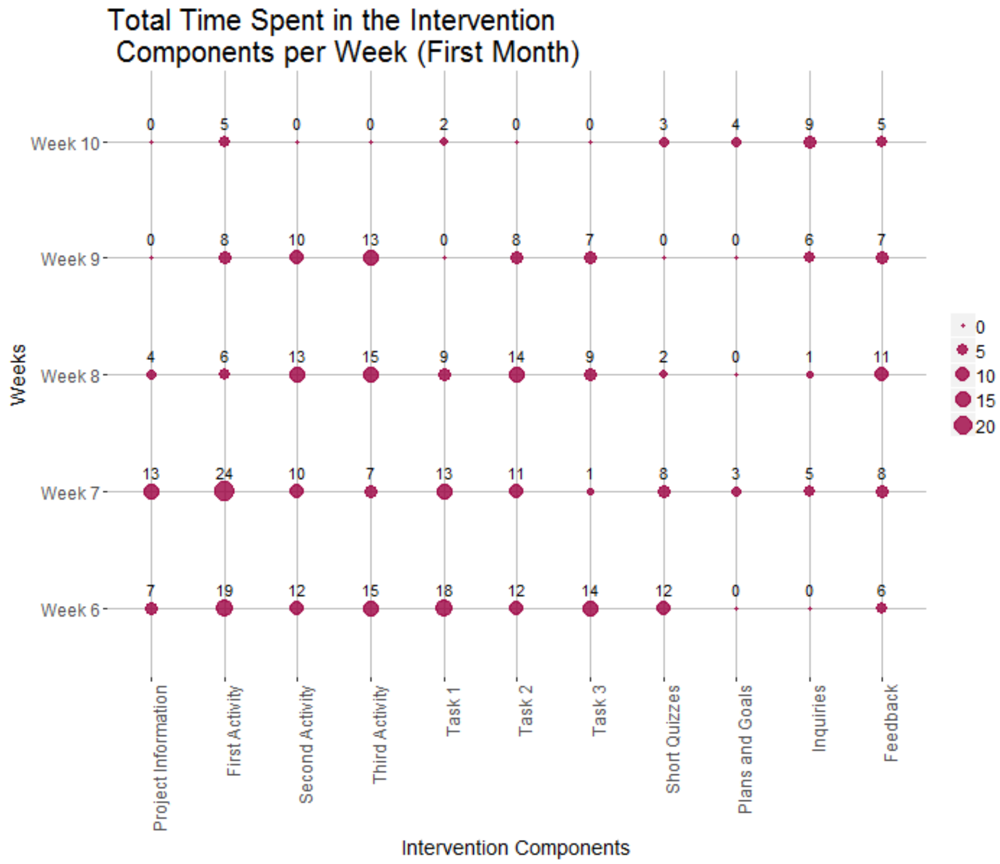

FIGURE 7.6: Time Spent Weekly in the mBCI Components

7.3.1 Intervention Components

The participants from the intervention group responded to surveys evaluating the intervention components, including project information, activities, tasks, short quizzes, goals and plans, notifications, inquiries, and feedback, after they used the mBCI for two months. The survey results (Table 7.3) showed that participants had positive experiences using these components to improve their perceived critical thinking skills in the context of research projects. Participants' reflections on the use of these components indicated that they were easy to use and that participants found them to be useful for supporting critical thinking skills in the context of research projects.

The results show different reflections from the participants regarding their mobile learning experiences with the intervention components. As shown in Table 7.3, 57% of participants found the activities to be helpful for learning about critical thinking (in Strongly Agree and Agree categories), while only 10% found goals and planning to be useful components. A total of 36% of participants had a neutral opinion regarding the usefulness of

Intervention Components	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	Sum
Project Information	27% (N=8)	30% (N=9)	27% (N=8)	13% (N=4)	3% (N=1)	71
Activities and Trainings	10% (N=3)	13% (N=4)	20% (N=6)	30% (N=9)	27% (N=8)	105
Tasks for Critical Thinking	27% (N=8)	20% (N=6)	30% (N=9)	20% (N=6)	3% (N=1)	76
Short Quizzes for the Progress	13% (N=4)	30% (N=9)	36% (N=11)	13% (N=4)	7% (N=2)	81
Goals and Plans to Achieve	33% (N=10)	27% (N=8)	30% (N=9)	10% (N=3)	0% (N=0)	65
Notifications for Engagement	10% (N=3)	33% (N=10)	27% (N=8)	20% (N=6)	10% (N=3)	86
Feedback and Instructions	17% (N=5)	3% (N=1)	30% (N=9)	33% (N=10)	17% (N=5)	99
Percentages/Totals	19.5% (T=41)	22.4% (T=47)	28.6% (T=60)	20% (T=42)	9.5% (T=20)	

Table 7.3: Intervention Components for Intervention Group

short quizzes. Participants had negative views on project information and tasks (57%), goals and plans (60%), and notifications (43%).

Similarly, the sum of the points for each component reveals different outcomes. For instance, the total score (105 points) for the Activities and Training component indicates that participants found that "Using the activities and trainings in my mobile application tend to help me to understand the concepts of critical thinking and research skills". Similarly, participants showed positive views (99 points) towards the Feedback and Instruction component, indicating that "Receiving feedback and direct instructions through the mobile application is a fixable way to improve my knowledge and behaviour in critical thinking during the period of the research project." The respondents scored the statement "The mobile notifications help me to stay engaged in the mobile application content and therefore it helps me to stay engaged in my critical thinking and the research work" with 86 points. The short quizzes component was similar, receiving 81 points in response to the statement "Short quizzes during the research project period to test the progress of my critical thinking skills is a useful way for self-reflection on my research project stages".

The 71 points given to the statement "Writing in research project information page can be helpful to rethink about my critical thinking and research skills during the research project" showed a medium level of satisfaction with the Research Information component. The mobile tasks component received a similar score (76 points) in response to the statement "Working on simple critical thinking tasks in my mobile application helps to improve my critical thinking and research skills for my research work". The participants were less interested in the Goals and Plans component, responding to the statement "According to my goals and plans written in my mobile device, I always succeed to make

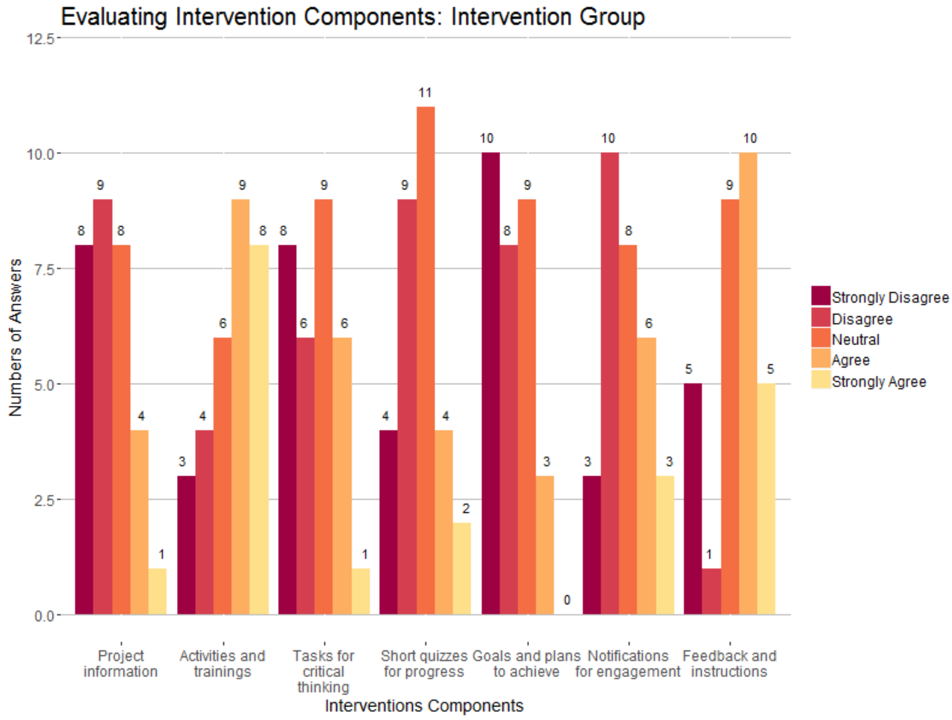

FIGURE 7.7: Reflections Intervention Components: Intervention Group

positive behaviours change to improve my critical thinking and research skills" with the lowest total score (65). Only a few suggestions were made by the participants at the end of the survey. For instance, the participant P14 suggested that using a website to support the mobile intervention would be a good idea. Another suggestion was made by participant P25, indicating that tutorial videos would also be useful for learning more about critical thinking.

7.3.2 Evaluating the mBCI Usability: System Usability Scale (SUS)

The thirty participants from the intervention group evaluated the mBCI using the SUS test. The statements in the test were modified to make them suitable for non-native English speakers. For instance, the word cumbersome was changed to awkward, as suggested by Bangor et al. (2008) and Finstad (2006).

To calculate the SUS scores, the current average SUS scores were compared with the total scores of the SUS results. According to Bangor et al. (2008), the current mean score for SUS tests, among 206 studies performed on 2,324 surveys, is 69.69. A mean score for an SUS test that is greater than or equal to this score indicates that the system being scored is easy to use. However, according to the same authors, the SUS scores can be deemed significantly different based on the type of interface being evaluated. To the best of our knowledge, there are no accumulated studies that indicate a mean score for

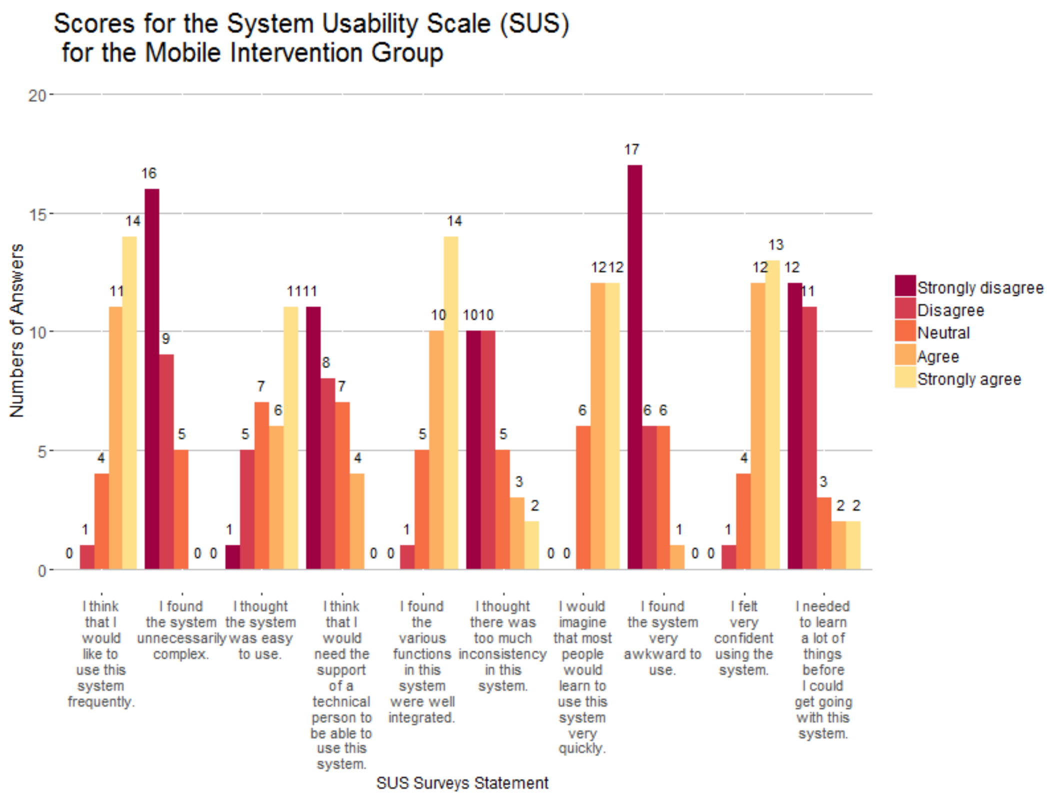

FIGURE 7.8: System Usability Scale (SUS) for the mBCI Group

SUS tests for mobile applications. Because the interfaces of smartphones are similar to the graphical user interfaces (GUIs) of computers, computer GUI scores were used for the SUS evaluation. The current mean SUS for GUIs is 75.24, as reported by Bangor et al. (2008). As the total mean SUS score for the current study of 77.3 is greater than the current mean SUS score for GUIs, the mBCI was determined to be usable.

7.4 Improvements in the Perceived Critical Thinking Skills among both Groups after the Experiment

All sixty participants from both groups participated in the post-intervention survey. The data from the pre-intervention surveys were matched with the data from the post-intervention surveys for each participant to examine the perceived improvements in critical thinking skills (POCT). A paired Student's t-test was used to identify whether the differences in the perceived improvements in critical thinking skills were significant. The results showed that both groups significantly improved their perceived critical thinking skills, with increases being found for some standards and some elements. However, the intervention group showed significant perceived improvements in more critical thinking skills than the control group, as discussed in detail in the following sections.

7.4.1 Intellectual Standards and Elements of Thought: Control and Intervention Groups

The results of the perceived progress in critical thinking skills (POCT), as reported by participants, indicated that the level of critical thinking skills among the control group also improved during the course of this experiment. As shown in Table 7.4, the most common answer for the control group, which constituted 27% of answers in the post-intervention survey, was 'Not sure', followed by 'Sometimes', which constituted 23% of answers. The responses 'Usually' and 'Always' constituted 21% and 17% of answers, respectively. 'No' comprised only 12% of answers in the control group. The results of the perceived progress reported by participants indicated that the level of critical thinking skills among the intervention group also improved. As shown in Table 7.5, the intervention group responded to 30% of the post-intervention survey questions with 'Usually', while 'Not sure' constituted 26% of answers. The responses 'Sometimes' and 'Always' constituted 15% and 20% of answers, respectively. 'No' comprised only 10% of answers for the intervention group.

Comparisons between the total scores of the pre- and post-intervention survey results for the control group indicated improvements (POCT) in most of the intellectual standards and elements of thought, as shown in Tables 7.1 and 7.4. However, the scores for the intellectual standards precision and depth showed slight decreases in the post-intervention survey results. Similarly, for the intervention group, comparisons between the total scores of the pre- and post-intervention survey results indicated improvements in most of the intellectual standards and elements of thought, as shown in Tables 7.2 and 7.5. However, the intervention group showed declining scores in more intellectual standards and elements of thought than the control group. For instance, the scores for the intellectual standard precision and the elements of thought concepts, assumptions and implications slightly decreased for the intervention group in the post-intervention surveys results.

Figure 7.9 shows the increases and decreases in the Likert scale responses of the post-intervention survey results compared with the pre-intervention survey results. For instance, for the intellectual standard clarity, the frequency with which participants of the intervention group answered 'Always' increased. However, the frequency with which the participants of the control group answered 'Always' decreased after the experiment.

PostControl	**No**	**Sometimes**	**Not sure**	**Usually**	**Always**	Mean values
Clarity	13% (N=4)	27% (N=8)	20% (N=6)	20% (N=6)	20% (N=6)	3.06
Accuracy	10% (N=3)	10% (N=3)	30% (N=9)	33% (N=10)	17% (N=5)	3.36
Precision	13% (N=4)	23% (N=7)	37% (N=11)	17% (N=5)	10% (N=3)	2.86
Relevance	10% (N=3)	13% (N=4)	27% (N=8)	30% (N=9)	20% (N=6)	3.36
Significance	17% (N=5)	20% (N=6)	23% (N=7)	27% (N=8)	13% (N=4)	3
Depth	13% (N=4)	20% (N=6)	27% (N=8)	20% (N=6)	20% (N=6)	3.13
Breadth	10% (N=3)	30% (N=9)	23% (N=7)	17% (N=5)	20% (N=6)	3.06
Logic	13% (N=4)	23% (N=7)	27% (N=8)	20% (N=6)	17% (N=5)	3.03
Fairness	10% (N=3)	33% (N=10)	27% (N=8)	17% (N=5)	13% (N=4)	2.9
Purpose	10% (N=3)	23% (N=7)	27% (N=8)	17% (N=5)	23% (N=7)	3.2
Questions	13% (N=4)	23% (N=7)	23% (N=7)	23% (N=7)	17% (N=5)	3.06
Information	17% (N=5)	7% (N=2)	23% (N=7)	33% (N=10)	20% (N=6)	3.33
Inferences	7% (N=2)	30% (N=9)	20% (N=6)	20% (N=6)	23% (N=7)	3.23
Concepts	13% (N=4)	20% (N=6)	37% (N=11)	20% (N=6)	10% (N=3)	2.93
Assumptions	13% (N=4)	23% (N=7)	33% (N=10)	20% (N=6)	10% (N=3)	2.9
Point_of_view	17% (N=5)	27% (N=8)	33% (N=10)	10% (N=3)	13% (N=4)	2.76
Implications	13% (N=4)	30% (N=9)	23% (N=7)	13% (N=4)	20% (N=6)	2.96

Table 7.4: Post-online Survey Results: Control Group

7.4.2 Statistical Results: Pre- and Post-intervention Surveys

This section presents the results of the statistical analyses used in this study. First, a paired Student's t-test was used to compare the mean values of the pre- and post-intervention surveys for each participant in both groups. Second, an independent Student's t-test was used to compare the mean values of the post-intervention surveys between the two groups.

PostInterv	**No**	**Sometimes**	**Not sure**	**Usually**	**Always**	Mean values
Clarity	3% (N=1)	7% (N=2)	30% (N=9)	37% (N=11)	23% (N=7)	3.7
Accuracy	10% (N=3)	17% (N=5)	30% (N=9)	30% (N=9)	13% (N=4)	3.2
Precision	10% (N=3)	20% (N=6)	27% (N=8)	27% (N=8)	17% (N=5)	3.2
Relevance	3% (N=1)	7% (N=2)	20% (N=6)	37% (N=11)	33% (N=10)	3.9
Significance	17% (N=5)	10% (N=3)	13% (N=4)	40% (N=12)	20% (N=6)	3.36
Depth	10% (N=3)	13% (N=4)	30% (N=9)	30% (N=9)	17% (N=5)	3.3
Breadth	3% (N=1)	20% (N=6)	20% (N=6)	33% (N=10)	23% (N=7)	3.53
Logic	7% (N=2)	17% (N=5)	23% (N=7)	27% (N=8)	27% (N=8)	3.5
Fairness	13% (N=4)	20% (N=6)	33% (N=10)	23% (N=7)	10% (N=3)	2.96
Purpose	7% (N=2)	23% (N=7)	27% (N=8)	30% (N=9)	13% (N=4)	3.2
Questions	13% (N=4)	10% (N=3)	13% (N=4)	37% (N=11)	27% (N=8)	3.53
Information	7% (N=2)	10% (N=3)	30% (N=9)	23% (N=7)	30% (N=9)	3.6
Inferences	13% (N=4)	13% (N=4)	33% (N=10)	23% (N=7)	17% (N=5)	3.16
Concepts	13% (N=4)	17% (N=5)	27% (N=8)	27% (N=8)	17% (N=5)	3.16
Assumptions	17% (N=5)	20% (N=6)	30% (N=9)	20% (N=6)	13% (N=4)	2.93
Point_of_view	10% (N=3)	10% (N=3)	23% (N=7)	33% (N=10)	23% (N=7)	3.5
Implications	10% (N=3)	20% (N=6)	30% (N=9)	27% (N=8)	13% (N=4)	3.13

TABLE 7.5: Post-intervention Survey Results: Intervention Group

7.4.2.1 Comparisons within the Same Group: Before and After the Experiment

As shown in Table 7.9, after the experiment, the results (POCT) for the control group showed significant differences (with $p<0.05$) for the intellectual standards relevance and logic and for the elements of thought questions and information. In contrast, after the experiment, the results for the intervention group showed statistically significant differences (with $p<0.05$) for the intellectual standards clarity, relevance, breadth, and logic and for the elements of thought questions, information and point of view, as demonstrated in Table 7.9.

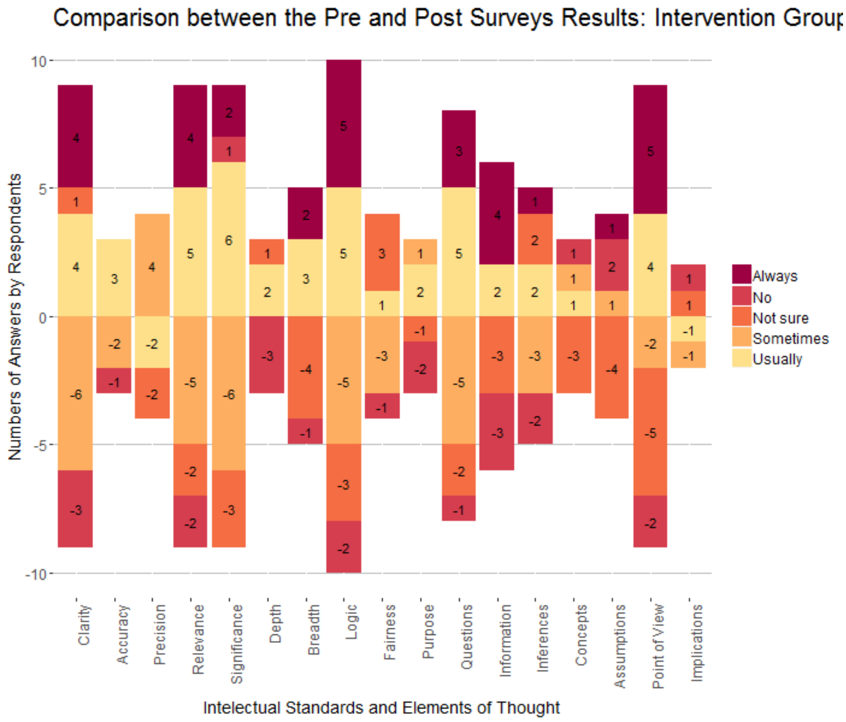

FIGURE 7.9: Comparisons of the Total Scores in the Pre- and Post- intervention Results for Intervention Group

	N		Min		Max		Sum		Mean		Std. Dev		Variance	
	Conl	Intv.	Conl	Intv.	Conl	Intv.	Conl	Intv.	Conl	Intv.	Conl	Intv.	Conl	Intv.
Overall Score Pre	30	30	40	41	60	61	1454	1536	48.46	51.20	4.94	4.22	24.46	17.89
Overall Score Post	30	30	42	46	62	67	1566	1707	52.20	56.90	5.01	5.88	25.20	34.64
Overall Score Standards Pre	30	30	20	19	34	35	771	812	25.70	27.06	3.79	3.25	14.42	10.61
Overall Score Elements Pre	30	30	18	17	30	32	683	724	22.76	24.13	3.28	3.28	10.80	10.80
Overall Score Standards Post	30	30	23	23	36	37	834	920	27.80	30.66	3.37	3.53	11.40	12.50
Overall Score Elements Post	30	30	18	19	31	36	732	787	24.40	26.23	3.02	4.60	9.14	21.22

TABLE 7.6: Overall Scores in Standards and Elements for Pre- and Post-intervention

In Table 7.6, the overall scores in CT performance, overall Standards and elements for pre- and post-tests are presented. The overall scores for the control group in the pre-intervention survey ($M = 48.6$, $SD = 4.94$) was 1454 and in the post-intervention-survey ($M = 52.2$, $SD = 5.01$) was 1566 which indicates the total scores has increased in the post-intervention survey with 112 points. The overall scores for the intervention group in the pre-intervention survey ($M = 56.9$, $SD = 4.22$) was 1536 and in the post-intervention-survey ($M = 51.2$, $SD = 5.88$) was 1707 which indicates the total scores has increased in the post-intervention survey with 171 points.

The overall scores in standards for the control group in the pre-intervention survey ($M = 25.7$, $SD = 3.79$) was 771 and in the post-intervention-survey ($M = 27.8$, $SD = 3.37$) was 834 which indicates the total scores in standards has increased in the post-intervention survey with 63 points. The overall scores in standards for the intervention group in the pre-intervention survey ($M = 27.06$, $SD = 3.25$) was 812 and in the post-intervention-survey ($M = 30.6$, $SD = 3.53$) was 920 which indicates the total scores in standards has increased in the post-intervention survey with 108 points.

The overall scores in elements for the control group in the pre-intervention survey ($M = 22.7$, $SD = 3.28$) was 683 and in the post-intervention-survey ($M = 24.4$, $SD = 3.02$) was 732 which indicates the total scores in elements has increased in the post-intervention survey with 49 points. The overall scores in elements for the intervention group in the pre-intervention survey ($M = 24.13$, $SD = 3.28$) was 724 and in the post-intervention-survey ($M = 26.23$, $SD = 4.6$) was 787 which indicates the total scores in elements has increased in the post-intervention survey with 63 points.

In Table 7.7, the total scores for each standards and elements before and after the intervention for both groups are presented.

The results of the reliability test (Cronbach's Alpha) for scale items at all testing times is (0.32) which shows low reliability. However, there are some significant correlations in pre- and post-intervention between the overall CT scores and some standards and elements. In Table 7.10, the correlations among overall CT, standards and elements at pre-intervention and post-intervention are presented. There was a significant correlation in pre-intervention between the overall CT scores ($r = 0.38$, $p < 0.01$) and overall standards, the overall CT scores ($r = 0.44$, $p < 0.01$) and overall elements, the overall CT scores ($r = 0.31$, $p < 0.05$) and clarity standard, and the overall CT scores ($r = 0.31$, $p < 0.05$) and implications element. In addition, There was a significant correlation in pre-intervention between the overall standards ($r = 0.37$, $p < 0.01$) and depth standard, the overall standards ($r = 0.26$, $p < 0.05$) and breadth standard, and the overall standards ($r = 0.26$, $p < 0.05$) and implications element.

There was a significant correlation in post-intervention between the overall CT scores ($r = 0.49$, $p < 0.01$) and overall standards, the overall CT scores ($r = 0.42$, $p < 0.01$) and overall elements, the overall CT scores ($r = 0.29$, $p < 0.05$) and clarity standard,

Standards and Elements	Total Sore Control Pre	Total Score Control Post	Total Score intervention Pre	Total Score Intervention Post
Clarity	84	92	87	111
Accuracy	99	101	89	96
Precision	92	86	102	96
Relevance	80	101	95	117
Significance	78	90	87	101
Depth	96	94	91	99
Breadth	88	92	97	106
Logic	77	91	81	105
Fairness	77	87	83	89
Purpose	95	96	91	96
Questions	79	92	88	106
Information	87	100	92	108
Inferences	89	97	84	95
Concepts	86	88	97	95
Assumptions	78	87	91	88
Point of View	83	83	85	105
Implications	86	89	96	94
Total scores for standards	771	834	812	920
Overall scores for elements	683	732	724	787
Overall scores (standards and elements)	1454	1566	1536	1707

Table 7.7: Overall Scores for each Standard and Element for Pre- and Post-intervention

the overall CT scores ($r = 0.34$, $p < 0.01$) and depth element, the overall CT scores ($r = 0.29$, $p < 0.05$) and fairness standard the overall CT scores ($r = 0.42$, $p < 0.01$) and concept element, and the overall CT scores ($r = 0.29$, $p < 0.01$) and implication element. In addition, There was a significant correlation in post-intervention between the overall standards ($r = 0.31$, $p < 0.05$) and clarity standard, the overall standards ($r = 0.39$, $p < 0.01$) and depth standard, and the overall standards ($r = 0.26$, $p < 0.05$) and breadth standard. Moreover, There was a significant correlation in post-intervention between the overall elements ($r = 0.41$, $p < 0.01$) and concepts element, the overall elements ($r = 0.44$, $p < 0.01$) and assumptions element, and the overall elements ($r = 0.34$, $p < 0.01$) and implication element,

Pairs	**Control_Group Pretest and Posttest**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t-test**	**Sig. (2-tailed)**
Pair 1	*Clarity*	-0.266	0.98	0.178	-1.49	0.147
Pair 2	*Accuracy*	-0.066	0.739	0.135	-0.49	0.625
Pair 3	*Precision*	0.2	0.61	0.111	1.795	0.083
Pair 4	***Relevance***	-0.7	1.441	0.263	-2.66	**0.013**
Pair 5	*Significance*	-0.4	1.404	0.256	-1.56	0.13
Pair 6	*Depth*	0.066	0.739	0.135	0.494	0.625
Pair 7	*Breadth*	-0.133	1.455	0.265	-0.5	0.62
Pair 8	***Logic***	-0.466	1.195	0.218	-2.14	**0.041**
Pair 9	*Fairness*	-0.333	0.994	0.181	-1.84	0.077
Pair 10	*Purpose*	-0.033	0.764	0.139	-0.24	0.813
Pair 11	***Questions***	-0.433	1.135	0.207	-2.09	**0.045**
Pair 12	***Information***	-0.433	1.04	0.189	-2.28	**0.03**
Pair 13	*Inferences*	-0.266	1.048	0.191	-1.39	0.174
Pair 14	*Concepts*	-0.066	1.172	0.214	-0.31	0.758
Pair 15	*Assumptions*	-0.3	1.489	0.271	-1.1	0.279
Pair 16	*Point_of_View*	0	0.787	0.143	0	1
Pair 17	*Implications*	-0.1	0.994	0.181	-0.55	0.586

TABLE 7.8: Paired Sample Student's t-test for Pre- and Post-intervention Surveys: Control Group

Pairs	**Intervention Group Pretest and Posttest**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**t-test**	**Sig. (2-tailed)**
Pair 1	***Clarity***	-0.8	1.517	0.277	-2.89	**0.007**
Pair 2	*Accuracy*	-0.233	1.04	0.189	-1.23	0.229
Pair 3	*Precision*	0.2	1.73	0.315	0.633	0.532
Pair 4	***Relevance***	-0.733	1.638	0.299	-2.45	**0.021**
Pair 5	*Significance*	-0.466	1.525	0.278	-1.68	0.105
Pair 6	*Depth*	-0.266	1.529	0.279	-0.96	0.348
Pair 7	***Breadth***	-0.3	0.702	0.128	-2.34	**0.026**
Pair 8	***Logic***	-0.8	1.186	0.216	-3.69	**0.001**
Pair 9	*Fairness*	-0.2	1.471	0.268	-0.74	0.463
Pair 10	*Purpose*	-0.166	0.949	0.173	-0.96	0.344
Pair 11	***Questions***	-0.6	1.191	0.217	-2.76	**0.01**
Pair 12	***Information***	-0.533	1.357	0.247	-2.15	**0.04**
Pair 13	*Inferences*	-0.366	1.629	0.297	-1.23	0.228
Pair 14	*Concepts*	0.066	1.779	0.324	0.205	0.839
Pair 15	*Assumptions*	0.1	1.539	0.281	0.356	0.725
Pair 16	***Point_of_view***	-0.666	1.124	0.205	-3.25	**0.003**
Pair 17	*Implications*	0.066	1.08	0.197	0.338	0.738

TABLE 7.9: Paired Samples Student's t-test for Pre- and Post-intervention Surveys: Intervention Group

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1.Overall CT	.598**	.496**	.426**	.294*	.185	.088	-.066	.043	.344**	.039	.190	.294*	-.050	.174	.171	-.008	.429**	.162	.119	.292*
2.Overall Standards	.380**	.516**	.083	.312*	.252	.088	.078	.182	.395**	.267*	.020	.255*	-.199	.100	-.002	-.238	.189	-.202	.022	.072
3.Overall Elements	.448**	.157	.521**	.085	-.006	.032	-.178	-.134	.067	-.231	.251	.148	.143	.142	.247	.245	.412**	.448**	.147	.340**
4.Clarity	.312*	.238	.242	.851**	-.092	-.187	.015	-.046	.135	.132	-.002	-.016	-.072	-.109	.179	-.158	.109	.020	.190	.082
5.Accuracy	-.135	-.018	-.184	-.073	.911**	-.001	.009	.026	-.088	-.013	-.044	.037	-.010	.010	-.173	.143	.096	-.093	-.154	-.073
6.Precision	.194	.143	.155	-.065	-.004	.930**	-.089	-.026	-.013	-.142	-.096	-.197	-.109	-.033	-.097	.019	-.014	-.058	.046	.056
7.Relevance	.085	.177	-.038	.166	.031	-.173	.641**	-.159	.094	.128	-.378**	.078	-.046	-.081	.041	-.192	.073	-.037	-.112	-.081
8.Significance	.092	.144	.002	-.106	.200	.000	-.031	.693**	-.106	.163	-.215	.038	-.106	.030	.040	-.227	-.075	-.180	.200	-.303*
9.Depth	.250	.371**	.024	.185	-.154	-.062	.139	-.064	.927**	.030	-.001	-.008	-.124	.149	.025	-.048	.078	-.096	.046	.262*
10.Breadth	.109	.262*	-.083	-.051	.024	-.008	-.099	.097	.165	.665**	-.036	-.035	.225	-.081	-.031	-.345**	-.174	-.187	.000	-.037
11.Logic	.012	-.015	.032	-.026	-.165	-.084	-.336**	-.078	-.044	-.099	.744**	.038	-.082	.190	.036	.025	.129	.102	-.111	.155
12.Fairness	.149	.137	.095	-.037	-.019	-.100	-.064	.067	-.035	-.139	.120	.824**	-.253	.215	-.043	.133	.334**	-.034	-.060	.144
13.Purpose	-.065	-.141	.035	-.052	-.100	-.124	-.071	-.124	.015	.145	-.013	-.189	.910**	.010	.154	-.228	-.270*	-.022	-.192	-.223
14.Questions	.213	.175	.154	-.095	.024	.031	-.132	.045	.109	-.248	.262*	.215	-.047	.800**	-.166	.163	.124	.135	-.219	.033
15.Information	.103	-.006	.159	.128	-.165	-.045	-.040	-.192	.123	-.054	.121	.054	.087	-.164	.824**	-.206	-.080	.132	.009	-.108
16.Inferences	.073	-.044	.150	-.175	.270*	.021	-.074	.068	-.053	-.181	.001	.041	-.146	.059	-.226	.837**	.329*	.078	-.148	.226
17.Concepts	.225	.115	.228	.232	.121	-.088	-.076	-.020	.008	-.131	.120	.399**	-.170	.043	.058	.139	.762**	.138	.161	.155
18.Assumptions	.154	.105	.131	-.082	-.038	.129	.069	-.224	-.186	-.075	.054	-.130	.164	-.066	.192	-.020	.048	.576**	-.101	-.001
19.PoView	.221	.089	.245	.203	-.012	.057	-.113	.096	.043	.140	-.114	.048	-.110	-.319*	.016	-.163	.062	.111	.890**	.012
20.Implications	.311*	.145	.327*	.099	-.130	.115	-.039	-.021	.113	-.208	.243	-.042	-.311*	-.032	-.165	.095	.152	.100	.064	.839**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 7.10: Correlations Among Overall CT Standards and Elements at Pre-testing (below diagonal) and Post-testing (above diagonal)

	df	df(error)	F	P
Overall CT				
Group	1	58	10.52	.002
Time	1	58	57	.000
Group x time	1	58	2.47	.121
CT Standards				
Group	1	58	7.38	.009
Time	1	58	38	.000
Group x time	1	58	2.68	.106
CT Elements				
Group	1	58	3.96	.06
Time	1	58	15.75	.000
Group x time	1	58	2.46	.622

Table 7.11: ANOVA Summary for Experimental Study

As shown in Table 7.11, a series of 2 (time: pre-and-post-intervention) x 2 (group: intervention group and control group) Mixed ANOVAs were conducted to examine the effects of both time and mBCI group on overall CT performance, CT standards and CT elements. Results revealed that there was no significant effects of group x time on overall CT performance, CT standards, and CT elements. In addition, there was no effect of group on CT elements. However, there was a significant effect of group and time on overall CT performance and CT standards.

7.4.2.2 Comparisons Between Different Groups

The results showed that there were statistically significant differences ($p<0.05$) between the two groups for the intellectual standard clarity and for the element of thought point of view after the mBCI experiment was performed. The comparison of the pre-intervention survey results between the intervention and control groups indicated that participants had different perceived levels of critical thinking (POCT) in the intellectual standards and elements of thought. Participants in the intervention group self-reported that they improved at least one intellectual standard and one element of thought. Details of the independent student's t-tests used to compare the pre-intervention surveys between groups are provided in Appendix H. Comparisons between the total scores of the pre- and post-intervention surveys results for both the control and intervention groups indicated improvements in most of the intellectual standards and elements of though, as shown in Tables 7.4 and 7.5. However, the control group had slightly, but not significantly, higher total scores than the intervention group for accuracy and inferences in the post-intervention survey results.

7.4.2.3 mBCI and Improvements in Critical Thinking: Intervention Group

As shown in Figure 7.10, the combination of results from the mobile experiment and those from the post-intervention survey show a correlation between the overall time spent in the intervention and the perceived improvement in critical thinking skills (r=0.65). However, as illustrated in Figure 7.11, considering only the time spent on the each intervention component of the activities with the its designed standard showed no correlation between them. For example, the first activity was meant to specifically support the standards: Depth, Breadth and Logic. In this case, the time spent in the first activity did not show any correlation with the total scores of the perceived improvement in the standards: Depth, Breadth and Logic reported by participants in the post-intervention survey.

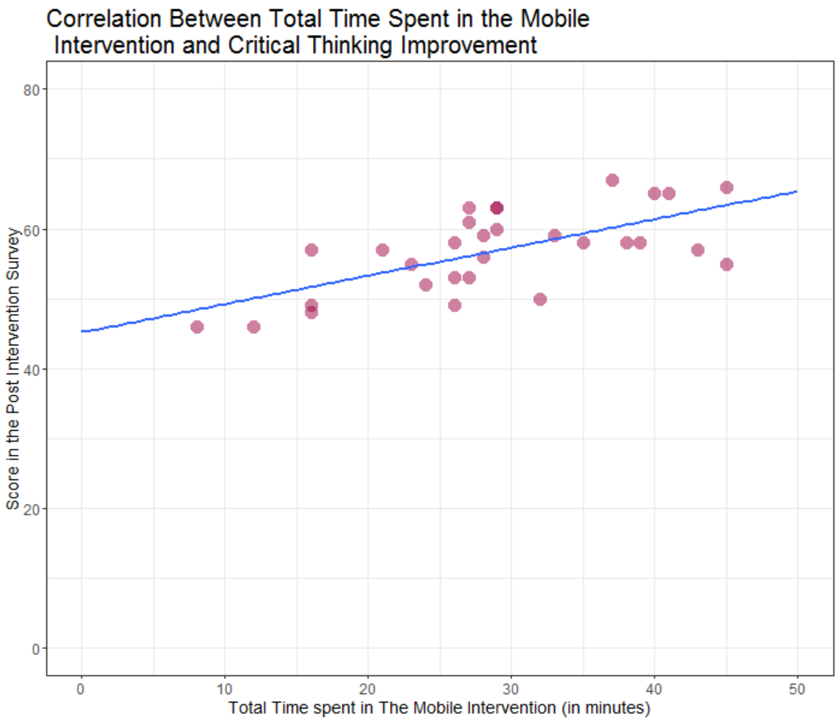

FIGURE 7.10: Correlation Between the Total Time Spent in the mBCI and the Total Scores of Post-Intervention Surveys

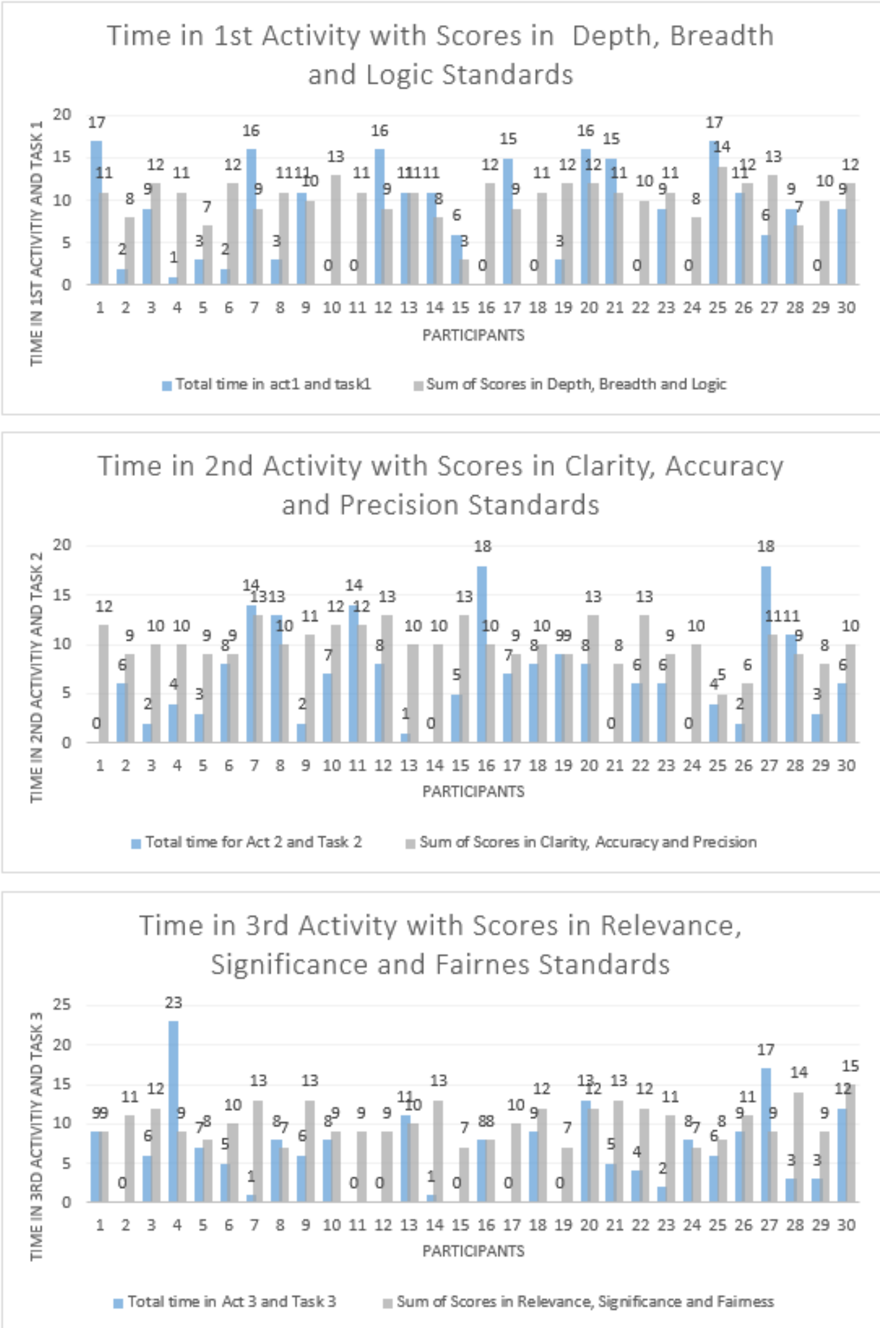

FIGURE 7.11: Correlations Between the Time Spent in Components and The Total Scores of Mapped Intellectual Standards

7.5 The Assessments of the Research Reports and Mobile Texts

This section presents the assessments made by academics of the work delivered by participants. The aim of this section was to reduce the subjectivity of the experiment caused by participants overestimating or underestimating their critical thinking skills when self-reporting. As described in Chapter 6, academics were asked to assess the research reports of the participants in both groups (intervention and control) after the mBCI experiment. Similarly, academics were asked to review the mobile texts entered by participants in the intervention group during the experiment. The assessments and reviews were performed based on the instrument that was designed to measure critical thinking skills in this study (see Chapter 4). The focus was on the assessment of intellectual standards, including clarity, accuracy, precision, relevance, significance, depth, breadth, logic, and fairness.

7.5.1 Assessment of Research Reports by Academics

Only some of participants, including 8 participants from the mBCI group and 5 participants from the control group, agreed to share their documents with the researcher. Students are not generally allowed to share their complete documents any under circumstances, according to the copyright, plagiarism and academic integrity policy of the University of Southampton. Although participants were shown the study approval documents, many still did not feel comfortable sharing their work. Moreover, the assessment of a complete research document is time consuming for supervisors. Many attempts were used to convince participants that their documents would be securely encrypted, stored on the researcher's university desktop, and deleted following the data analysis stage. Despite participants having signed consent forms at the beginning of the study agreeing to share their documents or part of the work at the end of the study, being reminded of the legal right to collect their work for this study, being reminded that the study was approved by ERGO, and being highly assured and guaranteed that their work would remain safe, the majority of the participants refused to share their documents out of fear that their documents would be distributed or lost, which would expose them to academic integrity policies. The students at this university are constantly reminded not to share their work under any circumstances, which reduced the number of documents collected and analysed in this study. This problem has also been encountered in other studies when gathering sensitive data from participants involved in research.

Therefore, a compromise solution was proposed to resolve this issue, as described in this section. Three of the previously interviewed supervisors agreed to assess the work of participants. Each supervisor received certain documents, along with a survey designed to evaluate the work. Text boxes were provided to allow supervisors to comment on and discuss each item.

A total of 13 participants agreed to share their research reports, 8 participants from the intervention group and 5 participants from the control group, as shown in Figure 7.12. To assess these reports, the following two approaches were used. First, these documents, along with the assessment sheet in Google forms (see Appendix H), were sent to three academics. Second, Linguistic Inquiry and Word Count (LIWC) software (Tausczik and Pennebaker 2010) was used to analyse the reports[1].

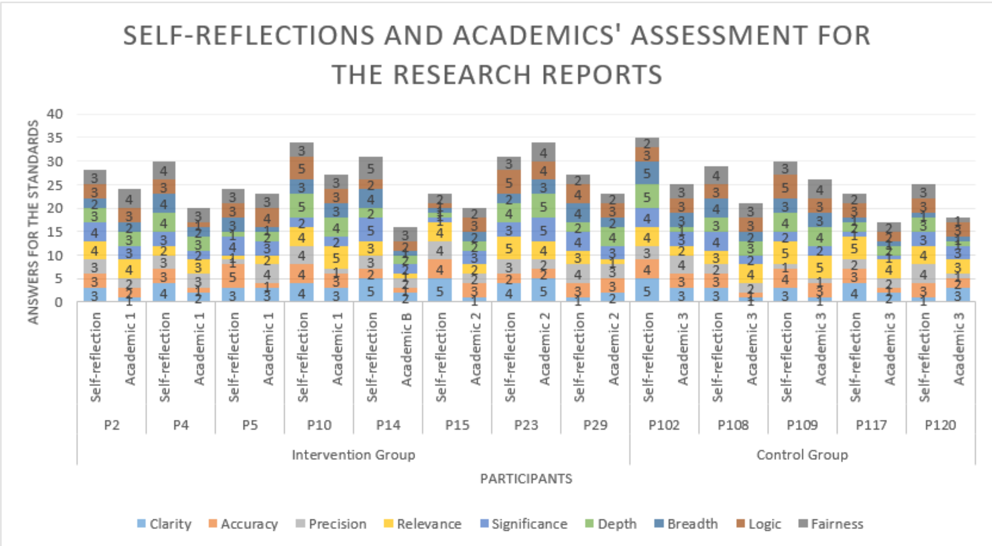

FIGURE 7.12: Comparisons between the Participants' Self-assessments and the Assessments of Academics

As shown in Figure 7.12, participants in both groups generally received low ratings when assessed by academics for critical thinking standards. For instance, the total score for the self-assessment (POCT) of participant P2 across all standards was higher than the total score for participant P2 given by the academics. A similar pattern can be observed for participant P102 in the control group. No differences were found between the two groups, based on the provided reports. However, two participants (P5 and P23) from the intervention group and one participant (P109) from the control group assessed themselves more similarly to the assessments made by academics than the other participants.

The general comments from the academics referred to the lack of critical thinking skills demonstrated in the literature review sections:

[1]LIWC Website: https://liwc.wpengine.com/

> "*A good literature review must review the methods to be employed in a study, which in turn justifies its use. This wasn't done in this report. No literature was referenced to prove this.*" (Academic 1 on [P4])

> "*The research didn't define or describe similar studies to it, which would reveal a gap in knowledge which this work attempts [to fill].*" (Academic 3 on [P117])

Other examples demonstrated the lack of accuracy and precision in some of the reports:

> "*There was no description on how the earlier defined hypothesis would be tested and validated.*" (Academic 2 on [P10])

> "*The report summarily is lacking in robust theoretical background evaluation that supports or opposes the researcher's position. More work should be done in that area. The report failed to indicate succinctly the evaluation methods to be adopted on the qualitative and quantitative data to be obtained from system testing. This should be clearly stated.*" (Academic 1 on [P14])

A lack of clarity was also reported:

> "*The study is truly lacking in focus. [It] is difficult to understand the research direction of the student. What would be the deliverable of this pursuit?*" (Academic 3 on [P108])

The intervention and control groups showed similar levels of critical thinking in their research reports. No major differences were revealed in terms of the intellectual standards that were assessed. However, some observations can be made based on the reports submitted by the two groups. First, the research reports from the intervention group used specific words that were provided in the mobile intervention. Moreover, the reports are more likely to follow clear steps to explain the research problem and how to study it. For example, the report from participant P09 demonstrated that attention was paid to clarity when explaining the purpose of the project.

7.5.2 Assessments Made by Academics of Mobile Texts

A total of 19 participants actively participated in the tasks and the project information components provided in the mBCI. To assess these texts, these documents, along with an assessment sheet in Google forms (see Appendix I), were sent to two academics. As mentioned earlier, the assessments focused only on the nine intellectual standards (clarity, accuracy, precision, relevance, significance, depth, breadth, logic, and fairness) because the activities were designed to support these standards and were mapped to specific standards.

The results of the academics' assessments, shown in Figure 7.13, demonstrated that the participants lacked critical thinking skills during the experiment. This result might

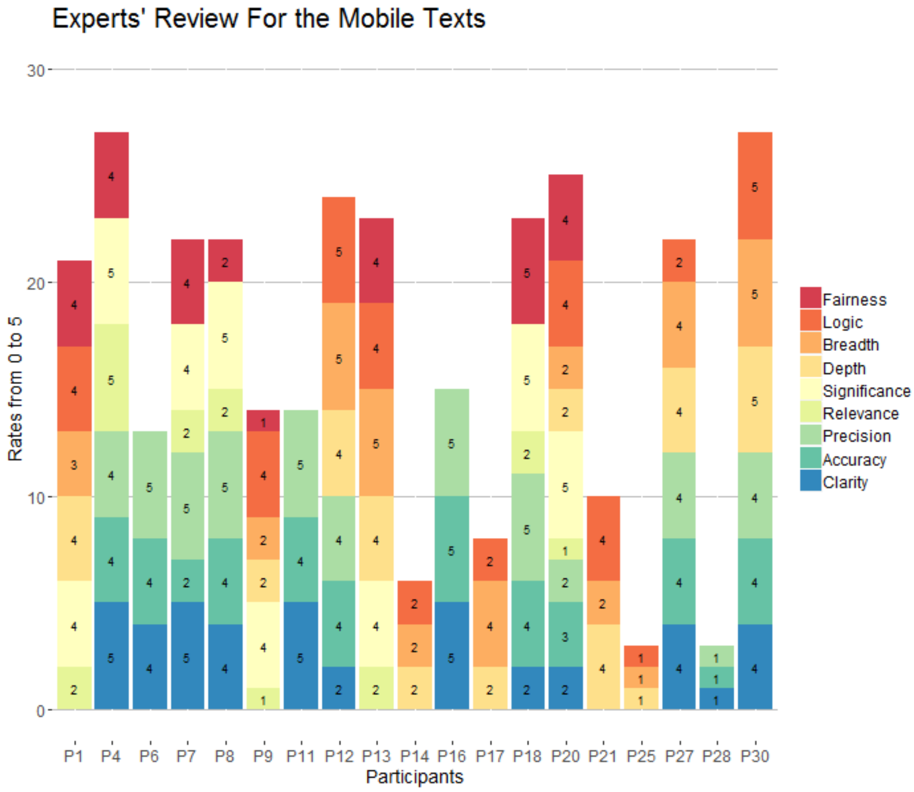

FIGURE 7.13: Comparison Between the Participants' Self-reflections and Academics' Reviews of mBCI Texts

be due to participants not providing enough data regarding their research projects or not applying the critical thinking skills they learned during the experiment. However, participants showed some improvements in their critical thinking skills, based on the feedback they received during the experiment. For example, participants P4, P7, P18, P27, and P30 provided clear information regarding their work when they were triggered by useful feedback regarding clarity and accuracy. As an example, to show the impact of the nudges received in the form of notifications, participant P12 entered this text in the second task during week 1:

> "*One interesting paper here (A systemic approach for iot security, 2013) says no concrete definition of IoT devices currently exists, it's defined differently from person to person and group to group, these objects are connected to the internet to provide some kind of enhanced functionality to the user.*"

The participant received this feedback:

> "*Use very simple methods to identify the main issues in your project by asking what, how, why, and when, who. By asking these questions, [you] will have clearer idea about what you are working on. Based on your work on the activities, you must be now able to*

> *start reviewing other work, which will be included in the literature review section in your document.*"

Accordingly, the participant provided clearer information regarding the discussed paper in the task:

> "*My project aims to create a tool to combat the described problem, promoting a change in attitude towards the security of IoT devices. Internet of Things (IoT) devices never fail to provide the media with some of the most technologically worrying headlines. Many of these devices have the potential to be secure if the setup instructions are followed, but most end users forget about the instructions in the excitement of using their new device.*"

7.6 Discussion

Evaluating the use of a DBCI to promote critical thinking skills in the context of research projects has led to multiple insights. First, the overall results indicated that students still require support for their critical thinking skills when working in research projects. This finding was also reported by other studies (Al-Mubaid and Bettayeb 2017; Alnuaim et al. 2014). Assessing critical thinking skills by measuring improvements over a period of time is difficult to achieve. Some studies have relied only on subjective assessments (POCT) provided by participants, whereas other studies have used more objective assessments by using academics to review the work based on rubrics or certain criteria, as discussed in Chapter 2. In this study, both methods were used to assess and measure critical thinking skills. The results of self-reflection (POCT) by participants regarding their improvements did not align with the results of the assessment made by academics. The objective assessments made by the academics of the research projects submitted by students showed that fewer improvements were made in critical thinking skills compared to the subjective self-reflective assessment made by students. This discrepancy was also addressed by (Alnuaim et al. 2016), indicating that students sometimes overestimate or underestimate their abilities to acquire critical thinking skills.

Second, including the time spent with a DBCI to determine the level of engagement with the DBCI has been recommended by (Yilmaz and Keser 2016). In this study, the time spent in the mBCI was relatively low compared with the time spent in other relevant studies. The length of the experiment might result in reduced engagement with the mBCI. Critical thinking was deemed to be a behaviour in this study, which required a longer time to learn. In this study, the overall scores for critical thinking in the post-intervention surveys were modestly correlated with the total time spent in the mBCI for all participants. Another study reported similar results, showing a correlation between the time spent in the technology and improvements in critical thinking skills (POCT). However, in this study, the calculated times spent in specific activities and tasks within the mBCI were not significantly correlated with improvements in the specific intellectual standards and elements of thought that those activities and tasks were designed to map to. Critical thinking standards and elements interact with each other, making it impractical to support them separately through individual components, which could explain the insignificant correlations observed between the time spent in specific intervention components and improvements observed for the intellectual standards and elements of thought those components were designed to support.

Third, engagement with the mBCI in this study was relatively increased by providing feedback through mobile notifications that were designed to maintain participant engagement and specifically associated with their research projects during the experiment. The weekly feedback and comments provided by researchers to students also appeared to improve critical thinking skills during the experiment. Similar results have been reported by other studies examining the importance of feedback on the enhancement of critical thinking skills (Hermsen et al. 2016; De Kleijn et al. 2014). Feedback as an intervention component was strongly recommended by academics during the interviews reported in Chapter 4. The results showed that mobile notifications improved participant engagement with the mBCI throughout the experiment. In the first weeks, the level of engagement with the mBCI was low due to unfamiliarity with the mBCI. Another possible reason for low engagement was that participants were at the beginning of their research projects and may therefore have wanted to wait until they had clearer ideas regarding their topics. After the first three weeks, participants began to respond actively to the notifications they received by spending more time with the mBCI. The level of engagement continued to remain steady, with some fluctuations, until the last three weeks, which demonstrated the beginning of disengagement with the mBCI. This disengagement could be the result of these weeks being busy for students who are taking final exams and submitting research reports. The disengagement with web- or mobile-based DBCIs designed to improve critical thinking has been addressed in many studies, such as the study by Heflin (2017).

Last, the results of the usability test and the participants' reflections on the intervention components within the mBCI were positive and encouraging. The activities, tasks, and feedback as intervention components were viewed as useful and helpful components for supporting critical thinking skills in the context of research projects, which has also been reported by other studies (De Leng et al. 2009). However, goal setting and planning were considered to be less helpful for enhancing critical thinking skills.

7.7 Summary

This chapter covered the results of the experiment using an mBCI to promote the critical thinking skills of students in the context of research projects. This chapter presented the results of the pre- and post-intervention surveys for two groups, which measured the participants' perceived critical thinking skills (POCT) across two primary aspects: intellectual standards and elements of thought. The survey data were described and statistically analysed. The results of the data generated through user interactions with the mBCI were discussed. In addition, this chapter showed the results of the assessments of the mobile texts and research reports submitted by participants by academics and academics. An overall discussion of these results, including how the results of this experiment and those of previous experiments (Chapters 4 and 5) can be integrated, is presented in the next chapter.

Chapter 8

Overall Discussion

This chapter discusses the primary findings of this study, including the significance of this study and new insights that can be determined when the results of this study are compared with those of previous studies. In this chapter, the experiments of this study will be reviewed, and the results of the research phases will be integrated to provide a more thorough understanding of the use of DBCIs when improving the critical thinking skills of students in the context of research projects.

8.1 Review of Experimental Results

This study includes a number of experiments that were conducted to evaluate the impact of using a digital mBCI to promote the critical thinking skills of students in the context of research projects. The experiments described in this study were divided into two phases. The first phase consisted of the initial survey, academics' reviews, and a pilot study. The second phase involved interviewing academics and an experimental study. The primary focus of this study was to determine how to measure and enhance critical thinking skills in the context of research projects when using DBCIs, based on the perspectives of both students and academics. Before this study began, a literature review was performed to identify patterns and knowledge gaps among previous studies that utilized technology to promote critical thinking skills. Based on the literature review, proper methods, tools and content were designed and created to fill the identified research gaps. To understand how DBCIs can be used effectively to enhance critical thinking skills in the context of research projects, the following aspects were examined: how to measure critical thinking skills when using DBCIs; how to design and implement the tools necessary to facilitate the use of the digital intervention for both supervisors and students; what intervention components can be used to enhance the critical thinking skills of students when using mBCIs; and what methods should be used to evaluate the effectiveness of DBCIs and to demonstrate that students have gained critical thinking skills and enriched their learning experiences.

8.1.1 An Initial Survey: Level of Critical Thinking Skills in Research Projects and Supervision Experience

An initial survey was performed at the start of this study to explore the levels of critical thinking and research skills among undergraduate students (see Chapter 4). The survey was based on the literature review, and the survey statements and questions were divided into four sections. In the first section of the survey, statements were formed based on the Paul-Elder Critical Thinking Framework, and students were required to reflect on their current levels of critical thinking and research skills based on the nine intellectual standards of critical thinking. In the second section, students were asked about their previous experiences using mobile- and web-based technologies for learning purposes. The third section asked about students' views regarding the supervision process during research projects. The fourth section presented a list of educational techniques, and students were required to indicate which techniques they preferred to use to enhance their critical thinking and research skills.

As discussed in Section 4.2.4, the results showed a perceived lack of critical thinking and research skills (POCT) among students. The instrument that was designed to enable students to self-assess their critical thinking skills showed deficiencies identifying critical thinking skills and how to apply these skills in the context of research projects. The self-reflections of students with regards to their critical thinking skills (POCT) varied, with some students claiming to always apply a particular skill, some students admitting to not being sure of their abilities to apply a particular skill or to being unfamiliar with the terms, and some students admitting to a complete lack of specific skills. The survey responses also indicated that students struggle during their research projects because of either miscommunication with their supervisors or an inability to meet with their supervisors, due to busy schedules, which led to students being less capable critical thinkers during their research experiences. Mobile technology was highly preferred by the respondents in the initial survey, which encouraged the use of mobile phones as a method for delivering DBCIs to students. However, technology in general also is seen as a distracting tool for learners as reported in the interviews with academics 4 and reported by Tabuenca et al. (2014). Direct instruction and scaffolding were the most favoured techniques among students for learning, enhancing and promoting critical thinking skills in the context of research projects.

8.1.2 Interviews with Research Project Supervisors: Identifying Requirements and Expectations

After assessing the perceived critical thinking and research skills of students, based on the data collected from the initial survey, determining the expectations and requirements of supervisors with regards to a DBCI designed to enhance critical thinking skills was deemed necessary, as they are academics in the subject of teaching students to use critical thinking and research skills. The first five interviews revealed a number of insights into the methods that research project supervisors utilize to support critical thinking skills and how supervisors use technology for this purpose. To design an effective digital mBCI to improve critical thinking skills, the following steps were taken: the instrument that was designed to measure the perceived critical thinking skills (see Chapter 4) was validated by the supervisors; and the disadvantages and advantages of face-to-face meetings, compared with using available technological tools, to improve communication between supervisors and students during research projects were discussed. The results showed that academics highly encouraged using DBCIs to enhance the critical thinking skills of students in the context of research projects. The findings also showed that supervisors preferred intervention components that were designed to facilitate targeted critical thinking skills and to support these skills with relevant content. The identified components were critical thinking activities, basic project information, mini questionnaires, setting goals and plans, and email notifications. The requirements and limitations for designing an mBCI to promote critical thinking skills in the context of research projects were identified through these interviews.

8.1.3 A Pilot Study for the mBCI

Based on the previous experiments in this study, a pilot study was performed to examine the use of intervention components to improve the perceived critical thinking skills (POCT) of students in the context of research projects (see Chapter 6). The designed instrument was used to measure the perceived critical thinking skills before and after the experiment, allowing the detection of improvements in critical thinking skills following two months of using the mBCI, as discussed in Chapter 6. The mBCI was developed by adapting the existing LifeGuide Toolbox software, which facilitated the process of designing mBCIs through a web-based authoring tool that offers flexible steps. The mBCI content for critical thinking skills, including activities, practices tasks, and training modules, was fully designed using the LifeGuide Toolbox. Data generated from mBCI use was collected for analysis. The results showed perceived improvements in some critical thinking skills (POCT) but not in others. The findings indicated that the mBCI was an effective approach for supporting critical thinking and research skills. However, the mBCI required improvements, in both the design and the methodology, which are discussed in the next sections.

8.1.4 Interviews with Academics: Confirmation

Following the experiments performed during the first phase of this study, more academics were asked to validate the instrument and to review the intervention components. As discussed in Chapter 4, academics from different backgrounds, including the areas of human-computer interaction, computer science, education, eLearning, and research project supervision, and those with experience supervising students in the development of critical thinking and research skills were targeted. First, the survey-based instrument that was designed to measure the perceived critical thinking skills in the context of research projects was reviewed and confirmed to be sufficient by the academics. Second, the statements within the instrument were reviewed and validated by the academics and enhanced to more exactly reflect the targeted critical thinking skills. Third, the intervention components, which were derived from the literature review and designed to allow intervention builders to create supportive tools to assist certain critical thinking skills, were assessed and validated by the academics. The mBCI components included project information, activities to teach critical thinking, tasks to practice applying critical thinking skills in the context of research projects, plans and goals to organise the work, short quizzes to indicate the progression of critical thinking and research skills, inquiries to enable students ask questions, communications between the intervention creator and the students in the form of feedback and instruction, and notification features to engages students with the mBCI during their research work. The results showed that academics highly encouraged using the mBCI and its components to enhance the critical thinking skills of students in the context of research projects. However, the interviewees maybe biased in their opinions towards the questions, perhaps by the presence of the interviewer. The requirements and limitations for designing mBCIs to promote critical thinking skills in the context of research projects were identified through these interviews.

8.1.5 A Two-group Experimental Trial to Evaluate the Effectiveness of the mBCI and Formal Assessment by Academics

After the pilot study was performed, some of the mBCI features were enhanced, and new features were designed, as discussed in detail in Chapters 6 and 7. For instance, a major change was the addition of a control group to the experiment to determine whether the observed improvements can be attributed to the mBCI. In addition, academics were asked to assess the participants' work (project reports and mobile texts) to reduce the subjectivity of perceived improvements in critical thinking skills (POCT), which were based only on the self-reflections of students during the pilot study. Overall, the critical thinking skills of the participants in the intervention group improved more than those of the participants in the control group for certain standards and elements. However, the assessments performed by academics showed that the self-assessments of perceived improvements in critical thinking skills did not necessarily reflect actual improvements in critical thinking skills. The findings also showed that the notification feature, which nudged and triggered participants through the experiment, played a major role in the maintenance of participant engagement with the mBCI, and thus, helped participants to be more engaged with their research projects. The analysis of data from log files showed that participants successfully interacted with the mBCI for different lengths of time, and the usability test revealed that students found the mBCI to be useful, helpful and easy to use.

8.2 Integration of Findings from All Experiments

In this section, the findings from all of the different experiments conducted during the two phases of this study will be combined and discussed. The discussion will be supported and linked with the outcomes reported in the literature. An integration of the different findings will be explained using evidence-based justifications.

8.3 Measuring and Improving Critical Thinking Skills

An instrument to measure the perceived critical thinking skills in the context of undergraduate research projects was designed by the researcher to assess learners' critical thinking skills when a DBCI was used. The instrument was validated by multiple academics and supervisors, who agreed that the instrument can measure critical thinking skills in the research project context.

The instrument showed some consistency in the measurement of the perceived critical thinking skills when used throughout the different phases of this research. However, the accuracy of the instrument must be verified through further studies using different contexts. The resulting perceived improvements in critical thinking skills varied slightly during the different phases of this study, likely due to the differing levels of support that students received from the digital intervention.

As discussed in the literature review, measuring and examining the critical thinking skills of students is possible. In fact, standard tests such as Halpern assessment, Cornell test, Watson-Glaser appraisal, and Ennis-Weir essay test have been used to measure critical thinking skills. However, these standard tests only examine critical thinking for learners in general domains (Barak and Levenberg 2016). The literature review revealed the lack of an available instrument to measure critical thinking skills in the context of research projects. Therefore, an instrument was designed to fill this research gap. The instrument was specifically designed to measure critical thinking skills of students during the process of undertaking research projects. This instrument was used before, during and after the digital intervention to indicate the perceived improvements in critical thinking skills based on self-reflections.

As argued by Paul and Elder (2013), the quality of critical thinking skills during research projects can be assessed by examining the intellectual standards and the elements of thought. The intellectual standards represent the first part of the adopted Paul-Elder critical thinking framework and consists of nine standards that enable learners to assess the quality of thinking by applying those standards into the elements of thought (discussed in the next section). The intellectual standards are clarity, accuracy, precision, significance, relevance, depth, breadth, logic, and fairness. The elements of thought represent the second part of the adopted Paul-Elder critical thinking framework and consists of eight elements that allow learners to apply the intellectual standards to the scientific steps during a research project. Simply, the elements of thought represent the scientific method when conducting a research work. The elements of thought are purpose, questions, information, inferences, concepts, assumptions, point of view, and implications. These standards and the elements were used in the instrument to measure the perceived critical thinking skills during the students' research projects.

Students require support of their critical thinking skills when they are working on their research projects, which was demonstrated by the measurements of the perceived critical thinking skills using the instrument throughout the experiments in this research. Students require a high level of guidance and supervision for their critical thinking skills. As previously addressed (Alnuaim et al. 2016), critical thinking is a learned skill that requires both training and practice. Critical thinking is not an inherent ability and requires more than just simple student engagement during a course training or meeting. Critical thinking requires students to be actively engaged in the process of conceptualising, applying, analysing, synthesising, evaluating, and communicating information (Behar-Horenstein et al. 2011). Unfortunately, a significant number of students lack the problem solving and critical thinking skills necessary for many college majors (Shaw et al. 2013).

According to the findings of this research, students say that they struggle to know how to be clear, accurate, precise and fair when they are working on research tasks. Students believe that they cannot see how their work can be significant, logic, deep and relevant. Therefore, students require continuous and supportive assistance when working on research projects to obtain an accurate evaluation of their critical thinking progress. The survey results agree with previous research regarding collage students' critical thinking skills. Recent studies indicated that students are mostly weak in high-level thinking skills (Holzer et al. 2015; Alnuaim et al. 2016). There are many reasons why students lack critical thinking skills, such as the traditional methods that most instructors use to teach critical thinking skills. In addition, currently no well-designed technologies are available for the practice of critical thinking skills. According to Al-Emran et al.

(2016), research studies should emphasise the importance of using technology to foster and evaluate critical thinking skills, with much careful design.

In the present study, students reported finding it difficult to obtain useful feedback from their supervisors with regards to their research skills. The students also reported difficulties finding time to meet with supervisors. Most of the students indicated that using mobile technology to communicate with their supervisors regarding the completion of research tasks would be helpful and would support the development of their critical thinking skills. The unique features of mobile technology can help both students and supervisors contact each other, with fewer limits on time and place.

Generally, supervisors stated that students require continuous support for critical thinking skills during their research projects and that, regardless of the students' critical thinking abilities, they require constant reminders to apply critical thinking skills to their research tasks. According to supervisors, college students lack critical thinking skills at almost every step of research projects, starting from the literature review through the conclusion. In general, the interviewees stated that students still demand technological support for their critical thinking skills. An mBCI might allow students and supervisors to communicate with each other. An mBCI could also help supervisors create content that explains what critical thinking is and what skills students must learn to be critical thinkers. In addition, supervisors could use an mBCI to measure critical thinking progress by designing surveys and short questionnaires for their students. Similarly, students might benefit from an mBCI by reflecting on questions created by their supervisors and could take advantage of other features, such as a planning feature, a reminder feature, or a diary writing feature. The results generally have some positive findings for the use of mBCIs to maintain student engagement with their projects and to enhance the awareness of using critical thinking skills during research. In addition, an mBCI can allow the learning behaviours of students, with regards to critical thinking standards, to be monitored and guided by their supervisors.

There is a difference between measuring the actual critical thinking skills and measuring the self-reported perceived critical thinking skills (POCT). This research used a multiple-assessment approach which includes students to self-report their perceptions of their critical thinking, and later, students' actual critical thinking in their research reports were assessed by academics. The results of self-reflection by students regarding their improvements did not align with the results of the assessment made by academics. The objective assessments made by the academics of the research projects submitted by students showed that fewer improvements were made in critical thinking skills compared to the subjective self-reflective assessment made by students. This discrepancy was also addressed by (Alnuaim et al. 2016), indicating that students sometimes overestimate or underestimate their abilities to acquire critical thinking skills.

8.4 Engagement and Usability of the mBCI

This section continues to address the fourth research question, which explores how DBCIs can help improve critical thinking skills. This section presents evidence that a DBCI improved the critical thinking skills of students during the research project period, including how the mBCI contributed to maintaining student engagement with critical thinking skills while they were working on their research projects. Examining the responses to the notifications and the time participants spent in each intervention component allowed the assessment of the level of engagement with the mBCI. In addition, texts and answers inserted by participants were studied to determine improvements in critical thinking skills based on the level of engagement. Participant interactions with the mBCI were analysed to examine which intervention components supported those critical thinking standards and elements that showed the most improvements. To evaluate the interactions with the mBCI, user experiences were examined by studying the responses of participants to the usability tests.

The interactions with the mobile intervention not only included reading and learning critical thinking concepts from the activities but also included answering the tasks by providing texts. The texts were studied and analysed and subjected to assessment by academics. The answers to the short questionnaires were used to provided relevant feedback based on the self-reflection made by participants during the experiment. Based on the analysis of the data gathered from both categories of participants (supervisors and students), the mBCI was deemed to be useful for the promotion of students' critical thinking skills during their research projects. The findings align with those of previous relevant studies, which indicated the need for better technological practical mobile tool to enhance critical thinking skills for students (Crompton and Burke 2018; Huang et al. 2017). As a result, the use of an mBCI appeared to improve some students' perceptions of their critical thinking skills. However, the use of mBCIs to support critical thinking skills must still be evaluated on a wider scale, using real interventions provided by real supervisors over a reasonable span of time, to determine the different contexts where DBCIs can be beneficial.

This study has demonstrated that the integration of the LifeGuide Toolbox with the Paul-Elder Critical Thinking framework enabled the development of a mobile technology that could be integrated within the context of a behavioural intervention. However, the evaluation only uncovered perceived benefits, which might differ in a real intervention setting when the notification system is impeded. In addition, drawing generalized conclusions based on a DBCI without supervisors might introduce inaccuracies regarding the expected outcome of future DBCIs, due to the limited functionalities of the prototype. Currently, this study has addressed the four research questions described in the introduction chapter and the results appear to demonstrate that the primary research hypothesis that DBCIs can help students' to improve their critical thinking during their research projects is correct.

The responses to the notifications and the time spent in each intervention component revealed the level of engagement with the mobile intervention. In addition, texts and answers inserted by participants were studied to examine improvements in critical thinking skills based on the level of engagement. Student interactions with the mobile intervention were analysed to determine which intervention components supported the critical thinking standards or elements that were the most improved. User experience was also evaluated based on the responses to the usability tests, which allowed participants to reflect on the design of the mBCI.

Throughout the two months of the experiment, participants remained engaged in the activities and tasks. During the first month, participants spent more time on the project information components. During the second month, participants spent more time on feedback. No differences were observed in the level of engagement with the rest of the components during the two-month period. The maximum number of active users recorded per day was ten participants. Notifications helped maintain user engagement with the mobile application.

The time spent in the mobile components does not indicate that participants were engaged with the content presented in the notifications. Participants responded to notifications only as a trigger to participate more in the mobile application, regardless of the content of the notification (Huang et al. 2017). However, some of the notifications showed higher engagement, based on the amount of time spent on the mobile application. For example, when the notification asked the participants to check their work in the intervention tasks, the time and the text revision activity revealed a longer time spent with the mBCI for the majority of the participants. In contrast, when the notification asked a short question about the progress of the critical thinking, the participants preferred to respond to the question without spending time in the mBCI.

The notification features appeared to play roles in the participants' engagement. The number of times the mBCI was accessed increased when the users received a notification. Participants were more engaged and spent more time with the mBCI when they were notified. Therefore, this helped participants to be more engaged with their research projects. In the last three weeks, the engagement level fell continuously, likely because the participants were too busy planning to submit their research reports before deadlines. However, interactions with the mBCI showed 40% disengagement during the experiment for all participants. There are a few reasons that would explain this perceived disengagement. Answers to the participants' inquiries, constrictive feedback, and supportive information did not come directly from supervisors, which may have limited the motivation or reward aspects of the mBCI for participants. Limited collaboration features in the mobile application or participants having other priorities, no experience dealing with such tool, or a lack of confidence or faith in the DBCI may also explain disengagement, as have been addressed in other studies. Other reasons for disengagement with DBCI systems have been discussed in previous DBCI studies (Al-Mubaid and Bettayeb 2017; Asiri et al. 2018; Alnuaim et al. 2016; Weston et al. 2015).

Some days showed that no engagement occurred by any participant. Notifications were sent twice a week to maintain participant engagement with the mobile application and with their research projects. The second notification in every week was intended to include feedback regarding the participants' critical thinking performance, based on responses to the tasks and project information pages. In addition, the feedback sometimes contained encouragement to participate in specific components. Accordingly, participants showed different levels of engagement based on the weekly notifications. On a daily basis, there were differences in the levels of participation with the various intervention components. When a notification included feedback, participants tended to read the feedback and to review the relevant material in the mBCI. Disengagement was observed for some participants during the experiment. Some participants disengaged completely from participating in the experiment during the last three weeks, which likely affected the average level of engagement with the mBCI. The researcher attempted to prevent disengagement by sending notifications through the mobile application and through emails, but this strategy was not successful for some of the disengaged participants.

8.5 Digital Intervention to Change Critical Thinking Behaviour in Research Projects Supervision

The results from the interviews with academics and supervisors were encouraging, in terms of using the mBCI to support students' critical thinking skills. Moreover, a DBCI could help to maintain student engagement with their projects and awareness of using critical thinking skills during research. Generally, supervisors stated that students require continuous support during their research projects, providing them with information about critical thinking skills. Regardless of the level of critical thinking that students have, they still require reminders and scaffolding to utilize critically thinking skills in their research projects. Based on the views of academics and supervisors, college students lack critical thinking skills during almost every step of research projects, starting from the literature review through their research conclusions.

Supervisors might require the ability to measure their students' critical thinking skills by designing surveys, short questionnaires and providing relevant activities. Similarly, students might benefit from the mobile application by reflecting on questions that were created by their supervisors. Students also might use the other features of the mBCI, such as activities and tasks designed to practice critical thinking skills, a planner, a reminder, and diary writing, combined with a notification system to maintain engagement with the critical thinking process. Student's learning behaviours while approaching critical thinking standards can be monitored and guided by the DBCI.

Identifying the most effective components when designing a DBCI is important (Weston et al. 2015). The specified intervention components were selected because they are considered to be more effective for the promotion of critical thinking as a behaviour in the context of research projects. The specific intervention components used in this study were the project information page, activities and training, tasks for practising, short questionnaires, goals and plans settings, notifications for nudges and triggers, inquiries and answers, and providing feedback and instructions.

The DBCI system helped students remain engaged in the process of critical thinking and research work. The evaluations of student performance and their reflections on their own abilities indicated that the system can potentially be applied to other disciplines. The study examined the usefulness of using DBCIs to support critical thinking skills in situations where independent study can be effective. The results of this study led to the exploration of the challenges associated with using mobile technology to support critical thinking skills in a research context. This study highlights the major issues of behaviour learning when critical thinking is required. This study also addressed the key components of a successful behavioural learning experience to support critical thinking skills in university students. Moreover, that ability of supervisors to support their students' critical thinking and research skills can be facilitated using mobile technology.

However, a few challenges might arise when using such a system with real supervisors, due to their busy schedules. Supervisors may encounter technical issues when building mobile intervention components to support critical thinking skills. Additionally, the impacts of mBCIs on critical thinking skills in this study was examined over a long periods of time to determine long-term effects, which may have been limited by the engagement of participants. However, research on CT enhancement indicates that 8 weeks may not be enough. Further studies examining the impacts of the mBCI on critical thinking skills over a shorter time period should be performed to assess its impacts. Further evaluation of designs should be considered when implementing flexible software engineering methods to ensure the functionality of the software tools. The design of the surveys and interviews must consider specific issues, such as focusing on one or two research steps with deep analysis techniques to analyse the gathered data.

Because the interviewees stated that students demand technological support for their critical thinking skills, the mBCI was designed to enable students and supervisors to communicate with each other during this study. The mBCI aided the researcher and supervisors to create of relative content to support critical thinking skills and to determine which skills the students required to become better critical thinkers. In addition, the mBCI allowed the measurement of student's perceived critical thinking skills through surveys and short questionnaires. Similarly, students have benefited from the mBCI by reflecting on the questions written for them by their supervisors. Students were able to successfully use the features that the mobile application provided, such as the planner, reminder, and diary writing features (Pimmer et al. 2016). Accordingly, the impacts of mobile interventions can be determined based on the time preferences, student's situations, and the overall progress made.

The existing LifeGuide Toolbox framework was useful and helpful for creating a mobile intervention to assist critical thinking skills. The LifeGuide Toolbox software package consists of an authoring tool that enables intervention builders with minimal programming backgrounds to easily create digital interventions. As a result, the tool could be widely used by a large number of researchers and scientists and can provide them with data regarding the critical thinking skills and behaviours of students during research projects.

During this study, some students perceived that their critical thinking and research skills (POCT) were improved by using the mBCI. The system helped students remain engaged in the process of critical thinking and research work. The evaluations of the students' performance and their self-reflections indicated that the system was able to enhance certain critical thinking skills and could potentially be applied to other disciplines. The study examined the usefulness of using DBCIs to support critical thinking skills in situations where independent study can be effective. This study also explored the challenges of using mobile technology to support critical thinking and in the context of research and highlighted the major issues for behaviour learning when critical thinking is required. This study attempted to identify the key components of a successful behavioural learning experience for the critical thinking skills of university students. Moreover, the ability of supervisors to support the critical thinking and research skills of their students can be enhanced through the use of mobile technology. However, some challenges may still exist when using such system with real supervisors due to their busy schedules, and engaging supervisors to build mBCI components to support critical thinking may also be difficult due to technical issues. In addition, studying the impact of mobile technologies on critical thinking requires a long observation time to identify changes, which limited the engagement of participants. Further evaluation designs should be considered when implementing flexible software engineering methods to ensure the functionality of the software tools. Additionally, the design of the surveys and interviews must consider specific issues, such as focusing on one or two research steps, combined with deep analysis techniques for the gathered data.

8.6 Research Limitations, Implications and Recommendations

In this section, the research limitations are presented for the several studies conducted in this research. It starts by presenting the limitations of the initial survey and the interviews with the supervisors and academics. This is followed by presenting the limitations for the pilot study and the experimental trail.

8.6.1 Limitations in the Initial Survey

The initial survey attempted to address one component of the first research question, which involved designing an instrument to measure student perceptions of their critical thinking skills. These perceptions were assessed by asking students to self-reflect on their critical thinking and research skills. Relationships between critical thinking skills and mobile use were also ascertained. The most effective educational techniques for improving the critical thinking skills of students were examined in this survey. However, the initial survey did not include an experimental study to match the self-reflections with the actual performance of critical thinking skills.

The second limitation for the initial survey (Chapter 4) is that the instrument was not validated by academics which may lack a comprehensive conceptualisation of the critical thinking standards and elements adopted from Paul-Elder framework. This limitation was considered in the interviews conducted in the following studies.

Third, the initial survey only focused on the first part of the Paul-Elder critical thinking framework which was the intellectual standards. However, this limitation was considered in the later versions of the instrument that was designed to measure the perceived level of critical thinking by also including statements to assess the critical thinking elements.

8.6.2 Limitations in the Supervisors' and Academics' Interviews

The interviews were conducted to ascertain the views of supervisors regarding the instrument that was designed to measure critical thinking in research projects and regarding the use of digital mBCIs to foster the critical thinking skills of students.

However, there is a limitation for the first interviews with supervisors (Chapter 4) that the interviews were mainly focused on the supervisors from the Computer Science and Human-computer Interaction fields. This may have caused to miss some of the theoretical aspects of critical thinking. Therefore, this limitation was considered in the second interviews with the academics which involved interviews with more academics from different fields, including Computer Science and Human-computer Interaction; such as Education, eLearnig and Psychology.

In first interviews, the process of validating the instrument was unclear, accordingly, the seconds interviews included a clear and concise process for validating the instrument as discussed in Chapter 4.

8.6.3 Limitations in the Pilot Study

The pilot study was performed to examine the use of intervention components to improve the perceived critical thinking skills (POCT) of students in the context of research projects. However, there were a number of limitations in the pilot study.

A potential weakness of this study was the lack of using a standardised test to assess critical thinking. In the pilot study, self-reflections (POCT) were the only inputs considered when evaluating improvements in critical thinking, which may have resulted in subjective assessments, as addressed by Alnuaim et al. (2016). Therefore, including assessments by supervisors was involved to provide a multiple-assessment approach for critical thinking in the next study. The supervisors' assessments were used to assess critical thinking skills in the participants' research reports submitted at the end of the study. Other critical thinking assessments could have been used in this research. However, the available standardised tests (i.e. Cornell, California, Halpern) were developed to measure critical thinking in a course-based or everyday settings, but not for research projects context. A potential solution is to use multiple assessments in the form of self-reflections, standardised test and qualitative evaluation. Then, fair comparisons between the perceived improvement of students' critical thinking with the results of a standardised test and the qualitative evaluation would be possible.

The pilot study lacked a control group, which should be included in any human-computer interaction study, to control for potential external factors (McLean 2005). Therefore, a control group was included in next experimental study to evaluate whether any observed improvements could be reasonably attributed to the mobile intervention tools.

The participation in this study by students was voluntary. Moreover, the targeted students of this study was only the ECS third-year students who had mandatory research projects to work on during their last undergraduate year. The limited targeted population had possibly led to a reduced number of participants which may have been the reason for a negative impact on statistical power.

The feedback was supported manually by the researcher during the experiment which would have been more effective if the feedback were directly provided by their actual supervisors to be more tailored and personalised feedback. As stated in a meta-analysis conducted by Marzano (1998), feedback is one of the important factors to enhance and support learners' abilities in the educational process. It was also reported that effective feedback could increase the learners' engagement and motivation to improve their learning to improve critical thinking (Dwyer et al. 2012).

The pilot study did not show a clear use of the intervention components with sufficient content and exercises to support critical thinking and research skills. Thus, improvements were made to the methodology of studying the use of mBCIs to promote critical thinking in the following experimental study.

In the following experimental study, academics were also asked to assess the critical thinking skills displayed by participants in the submitted work (research reports and mobile texts). In addition, to avoid the limitations of the pilot study, new intervention components were added and mapped onto suitable learning content designed to support critical thinking and research skills. Moreover, additional datasets were collected for the evaluation of other aspects, such as the level of engagement with the mobile intervention, which was assessed by considering the time spent on the application and the frequency of access according to mobile log files. Engagement was considered in the experimental study to be a key factor when examining the level of DBCI participation (Weston et al. 2015). The next experimental study more carefully designed intervention components that mapped directly to critical thinking standards and the elements of thought, which allowed the evaluation of which specific intervention components were responsible for improvements and which areas of critical thinking were improved. Among the intervention group, it was essential to determine whether there were any correlations between mobile intervention use and improvements in critical thinking.

8.6.4 Limitations in the Experimental Study

The previous studies of this research showed informative results in terms of understanding the use of mBCI to promote critical thinking in the context of research projects. However, in the experimental study, a number of limitations have impacted the outcomes.

The previous studies in this research may lack a comprehensive methods for studying various factors that could potentially affect the outputs of using digital mBCI as discussed in Chapter 6. Alterations have been made to the design of the pilot study to include a more rigorous methodology and to include better tools to accurately evaluate the factors that might affect critical thinking behaviours in research project-based areas when an mBCI is used.

First, due to the limited time available to supervisors during the semester, the researcher was used as a proxy for supervisors during this experiment, providing critical thinking content, feedback, and answer to the students' inquiries. Therefore, generalising the effectiveness of this mBCI is difficult because mBCIs that utilise direct involvement with supervisors might have different outcomes. The attempted identification of a supervisor willing to participate in this experiment for two months failed repeatedly. However, supervisors were willing to assess the participants' work after the experiment was undertaken, which reduced the effects of the researcher's biases and the subjectivity of self-reflections provided by participants with regards to their critical thinking progress. Including objective assessments by supervisors was involved to provide a multiple-assessment approach for critical thinking. The supervisors' assessments were used to assess critical thinking skills in the participants' research reports submitted by the end of the study.

There is a limitation in regards with the reliability of the instrument designed to assess the perceived improvement for critical thinking (POCT). The results showed that the Cronbach's Alpha for scale items at all testing times in the experimental study was (0.32) which shows low reliability. This was also shown for the pilot study, where the total result for the Cronbach's Alpha for scale items at all testing times in the pilot study was (0.56) which also shows low reliability.

Another limitation with regards to the 5-point Likert scale (No = 1, Sometimes = 2, Not sure = 3, Usually = 4, and Always = 5) which was chosen to assess the behaviour of using critical thinking skills during the research projects. Though the pre- and post-intervention surveys have numbers from 1 to 5 were presented next to each item to show the level of the scale for the participants, the 'Not sure' item might not indicate the actual assessment of the critical thinking standards and elements. Therefore, using 'neutral' instead of 'Not sure' would have prevented the limitation of the 'Not sure' item.

Including students from different disciplines might lead to different findings. This study targeted students from ECS because the researcher was more familiar with those topics and areas, making it possible to provide feedback and to better interact with the students in the experiments. Furthermore, this study did not have prior CT trainings which would have an impact on the understanding of the CT and how to be applied on the context of research projects for students.

8.6.5 Implications and Recommendations

This research could provide a basis for instructors, educators and policy makers in education to change undesirable behaviours in university students, not only in the areas of critical thinking and research projects but also in other areas of learning. In fact, many skills necessary for learning, such as teamwork, time management, and attending lectures, could be improved and promoted by offering tested methods and robust tools in the form of mBCIs. Current tools lack the flexibility to support the abilities of intervention builders to design complex interventions, which could be alleviated by using the LifeGuide Toolbox to design interventions. However, this study does not claim that a mBCI could be a replacement for the current methods through which supervisors communicate with their students. Instead, this study suggests that the mBCI could reduce the time spent in unnecessary meetings and, thus, enhance the relationship between supervisors and their students. In addition, using the DBCI can help identify critical thinking weaknesses that require support at early stages, which could be beneficial for supervisors. The present proposed system provides supervisors with the flexibility to design reusable complex interventions, to deliver tailored information to users on a large scale, and to measure and monitor critical thinking progress during research projects. Similarly, the system can be useful for students, allowing them to learn new skills, ask questions, and reflect on their progress throughout their research projects.

Promoting the use of mBCIs in research projects to support critical thinking can be achieved by encouraging both supervisors and students to use tools that facilitate the process of developing and measuring critical thinking skills during research projects. Enabling supervisors to evaluate the learning experiences of their students, through the collection of data when students interact with the system, can help supervisors identify when students require interventions and allow them to identify the necessary supports. Students can benefit from a DBCI by learning what skills they lack and understanding what to expect from their supervisors during the process of conducting their research projects.

8.7 Summary

This chapter presented a discussion of the findings and insights resulting from this study. This chapter provided summaries of the primary phases of this study, examining the use of DBCIs to support critical thinking skills during research projects for university students. The findings from the different experiments performed in this study were integrated and discussed. First, the level of critical thinking skills required during research projects was discussed, as related to relevant studies and to the outcome of this study. Second, a discussion of DBCIs, as techniques to change critical thinking behaviours and to overcome current challenges, was presented. Third, the challenges faced in this study were discussed.

Chapter 9

Conclusions and Future Research

This chapter summarises the findings from the study of the use of digital mobile-based behaviour change interventions (mBCIs) to foster the critical thinking skills of university students in the context of research projects. This study was performed to evaluate the feasibility of designing and implementing a digital mBCI to promote critical thinking skills during research projects for university students. This chapter presents an overview of the key findings revealed by this study and discusses the implications of this study and recommendations for future work.

9.1 Research Overview

A review of the literature regarding the tools that have been designed to support critical thinking demonstrated that these tools lack the flexibility to allow people with minimal programming backgrounds to design reusable intervention components to promote certain critical thinking skills (Chapter 2). In fact, the available web- and mobile-based tools that support critical thinking skills were designed to serve a one-size-fits-all model. In addition, the existing tools were not specifically designed to promote the critical thinking skills of students in the context of research projects; therefore, they may utilize inaccurate instruments to assess critical thinking skills in this context. The existing research demonstrated a lack of knowledge and limited evaluation methods for examining critical thinking as a behaviour, which requires the evaluation of noticeable patterns that can be monitored and changed over time with proper and timely interventions, as has been proposed in this study.

The existing tools and methods that support critical thinking skills were designed without considering the nature of critical thinking as a behaviour, which requires regular supervision and constant, tailored, individual support to promote positive changes. The existing technological frameworks also lack the richness that is provided by the adopted

Paul-Elder Critical Thinking Framework when assessing and improving critical thinking skills in research project-based work. In this study, an extended version of the existing and well-tested LifeGuide Toolbox software was used. This software was designed to facilitate the design of reusable digital mobile- or web-based interventions to change behaviours. The combination of the Paul-Elder Critical Thinking Framework and the LifeGuide Toolbox software could potentially succeed at improving the critical thinking skills of students in the context of research projects. This study attempted to support critical thinking skills in research projects through the use of a digital mBCI, which was approached through the development of specific research questions and an appropriate methodology for evaluating the effectiveness of the mBCI, as described in the following sections.

This study focused on university students, who are required to engage with various research projects under academic supervision during the course of their studies. For research projects, critical thinking represents an essential targeted skill that students are required to acquire and apply. This study aimed to design a digital mBCI to promote critical thinking skills for these students and to evaluate the impact of the mBCI on the development of critical thinking skills, divided into the following three phases.

The aims of the first phase were to create and validate an instrument for measuring the perceived critical thinking skills in the context of research projects and to identify which intervention components within the mBCI were necessary to support critical thinking. Interviews with supervisors were undertaken to achieve the goals of this phase. The supervisors encouraged the use of both the designed instrument and the designed intervention components, as discussed in Chapter 4.

The aims of the second phase were to develop and implement a mBCI to support the critical thinking skills of third-year students during two months of their research project period. A pilot study was conducted to assess the usability of the intervention components. The instrument was used to assess the perceived critical thinking skills, both before and after the experiment. The primary outcomes demonstrated that students perceived improvements in their critical thinking skills for some of the standards. This phase was detailed in Chapters 5 and 6.

The third phase built upon the findings from the previous studies, and included an experiment comparing two groups to evaluate the effectiveness of the mBCI for the support of critical thinking skills. Improvements to the contents of the intervention components and to the implementation methods were made for this experiment. The results showed that more students in the intervention group than in the control group perceived progress in their critical thinking skills. As discussed in Chapter 7, this experiment included analyses of the interactions with the mBCI and assessments of the work submitted by participants by academics.

9.2 Research Questions

The goal of this study was to evaluate whether a digital mBCI has the potential to measure and enhance the perceived critical thinking skills of university students. To achieve this goal, the following set of research questions (RQs) were proposed and addressed.

RQ1: What are the standards and elements for measuring students' critical thinking in the context of research projects?

The first research question was addressed by designing an instrument to measure critical thinking skills in students in the context of research projects when a mBCI is used (see Chapter 4, RQ1). First, the literature was reviewed to examine how critical thinking has previously been assessed using standardised and non-standardised tests. The Paul-Elder Critical Thinking Framework was adopted for use in the instrument designed to measure critical thinking skills in the current study, which took the form of a survey asking students to self-reflect on their critical thinking standards and research skills. This instrument was used during the first phase of this study and was further validated by interviewing academics and supervisors from various fields. As described, the instrument assessed nine intellectual standards, including clarity, accuracy, precision, relevance, significance, depth, breadth, logic, and fairness, and eight elements of thought, including purpose, questions, information, inferences, concepts, assumptions, point of view, and implications. After being validated, the instrument was used in the remaining stages of this study to measure the critical thinking skills of participants, including the initial survey (see Chapter 4), the pilot study and the final mBCI experiment (see Chapters 5 and 6).

RQ2: What are the tools and techniques for using a digital mBCI to promote critical thinking skills in students?

To address this question, the existing tools and techniques used to promote critical thinking skills were reviewed. In addition, supervisors were interviewed to understand their expectations for an mBCI to support critical thinking skills, using semi-structured interviews to allow supervisors to specify technical methods for using digital mBCIs to promote the critical thinking skills of students. Together, these steps led to the development of the intervention components, which were project information, activities, tasks, goal setting and planner, inquiries and answers, and notifications with feedback (see Chapter 4, RQ2).

RQ3: What are the technical methods for designing and implementing a digital mBCI for the improvement of critical thinking skills in students?

The third research question was addressed by identifying the principles necessary to design and implement an mBCI to foster the critical thinking skills of students in the context of research projects (see Chapter 5, RQ3). After the initial survey results were analysed, and based on the interviews with supervisors regarding the effectiveness of using an mBCI to foster critical thinking and research skills, the need for such a tool became obvious. Supervisors were convinced that the mBCI could have an impact on the critical thinking skills of students and improve their independent study experiences, in general. To identify the proper implementation protocol for an mBCI, we designed an experimental prototype and performed a pilot study to examine the effectiveness of using the mBCI and to study the usability and utility of the tool.

RQ4: How does a digital mBCI improve the critical thinking skills of students in the context of research projects?

To address this question, a study was conducted comparing two groups (control and intervention), containing thirty participants each, to evaluate the improvements in critical thinking skills over a two-month period with and without the use of the designed mBCI. The experiment examined the usability and impact of the designed mBCI (see Chapter 6), followed by formal assessments of the work submitted by participants by academics.

A mixed-methods approach, using pre- and post-intervention surveys and semi-structured interviews, was adopted for this study to address the four research questions. Based on the analyses of the data gathered from both supervisors and students, the mBCI was deemed to be useful and helpful for promoting the critical thinking skills of students in the context of research projects. The current study incorporates existing literature regarding critical thinking definitions, measurements of critical thinking skills and the relationship between critical thinking and digital interventions. The findings of the current study are in accordance with relevant studies that indicate a need for a practical digital intervention tool to enhance the critical thinking skills of students. The results of this study indicate that using the mBCI improved students' perceptions of their abilities to perform critical thinking skills.

9.3 Research Contributions

This study provides the following contributions to the body of knowledge.

The first contribution presented in this thesis is the ability to design and validate an instrument to measure the perceived critical thinking skills of students in the context of research projects using a mBCI. The instrument was inspired by the Paul-Elder Critical Thinking Framework and was validated and confirmed by research supervisors in interviews. The instrument was used throughout the different phases in this study to measure the critical thinking skills of participants, both before and after the experiments.

The second contribution presented in this thesis was the identification of intervention components to foster critical thinking and research skills when designing digital interventions, which were revealed in interviews with supervisors. The views of supervisors were essential for understanding the different levels of critical thinking skills that students required technological support for. Several faculty members from the University of Southampton, specialising in computer science, education, e-learning, m-earning, and human-computer interaction, were interviewed to obtain insights regarding their experiences using technology during research supervision to support the critical thinking skills of students, as well as their requirements for using mBCIs, as proposed in this thesis.

The third contribution presented in this thesis was the development of design principles for the implementation and evaluation of digital mBCIs containing educational content designed to promote the critical thinking skills of students in the context of research projects.

Finally, this thesis contributes to the area of critical thinking by exploring the challenges inherent to designing mBCIs to enhance the learning experience during research projects, for both supervisors and students.

The aim of this study was to determine the impacts of using an mBCI to support the critical thinking skills of third-year students during research projects. The study examined the students' perceived abilities to use critical thinking skills (POCT), both before and after the intervention. The mBCI contained intervention components designed to support the critical thinking behaviour of students, such as working on research activities and tasks, answering short questionnaires, organising the work using plans and goals, and receiving notifications containing feedback and answers to the users' inquiries. Students received notifications containing tailored information and targeted advice. To the best of my knowledge, there is no generic framework that uses a digital mBCI to support the critical thinking skills of students in the context of research projects. As such, there remains a need to provide supervisors with an authoring tool that can be used to design and deploy digital interventions for their students in the context of higher education research projects. An authoring tool could help intervention creators, i.e., the supervisors, develop digital interventions in different contexts for a wide range of users. Students can receive supportive assistance for their critical thinking skills through digital mBCIs whenever necessary, regardless of time or place, which could be a cost-effective method of facilitating communications between supervisors and students. Using the existing LifeGuide Toolbox framework to create mBCIs to assist critical thinking skills has much potential for success. The LifeGuide Toolbox software package consists of an authoring tool that enables intervention builders with minimal programming background to easily create digital interventions. As a result, the tool could be widely used by a number of researchers and scientists and can provide them the necessary data regarding the critical thinking behaviours of students during research projects.

9.4 Future Research

The following section details some plans for future research in area of using mBCIs to promote the critical thinking skills of students in the context of research projects based on the findings of this research and the extant research.

A number of suggestions are recommended as future work to conduct further research in the use of digital behaviour change interventions to improve and support critical thinking skills. The two main areas suggested for further research with regards to the use of mBCI to enhance critical thinking are (1) the development and implementation of mBCI tools and (2) the factors of the study design based on the studies conducted in this research.

For mBCI development, an auto-notification system for nudges, utilizing machine learning techniques, is recommended to be be added, and users could be provided and delivered with the opportunity to specify their notification preferences according to time and location. As argued by a number of researchers (Morrison et al. 2018) that using auto-notifications could help to avoid disruption when using digital intervention. The use of machine learning (ML) techniques help to find the best time and locations to notify with prober content. The use of machine learning to improve the digital interventions was addressed by Yardley et al. (2016) and Michie et al. (2017). There are many approaches to use ML in digital intervention, especially for enhancing critical thinking for learners Nappi and Cuocolo (2018). For example, algorithms can be used to analyse the inputs (texts, ratings, answers, locations, voices) inserted by users in the mobile or web platform. The outputs of the analysis can be used to intervene in the proper time when necessary. This could be also used to deliver the best content to users based on the inputs provided. The effects of these techniques and algorithms can be tested and compared for the best use for critical thinking in the different stages of research projects. Nappi and Cuocolo (2018) has addressed the importance of using ML for predicting the different situations of critical thinking in the medical field. The use of ML can help to make the use of intervention components to be interactive when used by users. Accordingly, there any many ways to study the effect of the notification in mBCI when compared with the manual notification. For instance, difference groups can be used to study the different responses to the different types of notification during the research projects.

The web-based interventions are also recommended for further research to be supported by mBCIs for both learners and instructors. The use of web-based interventions has been introduced in previous studies (Weston et al. 2015; Williams et al. 2013) and showed significant results in changing undesirable behaviours. Based on the current findings, a web-based dashboard that allows supervisors to monitor their students' progress in the mBCI will be added. The authoring tool will be empowered to allow graphical visualisations to be linked to the dashboard, allowing supervisors to create and monitor the users' interactions with the mBCI. Improvements to the current LifeGuide Toolbox will be implemented to make it more suitable for educational purposes (Yardley et al. 2016; Asiri et al. 2018). Another reasonable suggestion in terms of the web-based intervention is study the effect of the integration of digital mBCIs with other online learning platforms, such as Massive Open Online Courses (MOOCs) can lead to a potential success. It has been addressed by Wilde and Zaluska (2016) that behaviours need to supported in the MOOCs platforms. Thus, DBCIs in such systems allow the learning process to be tracked using material available online, with collaboration between students or between students and their instructors or supervisors, and studying disengagement behaviours as it is a common obstacle in eLearning platforms. The importance of including critical thinking evaluations in MOCCS courses was addressed by Poce (2015). Also, the study of the impact of the web-based intervention on critical thinking can be compared with the impact of the mobile-based intervention (Asiri et al. 2020). Another feasible recommendation is to further investigate and determine how to develop a system that provides open access to a digital intervention bank; which is known as the digital intervention repositories (Michie et al. 2017), for critical thinking or other educational behaviours should be addressed.

For the study design, it is suggested that different disciplines could be included to extend the implications of the study as recommended by (Dos Santos and Cechinel 2019). Moreover, students at different levels, such as masters' students, can be recruited for experimental studies. Including more types of students may require experiments to focus on specific standards, elements or components, rather than supporting all of them (Al-Mubaid and Bettayeb 2017). Future studies may include only specific stages of the research projects (e.g., methodology stage or data analysis stage) to draw more precise conclusions. Furthermore, it is suggested to investigate the dispositions towards critical thinking in eLearning (Dwyer and Walsh 2019). Supervisors will be potentially engaged during the next experiments to examine differences in their approaches to critical thinking based on their actual engagement (Asiri et al. 2019, 2018). However, this task may be difficult to achieve because of supervisors' busy schedules.

The two main areas (development and study design) mentioned above, during future studies, to increase the potential usefulness of the system, more evaluations of the prototype mBCI will be performed to assess the usability and utility of the tools. These assessments will involve the collection of data from users through the use of questionnaires and interviews. Automatically logged data and data gathered from the users before, during and after using the intervention will be analysed and evaluated, in addition to the contributions made by intervention supervisors. These future studies will aim to determine the benefits of mBCIs for the promotion of critical thinking and to further evaluate the mBCI design. All future analyses and results will be compared with previous studies to investigate how and why they might differ, enabling the evaluation of whether the use of mBCIs in critical thinking increases the success rate of achieving behaviour changes and how to make these changes more sustainable and positive. Analysing this data will allow a complete model for mBCIs to be built, which can be used when combining mBCIs and critical thinking, and will yield useful information regarding the future design aspects of these features. The findings from the data analysis and evaluation will be used in conjunction with published and peer-reviewed work to propose guidelines for the use of mBCIs in critical thinking. This will be a first-of-its-kind attempt to describe the details of mBCIs based on various criteria, such as the conditions being addressed by the intervention, the targeted users, and the duration of support.

9.5 Summary

This chapter summarised the findings from the study of the use of digital mobile-based behaviour change interventions (mBCIs) to foster the critical thinking skills of students in the context of research projects. This study was performed to evaluate the feasibility of designing and implementing a digital mBCI to promote critical thinking skills during research projects for university students. This chapter presented an overview of the key findings revealed by this study and discusses the implications of this study and recommendations for future work.

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Appendix A

Initial Online Survey: Email Invitation for Participation and Participant Information Sheet

A.1 Email Invitation for Participation in An initial Survey Study for Undergraduate Students

Hello,

My name is Yousef Asiri. I am a PhD student in Web Science and Internet. My supervisors are Mark Weal and Dave Millard. I have a study to conduct with undergraduate ECS students. It's basically an online questionnaire to explore the level of critical thinking and research skills for the undergraduate students. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 19224). There will be a chance to win one of two £50 amazon.co.uk vouchers as an appreciation for your time. Here is the link to the pre online questionnaire.

It takes 10 minutes to complete it: https://www.isurvey.soton.ac.uk/21357

For those who are willing to participate in the experiment after that with the mobile application for iPhone and Android users, please leave your email at the end of the questionnaire.

Best,

Yousef.

A.2 Participant Information Sheet for Participation in An initial Survey Study for Undergraduate Students

Study Title: Using Mobile Technology to Promote Student's Critical Thinking and Research Skills

Ethics number: 19224

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile technology to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK.

Why have I been chosen?

This study focuses on understanding student's thoughts towards critical thinking and mobile technology, and you are invited to participate as student because your opinion will help to gain better understanding.

What will happen to me if I take part?

You will find an online questionnaire that will take about 10 minutes to complete.

Are there any benefits in my taking part?

This research is not designed to help you personally, but your feedback as a user will help me to gather useful information for my research. However, after completing the questionnaire, if you wish you will be entered in a prize draw, where you have the opportunity to win one of two £50 amazon.co.uk vouchers as an appreciation for your time. If you wish to take part, you will need to provide your email address at the end of the study. This will be kept separately to the answers to your questions so there will be no way of linking your email address to your answers and you will be contacted by email if you win.

Are there any risks involved?

No.

Will my participation be confidential?

Yes. Your information will be stored and used on secure systems and will be used for the purpose of this study only, your responses are voluntary, and will not be linked to your username. All responses will be compiled and analyzed together.

What happens if I change my mind?

You have the right to terminate your participation in the research at any stage, you do not need to give any reasons, and without your legal rights being affected. Your data will be automatically deleted directly if you decide to withdraw at any time.

What happens if something goes wrong?

In the unlikely case of concern or complaint, please contact Research Governance Manager (02380 595058, rgoinfo@soton.ac.uk).

Where can I get more information?

For further details, please contact either myself (yaa1e15@soton.ac.uk) or my study supervisors, Dr Mark Weal (mjw@ecs.soton.ac.uk) and Dr David Millard (dem@ecs.soto.ac.uk).

A.3 The Online Survey

iSurvey

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Accessibility toolbar

Using Mobile Technology to Promote Student's Critical Thinking and Research Skills

Welcome!

Thank you very much for your interest in taking this questionnaire, I appreciate your time and valuable participation, **it should take about 10 minutes**.

This survey seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile technology to promote critical thinking in research work could be an effective tool to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK (Ethics number: 19224)

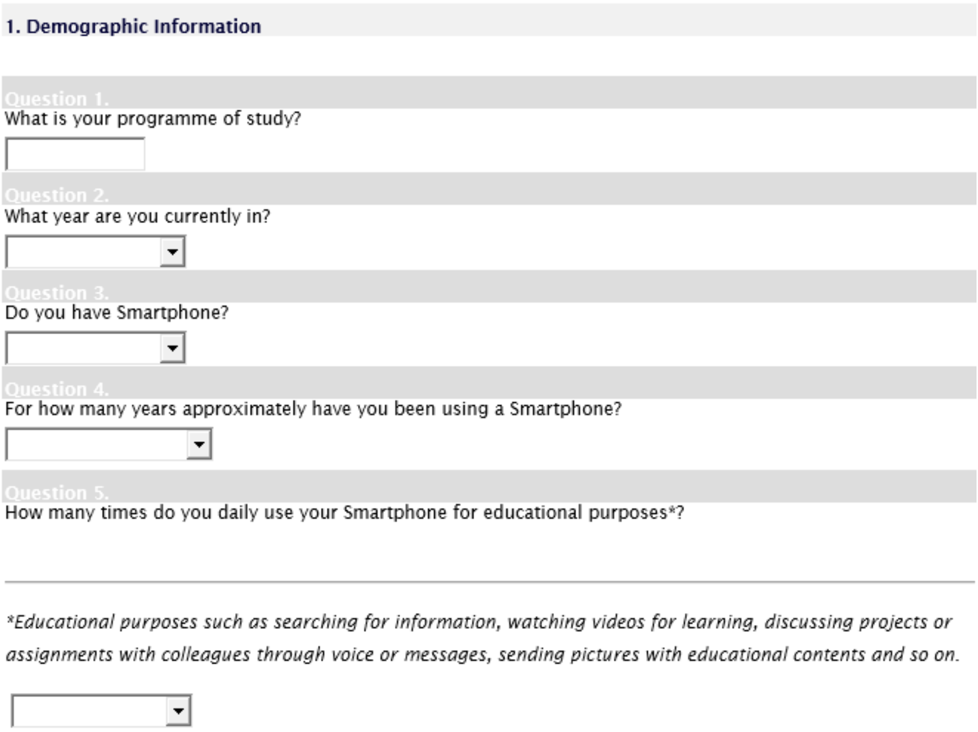
If you wish, ***you will be entered in a prize draw***, where you have the opportunity to win one of **two £50** amazon.co.uk vouchers as an appreciation for your time. If you wish to take part you will need to provide your email address at the end of the study. This will be kept separate from the answers to your questions so there will be no way of linking your email address to your answers and you will be contacted by email if you win.

Participant Information Sheet is available from this link: https://drive.google.com/file/d/0B4WPjxV-42nmajlVSkFWVUVZbkk/view?usp=sharing

☐ Please tick (check) this box to indicate that you consent to taking part in this survey

Click here to start this survey

FIGURE A.1: Consent Form for Participation in An initial Survey Study for Undergraduate Students



1. Demographic Information

Question 1.
What is your programme of study?

Question 2.
What year are you currently in?

Question 3.
Do you have Smartphone?

Question 4.
For how many years approximately have you been using a Smartphone?

Question 5.
How many times do you daily use your Smartphone for educational purposes*?

**Educational purposes such as searching for information, watching videos for learning, discussing projects or assignments with colleagues through voice or messages, sending pictures with educational contents and so on.*

FIGURE A.2: Questions about the Participants' Level of Study and Usage of Mobile Phone

2. Critical Thinking and Research Skills: Clarity, Accuracy, Precision, Significance, Relevance, Depth, Logic and Fairness

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	No	Sometimes	Not sure	Usually	Yes
Clarity: My writing is clear and the meaning is obvious and I am able to communicate what I want to say in a variety of ways.					
Accuracy: I think about evidence before I present my ideas, and When I examine an idea I tend to falsify it in order to prove it holds.					
Precision: I am aware of the different contexts when I think about any situation in order to be able to be precise in my life.					
Relevance: I give relevant examples when I think about a certain problem and I am mostly able to see the relevance between the different parts of my research work.					
Depth: I think deeply to understand any problem by focusing on the concepts by not following the same previous strategies that I normally do to solve any problem.					
Breadth: I tend to find new solutions with new ways when I think by broadly considering different point of views.					
Logic: I know what logical fallacies are and accordingly I give reasonable explanations when I present my ideas.					
Significance: In my analysis I always consider both positive and negative results.					
Fairness: I am aware in my work that I may have hidden biases and I often criticise myself.					

Figure A.3: Statements on Attitudes Based on the Nine Intellectual Standards

3. Feedback on Helpful Strategies and Technology and Educational Models

Question 1.

To what extent do you agree or disagree with the following statements?

	No	Sometimes	Not sure	Usually	Yes
Collaboration: I prefer to collaborate with others in research work and I find it easy to communicate with experts.	○	○	○	○	○
Feedback: I get useful feedback from lecturers or supervisors who I work with on my research work.	○	○	○	○	○
Technology: Mobile technology could be helpful to communicate faster with others for my research work.	○	○	○	○	○
Visualization: I used to draw my work to visualize the whole process which is a good way to keep my work organized and tracked.	○	○	○	○	○
Research Projects: I get lost in the middle of the research process while I am trying to solve a problem.	○	○	○	○	○
Peers Assessment: I tend to get my research work reviewed by peers.	○	○	○	○	○
Experiments: I test some of my own ideas by running some small experiments.	○	○	○	○	○
Self -Reflection: I can rely on my self-assessment for my research projects.	○	○	○	○	○
Supervision: I get sufficient time to discuss my work with the lecturer/supervisor	○	○	○	○	○
Reflective Journals: I mostly write reflective journals while I do my projects.	○	○	○	○	○
Direct Instructions: It's helpful for me to follow direct instructions to do what I am supposed to do.	○	○	○	○	○

Figure A.4: Statements on Research Activities and Technology and Educational Models

4. Research Projects' Activities

Question 1.

The most difficult parts in research work are:

(Place in order)

- -- Finding the topic
- -- Communicating with others
- -- Going through the literature review
- -- Doing the experiment
- -- Collecting data
- -- Analysis part
- -- Evaluation
- -- Writing the conclusion

Question 2.

I improve my weakness in research by

(Tick all that apply)

- Asking experts
- Doing more projects
- Reading about new techniques
- I am not sure what to do

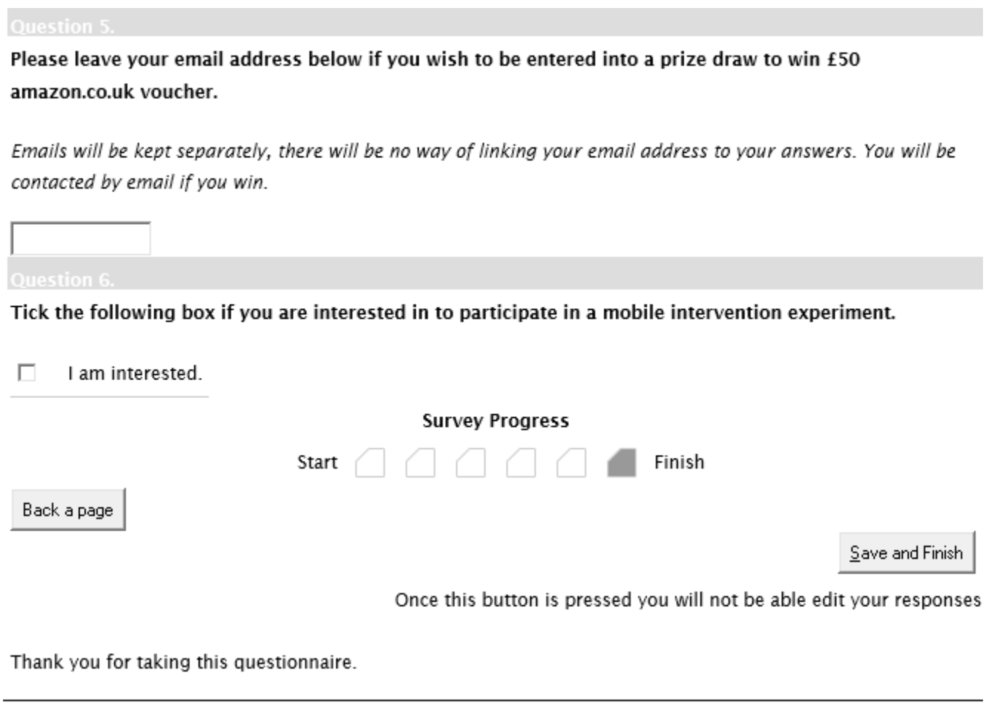
Question 3.

For my research work, I prefer to contact my supervisor via

(Tick all that apply)

- Face-to-face
- Emails
- Skype
- Instant messages like SMS, Telegram or WhatsApp

FIGURE A.5: Questions about the Research Skills and Ways of Communication with Supervisors



Question 5.

Please leave your email address below if you wish to be entered into a prize draw to win £50 amazon.co.uk voucher.

Emails will be kept separately, there will be no way of linking your email address to your answers. You will be contacted by email if you win.

Question 6.

Tick the following box if you are interested in to participate in a mobile intervention experiment.

☐ I am interested.

Survey Progress

Start Finish

Back a page

Save and Finish

Once this button is pressed you will not be able edit your responses

Thank you for taking this questionnaire.

Figure A.6: Intention for Participation in Further Studies

Appendix B

Supervisors' Interviews: Email Invitation, Participant Information Sheet, Consent Form and Interviews Guide

B.1 Email Invitation for the Participation in An Interview with Supervisors

Hello,

My name is Yousef Asiri. I am a PhD student in Computer Science department in University of Southampton. My supervisors are Dr Mark Weal and Dr David Millard. My research focus is to explore how to use mobile intervention to foster critical thinking and research skills among university students and their supervisors. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 19224).

I am emailing you to see if I can have a 30-45 minute meeting with you to discuss the main issues about students' critical thinking skills while they are doing their research projects. We already developed a software tool, which is part of the LifeGuide project that facilitates the interventions to promote critical thinking and research skills for students.

Questions in the meeting:

- What are the possible ways to measure critical thinking skills?
- In your experience, what are the most effective strategies you tried to promote students' critical thinking?

- Have you used web or mobile technology to help students in their critical thinking and their research work?
- What are the advantages and disadvantages? What are students strong and weak at in terms of critical thinking skills?
- How would you specifically use mobile technology to help students in their critical thinking and research skills?
- Are there any other suggestions to technologically improve the process of teaching critical thinking and research skills for both supervisors and students?
- In your opinion, what are the practical ways to improve the mobile CriticalThinking application that I am using for the experiment? Any suggestions?

Please feel free to pick the best time that suits you.

Best, Yousef.

B.2 Participant Information Sheet for the Participation in An Interview with Supervisors

Study Title: Using Mobile Technology to Promote Student's Critical Thinking and Research Skills

Ethics number: 19224

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile technology to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK.

Why have I been chosen?

This study focuses on understanding supervisors' thoughts towards critical thinking and mobile technology, and you are invited to participate as a supervisor because your opinion will help to gain better understanding.

What will happen to me if I take part?

You will find an online questionnaire that will take about 10 minutes to complete.

Are there any benefits in my taking part?

Your feedback as a supervisor will help me to gather useful information for my research.

Are there any risks involved?

No.

Will my participation be confidential?

Yes. Your information will be stored and used on secure systems and will be used for the purpose of this study only, your responses are voluntary, and will not be linked to your username. All responses will be compiled and analysed together.

What happens if I change my mind?

You have the right to terminate your participation in the research at any stage, you do not need to give any reasons, and without your legal rights being affected. Your data will be automatically deleted directly if you decide to withdraw at any time.

What happens if something goes wrong?

In the unlikely case of concern or complaint, please contact Research Governance Manager (02380 595058, rgoinfo@soton.ac.uk).

Where can I get more information?

For further details, please contact either myself (yaa1e15@soton.ac.uk) or my study supervisors, Dr Mark Weal (mjw@ecs.soton.ac.uk) and Dr David Millard (dem@ecs.soto.ac.uk).

B.3 Consent Form for Participation in An Interview with Supervisors

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CONSENT FORM

Study title: Participation in An Interview with Supervisors

Researcher name: Yousef Asiri
ERGO number: 19224

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet and have had the opportunity to ask questions about the study.	
I agree to take part in this research project and agree for my data to be used for the purpose of this study.	
I understand my participation is voluntary and I may withdraw (at any time) for any reason without my participation rights being affected.	

Name of participant (print name)..

Signature of participant...

Date...

Name of researcher (print name)...

Signature of researcher ....

Date...

Figure B.1: Consent Form for the Participation in An Interview with Supervisors

B.4 Semi-structured Supervisors' Interviews Guide

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Semi-structured Interview Guide (approx. 30-45 minutes)

Interview aim: To generate a deep understanding of how the supervisors improve their students' critical thinking, especially with technology, the motivations for its use, requirements and opinions on its application in research projects.

- What are the possible ways to measure critical thinking skills? What do you think of Paul-Elder critical thinking framework?
- In your experience, what are the most effective strategies you tried to promote students' Critical thinking?
    - Have you used web or mobile behaviour change intervention to help students in their critical thinking and their research work?
    - What are the advantages and disadvantages?
- What are students strong and weak at in terms of critical thinking skills?
- How would you specifically use mobile technology to help students in their critical thinking and research skills?
    - Are there any other suggestions to technologically improve the process of delivering critical thinking and research skills for both supervisors and students? (Brief description about LifeGuide Toolbox)
    - Any other suggestions?
- In your opinion, what are the practical ways to improve the *CriticalThinking* app that I am using for the experiment?

Figure B.2: Questions in the Supervisors' Interviews Guide

B.5 Codes and Labels for Interviews Thematic Analysis

Codes	Code labels	Subcodes	Subcode labels
A1	Definitions of critical thinking		
A2	Digital behavior change interventions (DBCIs)	A2:1	Psychological impact
		A2:2	Planned behaviour
		A2:3	Cost-effective
A3	Mobile intervention components	A3:1	Working on activities
		A3:2	Making plans
		A3:3	Setting goals
A4	LifeGuide Toolbox	A4:1	Notification system
		A4:2	Features of LifeGuide Toolbox
A5	Paul-Elder critical thinking model	A5:1	Nine intellectual standards: clarity, precision, accuracy, depth, breadth, logic, relevance, significance, fairness.
		A5:2	Elements of thoughts: questions, purpose, assumption, implication, point of view, inference, information, concepts.
A6		A5:2	Pre- and post-online surveys
		A5:3	Self-reporting measures
A7	*CriticalThinking* mobile App	A7:1	Implementation and design
		A7:2	Personalisation
		A7:3	Mobility challenges

TABLE B.1: Codes and Labels for Supervisors' Interviews

Appendix C

Pilot Study: Emails Invitations, Participant Information Sheets and Pre and Post-intervention Online Surveys

C.1 Email Invitation for the Participation in A Pilot Study: Mobile App-based Intervention

Hello,

My name is Yousef Asiri. I am a PhD student in Web Science and Internet. My supervisors are Mark Weal and Dave Millard.

I have an experiment to run with third-year ECS students. It's basically a mobile application to help students with their critical thinking skills during their 3rd projects. The study contains pre and post online questionnaire to examine the progress of their skills. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 23503).

There will be a chance to win £15 for each student who takes a part in this experiment at the end of the study. Here is the link to the pre online questionnaire. It takes 5 minutes to complete it: https://www.isurvey.soton.ac.uk/21357

For those who are willing to participate in the experiment with the mobile application for iPhone and Android users, please leave your email at the end of the questionnaire."

Best, Yousef.

C.2 Participant Information Sheets for the Participation in A Pilot Study: Mobile App-based Intervention

Study Title: Mobile Interventions for Fostering Critical Thinking Skills Among University Students and Their Supervisors

Ethics number: 23503

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile intervention to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK.

Why have I been chosen?

This study focuses on understanding student's thoughts towards critical thinking and mobile technology, and you are invited to participate as a 3rd undergraduate student because your opinion will help to gain better understanding.

What will happen to me if I take part?

You will find first pre online questionnaire that will take about five minutes to complete. After that, there will be an experiment to examine the usability of the mobile app. At the end there will be a post online survey to test the critical thinking progress of the users.

Are there any benefits in my taking part?

This research is designed to help you in your critical thinking and research skills while you are doing your third-year project. Moreover, your feedback as a user will help me to gather useful information for my research. After completing the pre and post online questionnaires and the experiment, you will gain £15 at the end. If you wish to take part, you will need to provide your email address at the end of the pre online survey. This will be kept separately to the answers to your questions so there will be no way of linking your email address to your answers and you will be contacted later by email to receive the award.

Are there any risks involved?

No.

Will my participation be confidential?

Yes. Your information will be stored and used on secure systems and will be used for the purpose of this study only, your responses are voluntary, and will not be linked to your username. All responses will be compiled and analysed together.

What happens if I change my mind?

You have the right to terminate your participation in the research at any stage, you do not need to give any reasons, and without your legal rights being affected. Your data will be deleted if you decide to withdraw at any time.

What happens if something goes wrong?

In the unlikely case of concern or complaint, please contact Research Governance Manager (02380 595058, rgoinfo@soton.ac.uk).

Where can I get more information?

For further details, please contact either myself (yaa1e15@soton.ac.uk) or my study supervisors, Dr Mark Weal (mjw@ecs.soton.ac.uk) and Dr David Millard (dem@ecs.soto.ac.uk).

C.3 Follow-up email invitation: Critical Thinking App for Third-year Students (Research Study)

Welcome,

Thanks for participating in the pre-intervention online survey "Mobile Interventions for Fostering Critical Thinking Skills Among University Students and Their Supervisors". In order to complete the study, please download the mobile app and start using it for your third-year research project. You don't have to fill out everything in one day. The mobile app is designed to support you throughout the semester period.

Here are the links. Choose the one for your device:

iPhone (AppStore): https://itunes.apple.com/us/app/criticalthinkingtool/id1163616877

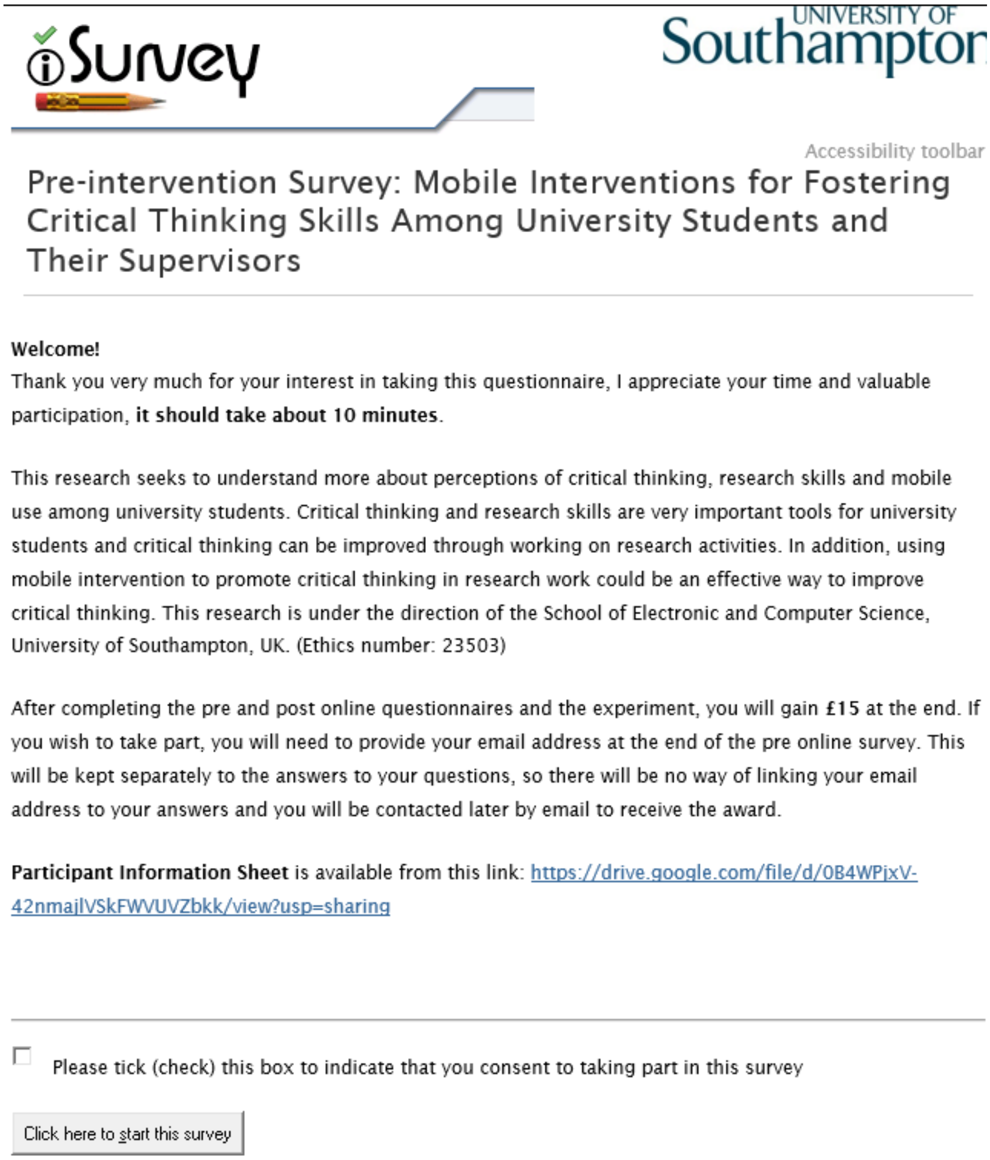
Android (Google Play): https://play.google.com/store/apps/details.criticalthinking

Please don't hesitate to contact me for any help or question.

Thanks again for your participation!

Best, Yousef.

C.4 Pre and Post-intervention Online Surveys the Pilot Study: Mobile App-based Intervention



Pre-intervention Survey: Mobile Interventions for Fostering Critical Thinking Skills Among University Students and Their Supervisors

Welcome!
Thank you very much for your interest in taking this questionnaire, I appreciate your time and valuable participation, **it should take about 10 minutes**.

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile intervention to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 23503)

After completing the pre and post online questionnaires and the experiment, you will gain **£15** at the end. If you wish to take part, you will need to provide your email address at the end of the pre online survey. This will be kept separately to the answers to your questions, so there will be no way of linking your email address to your answers and you will be contacted later by email to receive the award.

Participant Information Sheet is available from this link: https://drive.google.com/file/d/0B4WPjxV-42nmajlVSkFWVUVZbkk/view?usp=sharing

☐ Please tick (check) this box to indicate that you consent to taking part in this survey

Click here to start this survey

FIGURE C.1: Consent Form for the Participation in the Pre-intervention Online Survey and the Mobile Intervention

1. Critical Thinking and Research Skills: Clarity, Accuracy, Precision, Significance, Relevance, Depth, Logic and Fairness

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	Statements	No	Sometimes	Not sure	Usually	Yes
Clarity	My writing is clear and the meaning is obvious					
	I think about the different levels of listeners and the readers when I speak or write.					
Accuracy	I think about evidence before I present my ideas.					
	When I examine an idea, I tend to falsify it in order to prove it holds					
Precision	I am aware of the different contexts when I think about any situation.					
	I am able to be precise in every aspect in my life.					
Relevance	I give relevant examples when I think about a certain problem.					
	I am mostly able to see the relevance between the different parts of my research work.					

FIGURE C.2: Statements in the Pre-intervention Online Survey

Depth	I think deeply to understand any problem by focusing on the concepts.					
	I follow the same previous valid strategies that I normally do to solve any problem.					
Breadth	I tend to find new solutions with new ways when I think.					
	I criticise myself to improve my way of doing things in my daily life.					
Logic	I give reasonable explanations when I present my ideas.					
	I know what logical fallacies are.					
Significance	In my analysis, I always consider both positive and negative results.					
	I worry about insignificant results.					
Fairness	Everything must have a meaning.					
	I am aware in my work that I may have hidden biases.					

Question 2.

Please leave your email address below if you are still interested in to participate in a mobile intervention experiment.

Emails will be kept separately, there will be no way of linking your email address to your answers. You will be contacted by email if you win.

Survey Progress

Start Finish

Back a page

Save and Finish

Once this button is pressed you will not be able edit your responses

Thank you for taking this questionnaire.

FIGURE C.3: Continue for the Statements in the Pre-intervention Online Survey

iSurvey

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Post intervention Survey: Mobile Interventions for Fostering Critical Thinking Skills Among University Students and Their Supervisors

Welcome back!

Thank you very much for your interest in taking this questionnaire after completing the mobile intervention experiment, I appreciate your time and valuable participation, **it should take about 10 minutes**.

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile intervention to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 23503)

After completing the pre and post online questionnaires and the experiment, you will gain **£15** at the end. If you wish to take part, you will need to provide your email address at the end of the pre online survey. This will be kept separately to the answers to your questions, so there will be no way of linking your email address to your answers and you will be contacted later by email to receive the award.

Participant Information Sheet is available from this link: https://drive.google.com/file/d/0B4WPjxV-42nmajlVSkFWVUVZbkk/view?usp=sharing

☐ Please tick (check) this box to indicate that you consent to taking part in this survey

Click here to start this survey

Figure C.4: Consent Form for the Participation in the Post-intervention Online Survey

iSurvey

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Post intervention Survey: Mobile Interventions for Fostering Critical Thinking Skills Among University Students and Their Supervisors

1. Demographic Information

Question 1.

Please provide your email you used in the pre online questionnaire and in the mobile app experiment:

Question 2.

What kind of smartphone did you use in the experiment?

2. Critical Thinking and Research Skills: Clarity, Accuracy, Precision, Significance, Relevance, Depth, Logic and Fairness

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	Statements	No	Sometimes	Not sure	Usually	Yes
Clarity	My writing is clear and the meaning is obvious	○	○	○	○	○
	I think about the different levels of listeners and the readers when I speak or write.	○	◉	○	○	○
Accuracy	I think about evidence before I present my ideas.	○	○	○	○	○

Figure C.5: Statements in the Post-intervention Online Survey

	When I examine an idea, I tend to falsify it in order to prove it holds
Precision	I am aware of the different contexts when I think about any situation.
	I am able to be precise in every aspect in my life.
Relevance	I give relevant examples when I think about a certain problem.
	I am mostly able to see the relevance between the different parts of my research work.
Depth	I think deeply to understand any problem by focusing on the concepts.
	I follow the same previous valid strategies that I normally do to solve any problem.
Breadth	I tend to find new solutions with new ways when I think.
	I criticise myself to improve my way of doing things in my daily life.
Logic	I give reasonable explanations when I present my ideas.
	I know what logical fallacies are.
Significance	In my analysis, I always consider both positive and negative results.
	I worry about insignificant results.
Fairness	Everything must have a meaning.
	I am aware in my work that I may have hidden biases.

Survey Progress

Start Finish

Back a page

Save and Finish

Once this button is pressed you will not be able edit your responses

Thank you for taking this questionnaire.

FIGURE C.6: Continue for the Statements in the Post-intervention Online Survey

Appendix D

Configuration file (JSON file)


```
{
  "applicationName": "CriticalThinking Mobile App",
  "content": [
    {
      "content": {
        "items": [
          {
            "content": {
              "items": [
                {
                  "content": {
                    "questions": [
                      {
                        "choices": [
                          {
                            "choice": "Place each work in the context of its contribu
                          },
                          {
                            "choice": "Describe the relationship of each work to the 
                          },
                          {
                            "choice": "Identify new ways to interpret prior research.
                          }
                        ],
                        "question_id": "1",
                        "text": "The purpose of a literature review is to:",
                        "title": "Literature Review",
                        "type": "multiple-choice"
                      }
                    ]
                  },
                  "id": "First Activity ",
                  "label": "First Activity ",
                  "type": "survey"
                }
              ]
            },
            "id": "Activities",
            "label": "Activities",
            "type": "menu"
          },
          {
            "content": {
              "questions": [
                {
```

FIGURE D.1: An Example of The JSON file Generated by LifeGuide Toolbox Authoring Tool

Appendix E

Activities with Supportive Information for Critical Thinking and Research Skills

E.1 First Activity: What's their point? Identifying arguments

Learning outcomes: This activity has the following objectives for student learning:

- Identify the key parts of an argument.
- Develop strategies for identifying point of views, conclusions and arguments within a message.
- Identify simple arguments.

Estimation time to complete the activity: 7-10 minutes

E.1.1 Critical Thinking Skills will be gained

Depth: This pertains to the comprehensiveness of the argument. It allows students to explore the argument on a deep level. The argument is deemed to have depth when the argument includes all factors necessary to make the point. Questions to be considered include: How does your answer solve the difficulties in the question? How are you considering the problems in the question? Is that dealing with the most important factors?

Breadth: In this skill, the student takes into consideration the additional viewpoints present. Are all perspectives considered and discussed? The argument is deemed extensive when all sides of the argument are deliberated. Questions to be considered include:

Do we need to consider another point of view aside from the present one? Is there another way of looking at this question? What would it be? What would this look like from a conservative standpoint?

Logic: This deems that the argument is sensible, the thinking done throughout the argument analysis is consistent, and the conclusions are based on solid evidence. When something makes sense throughout the process, then it is rational. Questions to be considered include: Does this really make sense? Does that follow from what you said? How so? How can both be true when you implied this but you said that?

In this sense, critical thinking concentrates on 'argument'. This activity focuses on identifying the definition of 'argument' within critical thinking norms and its key features. You will be able to efficiently use your time and resources in looking for the significant or most appropriate material to be used in reading and/or writing if you know how to identify the main argument. Remember that the activities may ask you to make judgements about the arguments. However, none will ask whether you agree or disagree with them. With critical thinking in mind, this activity is focused on assessing the arguments in terms of the value of their formal features, such as the quality of the reasoning. Whether you support the opinion or not, does not matter for this skill. Good critical thinking includes identifying good arguments, even when you disagree with them, and identifying poor arguments, even when they support your position. Enumerated below are a few short passages to help you practise critical thinking skills.

E.1.1.1 The author's position

When we read, watch television or listen to people talking, we are presented with other people's opinions. Viewpoints or 'positions' are conveyed in those opinions.

Example: (1) We should increase prison sentences for crime Increasing prison sentences isn't helpful.

Overall argument:

Longer prison sentences should be introduced. (1)

Increasing prison sentences is not the way to stop crime. (2)

Contributing arguments:

Heavy punishments deter criminals. Current penalties for crime are too lenient and don't deter criminals. Since prison sentences were reduced, crime has increased. Victims need to see that perpetrators of crimes are punished. Crime was high even when punishments were more weighty. Prison teaches people how to be more skilled as criminals. Criminals who are imprisoned are more likely to take part in increasingly serious crime when released. Most crime is committed by people who are illiterate and lack work-related skills. Education rather than punishment is needed

Note how the positions of the authors relate to the overall arguments opposite. Key terms: Argument The word 'argument' is used in two ways in critical thinking. First, contributing arguments: Individual reasons are referred to as 'arguments' or 'contributing arguments'. Seocnd, the overall argument: This is composed of contributing arguments, or reasons. The overall argument presents the author's position. The term 'line of reasoning' is used to refer to a set of reasons, or contributing arguments, structured to support the overall argument.

Activities: Capturing the author's position

Read through the following passages and identify the author's stance:

- Skim over each passage. Note your first impressions with the goal of capturing the author's stance (the main message of the passage).
- Follow up by thorough reading to check whether you were right or wrong. This will give you an impression of how precisely you capture a message when speed reading.

Passage 1.1 Barristers do not have much direct contact with their clients, but it is possible to find a legal job that suits your preferences for court work. However, if an aspiring barrister wants to spend time in court, they need to select their field carefully, to see if the work patterns associated with it match their preferences. Every field is different. Criminal lawyers may spend most of their time in court. Tax lawyers, on the other hand, may spend only a day a month or less in court. Advocacy work requires less time in court than in the office.

Passage 1.2 The nature and origin of disease was unclear until relatively recently. At the end of the nineteenth century, Koch, a Prussian scientist, introduced a set of procedures now known as Koch's postulates. He experimented with bacterial colonies cultivated in the laboratory, made from the blood of dying cattle. When these cultures were injected into healthy live cattle, these also caught the same disease. At the time, these findings were astonishing. Koch had been able to provide proof to support the theory that disease was spread by germs. He contributed one of the most important methodological advances in the history of medicine.

Passage 1.3 The Sahara is a region worthy of serious investigation by travellers interested in the past. Ancient architectures are no doubt hidden beneath the Saharan sands. Somewhere in the eastern Sahara, there may lie the long-lost oasis of Zerzura. In the west, there lies the fabled city.

Critical Thinking Tasks in Research Projects:

Read the introduction and conclusion of three articles related to your subject.

1. What are the titles of these three papers and where have they been published?
2. How well does the introduction present the author's position: is it logical what the author is trying to persuade you to accept?
3. How well does the conclusion make clear what the author's position is?
4. Can you capture the arguments that the authors provided?
5. Do you think the arguments considered all the perspectives? How? Which of these three papers are holding deep or simple arguments? Why?

E.1.1.2 What's their point? Identifying arguments

Argument: Persuasion through reasons

In our daily communications, an 'argument' can suggest a poor message, a difficult relationship, hard feelings and, possibly, aggression. This is not the case with arguments in the context of critical thinking. In critical thinking, an 'argument' simply refers to the stated reasons in support of a position. If other people accept the presented reasons, they are more likely to be persuaded to your point of view.

An argument includes:

- the position or point of view;
- an attempt to convince others to agree with the position;
- reasons presented in support of the position.

To identify an argument, it is useful to keep in mind such questions as:

- What was the point of discussing this subject?
- What is the main message it is trying to convey?
- What does the author/producer want me to believe, accept or do?
- What reasons have been presented to support this argument?

In most cases, because authors believe in what they are saying, they also convince their audience to believe that position as well. However, sometimes, they may have an evident or a hidden agenda behind their persuasion. It may be that they are rivals with a different school of thought. It may be that they are part of a company that is trying to sell a product or service. Authors may also deliberately or inadvertently interpret information through their own political, religious or ideological views to make an argument invalid. In this case, you must be vigilant in identifying the position of the author in terms of these perspectives to know whether their line of reasoning is biased or not.

Activities: Identifying simple arguments

Read through the passages. Identify which are arguments, and which are not. If you are unsure, re-order the sentences to see if that helps you identify a conclusion and supporting reasons.

Passage 1.4 I like that picture. The colours create the powerful effect of a sunset, which is pleasant to look at. The figures are interesting and very well drawn. It is a good picture.

Passage 1.5 The Biscuits can be bad for your teeth. We often eat and mid-morning when the effects of breakfast have worn off. Biscuit companies, like other food manufacturers, require their employees to wear hats to hold back their hair for health and safety reasons.

Passage 1.6 Quantum physics has identified many more dimensions than height, width, depth and time, which most people are familiar with. Such research can take a long time. Discoveries have also been made on other aspects of the time-space continuum.

Passage 1.7 The Pied Piper played a magical pipe and the side of the mountain opened. He encouraged the children from the town to enter into the mountain, which closed behind them so they were lost forever. Their parents never saw them again and he intended this to be the case. The Pied Piper was angry at the townspeople because they refused to pay him for removing rats from the town. His action wasn't accidental; it was one of revenge.

E.2 Second Activity: How well do they say it? Clarity, consistency and structure

Learning outcomes: This activity allows you to:

- check the clarity and internal consistency of the argument;
- identify accuracy, precision, and logical consistency;
- determine if the argument is in logical order.

Estimation time to complete the activity: 10-15 minutes

Critical Thinking Skills:

Clarity: This skill forces thinking to be explained well so that it is easily comprehended. Thinking is deemed to be clear when it is easy to understand. Questions targeting clarity include: Could you expound on that point? Could you express it in another way? Could you give me a scenario related to it? Clarity is the gateway standard. If a statement is unclear, we cannot identify its accuracy and relevance to the argument.

Accuracy: This skill ensures the correctness and flawlessness of the information. Accuracy is present if the thinking is reliable. Questions targeting accuracy include: Is the argument true? How could we check if it is truthful? A statement can be clear, but it might not accurate. An example would be as follows: Most dogs are over 300 pounds in weight.

Precision: This skill is a step beyond accuracy. Precision demands exactness from the words and data being used. Being precise means that no more details can be added because everything is already included. Questions targeting precision include: Could you give more specifics regarding this? Could you be more specific? A statement can both be clear and accurate but not precise. Example: Jack is overweight. We don't know by how many pounds Jack is overweight. It could be by one pound or 30 pounds.

This activity examines how clear, consistent and logical the arguments are constructed. Using joint and independent reasons, interim conclusions and logical order, you will be able to look at the depth of the argument in terms of its structure as a line of reasoning. By understanding the structure of the argument, you will be able to focus reading, improve understanding by knowing the relation of one part of the argument to another, and apply these skills to create your own arguments, which can be used for your essays, reports and other needed requirements.

E.2.0.1 How clear is the author's position?

Clarity matters in good argument construction. Sometimes, an author can present thought-provoking information, but their position is lost in the details. If the author's position is clear, then the audience may fully grasp the message being conveyed and follow the argument through to the end. In a good argument, the author's position will be obvious through:

- the introduction;
- the final sentences;
- the conclusion;
- the overall line of reasoning;
- an overall summary of the argument;
- the presented facts.

Activity

Read the following passages. For each one, consider this: What makes the author's position clear or unclear?

Passage 2.1 The elephant is five times larger than that of humans. Some people elephants are very intelligent but, even if that were true, are they really five times brighter than human? But maybe we are looking at the wrong way. After all, is it fair to compare the brain size of a large animal with that of a small creature? Perhaps it is relative size that matters? Human brains weigh as much as 2.5 per cent of body weight whereas elephants' brains are less than half of a per cent of their total body weight. Proportionally the brain of a human is 10 times greater than that of an elephant. Maybe it is the ratio of brain to body size that matters? If that were the case, then the shrew, with its heavier brain, would be brighter than humans and elephants and yet shrews do little more than eat.

Passage 2.2 This report researched whether a new sports centre should be constructed in region X. Market research suggests that there is little popular demand for another sports centre in the area. However, very few people in the region use sports facilities to improve their health. The government is trying to encourage more personal responsibility for health and fitness. A sports centre would be useful in promoting this objective. People in the area are not aware of health issues and are not interested in sport. be government subsidies available. There may government subsidies available.

Critical Thinking Tasks in Research Projects

Find a paper which criticises another paper in your area/topic.

1. How clear and accurate the arguments are in the paper?
2. Are ideas connected with each other? How?
3. To what extent the data used in the paper is reliable?
4. Why do you agree (or disagree) with criticism in the paper?
5. What would you add or change to the criticism to make the argument in the paper more precise?
6. How would write about both papers in your literature review section?

E.2.0.2 Internal consistency: Clarity and internal consistency

One important part of presenting a clear authorial position is creating a consistent argument. All aspects regarding the line of reasoning should focus on contributing to the conclusion. Nothing should contradict or undermine the main message presented in the passage. When inconsistencies are present, the argument can be hard to follow, making the audience uncertain about what the author is trying to sway them to believe.

Example 1 Apples are good for your teeth. Acid corrodes. Apples can't be good for teeth because they consist mainly of acid. In this message, internal inconsistencies are present. The reader is left wondering whether or not apples are good your teeth. The inclusion of the opposing arguments in a strong line of reasoning will usually consider the alternative points of view, including those that may seem to contradict the main argument. A good argument handles such contradictions by clarifying the position it wants the audience to take throughout the line of reasoning presented. With alternative points of view present, you can show countering arguments to show why the alternative viewpoint is less convincing. This, in turn, would show that the main point of the argument is true.

Example 2 Apples are better for your teeth than refined sugar snacks. Some people argue that apples contain acid and that acid damages tooth enamel. However, any food, if left on the teeth, is bad for them. Refined sugars are particularly damaging to teeth. Compared with the sugary snacks most people eat, apples provide a more beneficial alternative and have long been recommended by dentists. Here, internal consistency is present in the argument: apples are better for your teeth than refined sugar products. All the reasons stated support the argument. The opposing view (that acids corrode teeth) is included, but its importance is minimized or negated by presenting a factual statement: However, any food, if left on the teeth, is bad for them. Take note that the main argument is strong partly because it is worded in a more cautious way, making it easier to defend. It is easier to argue that something is more beneficial than something else than it is to argue that something is detrimental or too support absolute statements like "Apples are good". This is because absolute statements may always not be true in every circumstance.

Precision

Example 2 shows that arguments may need to be worded in a precise manner. One of the common causes of inconsistency is imprecise wording. Take the case of Example 1 compared with Example 2. Apples are good for your teeth and have long been recommended by dentists. It may seem strange that this is the case in Example 2, given that, in Example 1, it is stated that apples consist of acid and acid corrodes enamel. However, if you investigate thoroughly, the acid is relatively harmless to teeth. Also, apples are more beneficial than alternative snacks made of refined sugar, such as sweets and cakes. Here, the argument is relatively well-structured and is more consistent than in Example 1. But it is still not a consistent argument. The author's opening statement is: 'Apples are good for your teeth.' Looking further, by the end of the argument, the author mentions that the acid is 'relatively harmless' and that 'apples are more beneficial than alternative snacks. An argument about relative benefits is not the same as an argument about absolute benefits, so there is internal inconsistency.

Activity

Read through the following passages. Identify whether each is: A. consistent, or B. inconsistent, and why. For the inconsistent passages, consider how you could adapt them to make them consistent.

Passage 2.3 All drugs which enhance performance should be banned from sport as they confer an unfair advantage on those who take them. Anyone caught taking them should be automatically banned from national and international competition. Sports people who take such drugs are not acting in the spirit of fair competition. On the other hand, if someone needs drugs on medical grounds, they should be allowed to compete as they did not intend to cheat.

Passage 2.4 Trainers should discourage sports people from taking performance enhancement drugs as these can have serious effects upon their health. Some of these drugs have resulted in distorted body shapes, skin conditions, and increased aggression. The long-term effects of some of these drugs are unknown. On the other hand, some individuals with conditions such as asthma need medication which contains those drugs. For them, taking the drugs may be more beneficial than not taking them. Therefore, it would be wrong to ban performance enhancement drugs altogether.

E.2.0.3 Logical consistency

In clear and consistent arguments, the reasons should support the conclusion drawn by the author. When evaluating an argument, be sure to check whether the reasons given support the conclusion. The argument should add up to all the reasons and the conclusion. In doing this, logical consistency is being checked. Sometimes, authors lose track of their own arguments and draw a conclusion that is not in accordance with the given reasons. Sometimes, the reasons are not good enough to support the argument. Thus, the audience may see the thin line between logical and illogical reasoning.

For Example 1, consider why the reason does not support the conclusion:

Example 1 There was a murder near the station last night. There are always young lads hanging around there. One of them probably did it. The local council should ban young people from hanging around the station. In Example 1, the conclusion is that young people should banned from hanging around the station. The reason given to support the conclusion is that one set of young people is often found near a station where a murder took place. This reason does not support the conclusion because not one piece of evidence shows that those young people did commit murder. Even if they did do it, then the other young people could do the same. Therefore, a nationwide ban on young people would prevent future murders. This is just partly a question of lack of evidence. There is also faulty reasoning, as the conclusion does not follow through from the reasons presented. An alternative conclusion might have been that, if the young people were in the area when the murder took place, they might have seen or heard something that would help solve the case.

For Example 2, see if you can identify the conclusion and the reasons given to support it before reading on.

Example 2 Behaviour at schools in rural areas is better than at inner city schools. Children brought up in the country have more responsibility for contributing to the family livelihood and care for vulnerable animals. This fosters a more mature attitude and a respect for life in general. Children in inner city schools often have more material possessions but value them less. They show less respect for parents and teachers. Children from the cities should be sent to school in rural schools. This would lead to more children who are respectful and well behaved. The conclusion is presented in the last two lines: if children were sent from city to country schools, there would be an improvement in both their attitude and behaviour. The main reason given is that better behaviours and attitudes are seen in children residing in rural areas. However, the alleged better behaviour of children in the countryside is attributed to how they are at home, not to the schools themselves. As city children would not have such responsibilities simply by going to rural school, it does not follow logically that moving children from one school to another would lead to a change in their behaviour. The reasons given in the example provide better grounds for an alternative conclusion: the behaviour of city children might improve if they were given more responsibilities.

Activity: Logical consistency

Read through the following passages. Decide whether or not each is logically consistent. Give your reasons.

Passage 2.5 The deepest parts of the oceans are known the abyssal zone. The bathyl zone, which that part of the abyssal zone found on the continental shelf is too deep even for light to penetrate. Despite this absolute darkness, animal life still thrives there. Humans form part f the animal kingdom. As animals survive in the bathyl zone, this proves that we do not need light in order to survive. (B inconsistent A consistent)

Passage 2.6 Accidents happen on building sites when workers don't take sufficient care of health and fety. Many employees are lax in following health and safety guidance. This means that there will be a rise in accidents on building sites over the next year. (B inconsistent A consistent)

Passage 2.7 Although subjects such as sports, media and popular culture involve theoretical understanding of the application of scientific principles, these subjects often have lower status at universities and with the public than subjects such history and the classics, which are less intellectually demanding. This is partly because the former subjects attract more students from working-class backgrounds. Students who take these subjects go on to earn less than those who take more traditional subjects. This perpetuates working- class people in lower-income jobs. Therefore, working-class students should be encouraged to take traditional subjects, such as history.

E.3 Third Activity: How can you substantiate this? Looking for and assessing sources of evidence

Learning outcomes: This activity allows you to

- recognize what are primary and secondary sources;
- know the meaning of a literature search;
- know the concepts being applied to research evidence.

Estimation time to complete the activity: 7-10 minutes

Critical Thinking Skills:

Significance: This skill allows you to take into account of the most important ideas. When making a point, it is important to include the important facts of an argument. There is importance when everything essential is included in an argument.

Relevance Every important part of the argument gives a significant impact to the whole picture. If an argument is focused on what needs to be said, there is Relevance. Questions to be considered: How can that be related to the question? What is its impact to the issue?

Fairness: This implies that the argument is balanced. No bias or no side is favoured in the argument. This skill provides an opportunity for assessing the impartiality and even-handedness towards the standpoint of the author. The argument is said to be unbiased when it has objectivity. Questions to be considered: Am I favouring one side in this issue? Am I representing both sides fairly to others?

In evaluating an argument, one does not need to be an expert in the subject matter. What matters is that one is knowledgeable of the facts. There are many cases where we still have to evaluate whether the reasons presented are in accordance with the conclusion and whether the reasoning is presented in an orderly fashion. However, in order to have a successful evaluation of the argument, one has to know whether the evidences provided are truthful. In order to do so, several sources must be referred to. It is important that the majority or all of the sources support the truthfulness of the evidences. In dealing with evidences, it is worth noting that they may be convincing in some situations but not in other scenarios, such as in an everyday conversation or a court of law. For courts of law and for academic or professional writing, greater efforts must be exerted to check whether the evidences are factual.

E.3.1 Relevant and irrelevant evidence

Important evidence is one that gives a good consideration of the issues in the argument. You can place substantiation that backs up the conclusion of the argument, important to the subject and important neither to the conclusion nor the subject. In identifying whether the evidence is important, the main question that should be asked is whether the conclusion will be different without the evidence presented?

Example 1 People need to improve their understanding of how language works so that they can use it more effectively. Research studies (Bloggs, 2003; Bloggs, 2006) show that the study of a foreign language improves our understanding of the structure of language, providing a way of comparing different language structures. Therefore, people who only speak one language should be encouraged to study a second language. In this example, the evidence provided about the benefits of studying a foreign language is connected and important to the conclusion that people who are monolingual are encouraged to be bilingual.

Example 2 People need to improve their understanding of how language works so that they can use it more effectively. Research studies (Bloggs, 2003; Bloggs, 2006) show that many people cannot describe the different components of their own language. A surprising number of people have difficulties remembering the rules even of their mother tongue. Therefore, people who only speak one language should be encouraged to study a second language. In this case, the proof that people are having a hard time in their own language is suggested to not learn a second language. The evidence is important to the debate, but it is not really connected to the argument. More information about the argument should be provided to be in line with the conclusion.

Check

When evaluating an argument check: Is the evidence relevant to the topic? Is it needed to substantiate the reasoning? Does it make a difference to the conclusion? If so, does it support it or contradict it? Is the evidence needed to substantiate interim conclusions?

Activity

For each of the following passages, identify whether the evidence and reasons are relevant to the conclusion. Then read the Commentary opposite.

Passage 3.1 Ice Age Winters are getting colder. Opinion polls show that most people think there is a new lce Age on the way. Therefore, we need to take measures to ensure that fuel resources are managed so that nobody is left to suffer from extreme cold during forthcoming winters.

Passage 3.2 Mr Charlton was given information, in confidence, that the price of shares in MKP2 Oils would rise suddenly if news of the new promotion reached the press before the share price was adjusted. Mr Charlton bought 50,000 shares in MKP2 Oils and leaked news of the promotion to the press. As a result, he made 10 million pounds personal profit. We can conclude that Mr Charlton abused the trust of the company and cheated it financially.

Commentary For Passage 3.1, the first reason, that winters are getting colder, is relevant to the conclusion about managing fuel resources. However, no evidence is given to substantiate this reason. The evidence from polls shows opinions, not facts, and this does not support the conclusion. An opinion is still only an opinion, even if held by a lot of people. The validity of an argument or of evidence does not normally rest on a majority decision For Passage 3.2, all of the evidence given is relevant to the subject and to the conclusion that Mr Charlton abused the trust of the company and cheated it financially. He betrayed a secret to the press so that he could make money at the Company's expense.

Critical Thinking Tasks in Research Projects

1. What makes you think your topic is significant/important?
2. If you had the chance to do your project in a different context, would you do it differently? How?
3. What data you will rely on in your research? Is it reliable?
4. What were the conferences/journals for most of the papers in you are citing in your research? Do you know their impact factors? What the impact factors tell you about them?
5. Do you have any assumptions that your results will be insignificant? Why?
6. What kind of evidence you are using in your research project?

E.3.1.1 Where's the proof? Finding and evaluating sources of evidence

Primary and secondary source materials

The most types of evidence can be divided into primary sources, such as data and documents, and secondary sources, such as books or articles based on primary sources. Primary source materials are first-hand information originating from the exact happenings of events being looked at. These include contemporary letters, documents, prints, painting and photographs newspapers, books and materials published at a specific time, media footage, radio broadcast recordings, remaining body parts and sources of DNA, relics, such as tools, pottery, and furniture, testimonies of witnesses, the raw data from experiments, autobiographies, and internet topics, if based on individual responses to surveys and questionnaires. Secondary sources are those materials written or produced about the event. These are generally based on first-hand experiences. Some examples are books, articles, web pages, documentaries about an event, person or item, interviews with people reporting what they heard from witnesses, biographies, articles in magazines, and papers and reports using the results of surveys, questionnaires and experiments.

Crossing between categories

How long ago an event occurred determines whether or not something is a primary source. Secondary sources sometimes serve as primary sources to others. For example, a biography is normally a secondary source, but when copies of original letters are reproduced, these become primary sources. Magazine articles from the 1990s were secondary sources when published, but these may serve as primary sources of information into the life in 1990s.

Reputable sources This is a source containing credibility. It can be believed with almost a 100% certainty. It probably provides accurate information because it is based on researches conducted, first-hand experiences or knowledge, or recognized expertise in a field or academic discipline. Usually, journal articles are considered the most reputable sources because these must be first reviewed and chosen by other leading academicians, through a process called peer review. A high level of competition is present in publishing journals, so articles that pass academicians' peer reviews are well-known topics. A reputable source in one field may not be so in another because each academic field has their own concepts and agreements. Fields like science and law have facts and figures that serve as the highest forms of evidence. For music and psychology, the highest form of evidence they have can be qualitative proof. But this is not an absolute law, as it can depend on the field, the subject being discussed and available proof.

Activity: Questions to consider

In deciding whether something is worth reading, always take into consideration the following: Has it been suggested by a trusted source, like a reputable company, or has it been peer reviewed? Is the line of reasoning clear? Does it have supporting evidences? Does it have specific references that indicate thorough research has been conducted? Does the source material look trustworthy, like books? Using older sources as authorities usually has a significant impact in a certain study. It is important to check the contribution of the source to the knowledge in the field. Just because something sounds or looks old does not mean it is reliable. Always be sceptical when choosing materials. Find out which ones are still applicable to today's research and gather information about it. Also, identify how the research was used as a source and how the original data have been improved or replaced by modern authorities to see if the source is still influential on the research.

Appendix F

Academics' Interviews: Email Invitation, Participant Information Sheet, Consent Form and Interviews Guide

F.1 Email Invitation for the Participation in An Interview with Academics

Hello,

My name is Yousef Asiri. I am a PhD student in the Computer Science department in the University of Southampton. My supervisors are Dr Mark Weal and Dr David Millard. My research focus is to explore how to use mobile intervention to foster critical thinking skills during the period of research projects among university students and their supervisors. I am working on a research study now to know more about academics' requirements and expectations in using mobile intervention to improve their students' critical thinking skills. I am emailing you to see if I can have a 30-45 minute interview with you in your office to validate an instrument designed to measure critical thinking in research project for students. Also to discuss the main issues about students' critical thinking skills while they are doing their research projects. We already developed a software tool that facilitates the interventions to promote critical thinking and research skills for students. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 30055).

Please feel free to pick the best time that suits you.

Best, Yousef.

F.2 Participant Information Sheet for the Participation in An Interview with Academics

Study Title: Mobile App-based Behaviour Change Intervention to Measure and Promote Critical Thinking and Research Skills Among University Students.

Ethics number: 30055

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This research seeks to to validate an instrument designed to measure critical thinking in research project for students and also to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile technology to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK.

Why have I been chosen?

This study focuses on understanding supervisors' thoughts towards critical thinking and mobile technology, and you are invited to participate as a supervisor because your opinion will help to gain better understanding.

What will happen to me if I take part?

You will find an online questionnaire that will take about 10 minutes to complete.

Are there any benefits in my taking part?

Your feedback as a supervisor will help me to gather useful information for my research.

Are there any risks involved?

No.

Will my participation be confidential?

Yes. Your information will be stored and used on secure systems and will be used for the purpose of this study only, your responses are voluntary, and will not be linked to your username. All responses will be compiled and analysed together.

What happens if I change my mind?

You have the right to terminate your participation in the research at any stage, you do not need to give any reasons, and without your legal rights being affected. Your data will be automatically deleted directly if you decide to withdraw at any time.

What happens if something goes wrong?

In the unlikely case of concern or complaint, please contact Research Governance Manager (02380 595058, rgoinfo@soton.ac.uk). Where can I get more information?

For further details, please contact either myself (yaa1e15@soton.ac.uk) or my study supervisors, Dr Mark Weal (mjw@ecs.soton.ac.uk) and Dr David Millard (dem@ecs.soto.ac.uk).

F.3 Consent form for Participation in An Interview with Supervisors

UNIVERSITY OF Southampton

CONSENT FORM

Study title: Mobile App-based Behaviour Change Intervention to Measure and Promote Critical Thinking and Research Skills among University Students.

Researcher name: Yousef Asiri
ERGO number: 30055

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet and have had the opportunity to ask questions about the study.	
I agree to take part in this research project and agree for my data to be used for the purpose of this study.	
I understand my participation is voluntary and I may withdraw (at any time) for any reason without my participation rights being affected.	

Name of participant (print name)..

Signature of participant..

Date..

Name of researcher (print name)..

Signature of researcher ....

Date..

Figure F.1: Consent Form for the Participation in An Interview with Academics

F.4 Semi-structured Supervisors' Interviews Guide

UNIVERSITY OF Southampton

Semi-structured Interview Guide (approx. 30-45 minutes)

Semi-structured Interview Guide (approx. 45-60 minutes):

Interview aim: To validate the instrument that was designed to measure critical thinking skills in the context of research projects, and to get suggestions and opinions about the intervention components that will be used in the mobile app to implement the digital mobile-based behaviour change intervention technique in critical thinking.

1. The researcher will give a brief description about the study and about the main purpose of the instrument.
2. Supervisor will be asked politely to fill out the survey (instrument) while taking notes about any comment the supervisor make during filling out the survey.
3. After the supervisor finish the survey, discussion about the consistency and the design of the survey and the words used in the survey will be recorded:
    - What do you think of the survey?
    - Does it lead to measure students' critical thinking skills in their research projects?
    - If there are any issues with the survey to reconsider, what are they?
4. Sketches of the mobile *CriticalThinking* app will be shown to the supervisor to see how the intervention components are implemented.
5. Discussion will focus on the intervention components:
    - Information about the student's research project.
    - Goals and plans to improve critical thinking skills for students.
    - Activities to practice Critical thinking skills in the context of students' research projects.
    - Mini quizzes to assess the level of students' critical thinking skills during the study to provide advice and supportive information.
    - Inquiries for students to ask questions and make comments about their skills they need to improve.
    - Notification settings and features in the mobile app.
6. Suggestions and opinions from the supervisor about the intervention components will be recorded.

FIGURE F.2: Questions in the Academics' Interviews Guide

F.5 Codes and Labels for Interviews Thematic Analysis

Codes	Code labels	Subcodes	Subcode labels
A1	Definition of critical thinking	A1:1	Psychological and behavioural impact
A2	Teaching and supporting critical thinking skills	A2:1	Course-based assignment, essays, projects, and planned behaviour theory
A3	Assessment of critical thinking	A3:1	Objective and subjective evaluation
		A3:2	Paper-based assessment and criteria for assessment
A4	Paul-Elder critical thinking model	A4:1	Planning for clarity, precision, accuracy, depth, breadth, logic, relevance, significance , fairness.
		A4:2	Goals for questions, purpose, assumption, implication, point of view, inference, information, concepts.
A5	Research skills for undergraduate students	A5:1	Active learning
		A5:2	Constructivism theory
		A5:3	Problem-based learning
A6	Supervision in research projects	A6:1	Cost-effective, time management, personalisation and setting goals
A7	Digital behaviour change interventions (DBCIs)	A7:1	Implementation and design and notification system
A8	Mobile intervention components	A8:1	Mobility,challenges, Project Information, Activities and Trainings, Practise,Tasks, Short Questionnaires/Polls, Setting Goals and Plans, Notifications for,Engagement, Inquiries and Answers, Feedback and Instructions,Designing,content for the intervention
A9	LifeGuide toolbox software package	A9:1	Authoring to design content for the intervention
A10	Critical Thinking mobile app-based intervention	A10:1	Self-reporting measures
		A10:2	Pre and post surveys for usability and utility

Table F.1: Codes and Labels for Supervisors' Interviews

Appendix G

G. Notification content and Timing for the Mobile Intervention Experiment

	20 Notifications	
	Nudge 1 (10 times)	Nudge 2 (10 times)
Week 1	02-Oct 2017 Welcome to the mobile intervention experiment. This experiment was designed to study how mobile behaviour change intervention could improve students' critical thinking on in their research work. I would like to thank you for accepting to participate in this study. Participation in this mobile intervention will be in the weekdays. No need to use the mobile application in the weekends. It is highly recommended to participant every day during the weekdays from 5-10 minutes. This will help you to know more about critical thinking and to receive important information and relevant advices about critical thinking and research skills. This will also help me as a researcher to collect enough data about your mobile usage and behaviours during the experiment. Please feel free to contact the researcher whenever you encounter any problem: yaa1e15@soton.ac.uk Enjoy the app!	05-Oct 2017 Do you have 5-7 minutes to participate today in the mobile application? Well done on finishing the first three days. I would like to explain more some of the Critical Thinking mobile application features. Activities: Each activity meant to support certain intellectual standards. Spending time to understand those standards will help you to improve your critical thinking skills. Tasks: The tasks are provided to help you to think specifically about your research project. You will be asked to link what you learn in the app with your research topics. Example, "Read the introduction and conclusion of three articles in your subject and answer the following." Inquiries: You can ask questions or provide suggestions on any problem you face in their critical thinking skills. Questions will be answered by the intervention researcher. Now, it is time to discover these features by yourself. Keep up the good work!

Week 2	09-Oct 2017 (Feedback) Do you have 5-7 minutes to go through the feedback provided based on your work on the app? Meanwhile, have you had a look at the first activity to improve your critical thinking skills? It is titled with "What's their point? Identifying arguments". Here is what the first activity can help you with: This activity presents information about how to identify arguments. It helps learners to know the types of arguments with examples. It involves some passages for training and practicing the critical thinking skills that are specified for the activity. This activity focuses on three critical thinking standards: depth, breadth, and logic. At the end of the activity there are tasks to work on based on their research projects. It gives the opportunity to imply the skills you learned into your actual research topic. You can now see what is in the first activity in this application.	12-Oct 2017 Do you have 5-7 minutes to work on your research project by using the help of task 1 in this app? Start by reading the introduction and conclusion of three articles related to your subject, and then try to answer those questions: How well does the introduction present the author's position: is it logical what the author is trying to persuade you to accept? How well does the conclusion make clear what the author's position is? Can you capture the arguments that the authors provided? Keep up the good work!

Week 3	16-Oct 2017 Do you have 5-7 minutes? Have you used the second activity to improve your critical thinking skills? It is titled with “How well do they say it? Clarity, consistency and structure”. Here is what the second activity can help you with: This activity helps learners to understand what it means to be clear, consistent, and structured as skills for critical thinking. Concepts, terms and examples are provided to help learners to understand the activity. This activity focuses on three critical thinking standards: clarity, precision, and accuracy. At the end of the activity there are tasks to work on based on their research project. It gives the opportunity to imply the skills you learned into your actual research topic. You can now see what is in the second activity in this application.	19-Oct 2017 Do you have 5-7 minutes to work on your research project by using the help of task 2 in this app? Find a paper which criticises another paper in your area/topic and try to work on these questions: How clear and accurate the arguments are in the paper? Are ideas connected with each other? How? To what extent the data used in the paper is reliable?

Week 4	23-Oct 2017 (Feedback) Do you have 5-7 minutes to go through the feedback provided based on your work on the app? Meanwhile, have you had a look at the third activity to improve your critical thinking skills? It is titled with “Where’s the proof? Finding and evaluating sources of evidence”. Here is what the third activity can help you with: This activity presents information about how to identify arguments. It helps learners to know the types of arguments with examples. It involves some passages for training and practicing the critical thinking skills that are specified for the activity. This activity focuses on three critical thinking standards: significance, relevance, and fairness. At the end of the activity there are tasks to work on based on your research projects. It gives the opportunity to imply the skills you learned into your actual research topic. You can now see what is in the third activity in this application.	26-Oct 2017 Do you have 5-7 minutes to work on your research project by using the help of task 3 in this app? Task 3 contains these questions to think about them while you are working on your project: What makes you think your topic is significant/important? If you had the chance to do your project in a different context, would you do it differently? How? What data you will rely on in your research? Is it reliable?
Week 5	30-Oct 2017 Do you have 5-7 minutes? project info and goals What? RQs? Why? Hypotheses? How? What to expect? Concepts Questions Purpose Assumptions, point of view Information Implication, inferences	02-Nov 2017 inquiries and short quizzes

Week 6	06-Nov 2017 (Feedback) Thanking for 1st month and encouraging By increasing the time you spent you will be mostly likely to change your behaviours in your critical thinking when you work in your research project. Meanwhile, have you had a look at feedback provided based on your work on the app?	09-Nov 2017 I would like to remind you about some of the Critical Thinking mobile application features. Goals and planning: It is provided in the app to help you set goals and plans for your critical thinking and for your research work. Now, it is time to rediscover these features by yourself. Keep up the good work!
Week 7	13-Nov 2017 Do you have 5-7 minutes? Have you used the first activity to improve your critical thinking skills? It is titled with “What’s their point? Identifying arguments”. Here is what the first activity can help you with: This activity presents information about how to identify arguments. It helps learners to know the types of arguments with examples. It involves some passages for training and practicing the critical thinking skills that are specified for the activity. This activity focuses on three critical thinking standards: depth, breadth, and logic. At the end of the activity there are tasks to work on based on their research projects. It gives the opportunity to imply the skills you learned into your actual research topic. You can now see what is in the first activity in this application.	16-Nov 2017 Do you have 5-7 minutes to work on your research project by using the help of task 1 in this app? Start by reading the introduction and conclusion of three articles related to your subject, and then try to answer those questions: Do you think the arguments considered all the perspectives? How? Which of these three papers are holding deep or simple arguments? Why?

Week	20-Nov 2017 (Feedback)	23-Nov 2017
8	Do you have 5-7 minutes to go through the feedback provided based on your work on the app? Meanwhile, have you had a look at the second activity to improve your critical thinking skills? It is titled with “How well do they say it? Clarity, consistency and structure”. Here is what the second activity can help you with: This activity helps learners to understand what it means to be clear, consistent, and structured as skills for critical thinking. Concepts, terms and examples are provided to help learners to understand the activity. This activity focuses on three critical thinking standards: clarity, precision, and accuracy. At the end of the activity there are tasks to work on based on their research project. It gives the opportunity to imply the skills you learned into your actual research topic. You can now see what is in the second activity in this application.	Do you have 5-7 minutes to work on your research project by using the help of task 2 in this app? Find a paper which criticises another paper in your area/topic and try to work on these questions: Why do you agree (or disagree) with criticism in the paper? What would you add or change to the criticism to make the argument in the paper more precise? How would write about both papers in your literature review section?

Week 9	27-Nov 2017 Do you have 5-7 minutes? Have you used the third activity to improve your critical thinking skills? It is titled with “Where’s the proof? Finding and evaluating sources of evidence”. Here is what the third activity can help you with: This activity presents information about how to identify arguments. It helps learners to know the types of arguments with examples. It involves some passages for training and practicing the critical thinking skills that are specified for the activity. This activity focuses on three critical thinking standards: significance, relevance, and fairness. At the end of the activity there are tasks to work on based on your research projects. It gives the opportunity to imply the skills you learned into your actual research topic. You can now see what is in the third activity in this application.	30-Nov 2017 Do you have 5-7 minutes to work on your research project by using the help of task 3 in this app? Task 3 contains these questions to think about them while you are working on your project: What data you will rely on in your research? Is it reliable? What were the conferences/journals for most of the papers in you are citing in your research? Do you know their impact factors? What the impact factors tell you about them? Do you have any assumptions that your results will be insignificant? Why?
Week 10	04-Dec 2017 (Feedback) Do you have 5-7 minutes to go through the feedback provided based on your work on the app?	07-Dec 2017 Please feel free to ask questions in the inquiries page and try to answer some of the short quizzes.

Appendix H

Experimental Study: Emails Invitations, Participant Information Sheets, Pre and Post-intervention Online and SUS Surveys, and Results Statistical Tests

H.1 Email Invitation for the Participation in an Experimental Study: Mobile App-based Intervention

Hello,

My name is Yousef Asiri. I am a PhD student in the Web Science and Internet group (WAIS). My supervisors are Mark Weal and Dave Millard. I have an experiment to run with third-year ECS students. It's basically a mobile app to help them with their critical thinking and research skills during their 3rd projects. The study contains pre and post online questionnaire to examine the progress of their skills. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 23503). There will be a chance to win £15 for each student who takes part in this experiment at the end of the study. Here is the link to the pre online questionnaire. It takes less than 5 minutes to complete it: https://www.isurvey.soton.ac.uk/24832

For those who are willing to participate in the experiment with the mobile application for iPhone and Android users, please leave your email at the end of the questionnaire (text box is available at the end).

Best, Yousef.

H.2 Participant Information Sheets for the Participation in an Experimental Study: Mobile App-based Intervention

Study Title: Mobile App-based Behaviour Change Intervention to Measure and Promote Critical Thinking and Research Skills Among University Students.

Ethics number: 23503

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile intervention to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK.

Why have I been chosen?

This study focuses on understanding student's thoughts towards critical thinking and mobile technology, and you are invited to participate as a 3rd undergraduate student because your opinion will help to gain better understanding.

What will happen to me if I take part?

You will find first pre online questionnaire that will take about 10 minutes to complete. After that, there will be an experiment to examine the usability of the mobile app. At the end there will be a post online survey to test the critical thinking progress of the users.

Are there any benefits in my taking part?

This research is designed to help you in your critical thinking and research skills while you are doing your third-year project. Moreover, your feedback as a user will help me to gather useful information for my research. After completing the pre and post online questionnaires and the experiment, you will gain £15 at the end. If you wish to take part, you will need to provide your email address at the end of the pre online survey. This will be kept separately to the answers to your questions so there will be no way of linking your email address to your answers and you will be contacted later by email to receive the award.

Are there any risks involved?

No.

Will my participation be confidential?

Yes. Your information will be stored and used on secure systems and will be used for the purpose of this study only, your responses are voluntary, and will not be linked to your username. All responses will be compiled and analysed together.

What happens if I change my mind?

You have the right to terminate your participation in the research at any stage, you do not need to give any reasons, and without your legal rights being affected. Your data will be deleted if you decide to withdraw at any time.

What happens if something goes wrong?

In the unlikely case of concern or complaint, please contact Research Governance Manager (02380 595058, rgoinfo@soton.ac.uk).

Where can I get more information?

For further details, please contact either myself (yaa1e15@soton.ac.uk) or my study supervisors, Dr Mark Weal (mjw@ecs.soton.ac.uk) and Dr David Millard (dem@ecs.soto.ac.uk).

H.3 Follow-up email invitation: Critical Thinking App for Third-year Students (Research Study)

Welcome,

Thanks for participating in the pre-intervention online survey “Mobile App-based Behaviour Change Intervention to Measure and Promote Critical Thinking and Research Skills Among University Students”. In order to complete the study, please download the mobile app and start using it for your third-year research project. You don’t have to fill out everything in one day. The mobile app is designed to support you throughout the semester period.

Here are the links. Choose the one for your device:

iPhone (AppStore): https://itunes.apple.com/us/app/criticalthinkingtool/id1163616877

Android (Google Play): https://play.google.com/store/apps/details.criticalthinking

Please don't hesitate to contact me for any help or question.

Thanks again for your participation!

Best, Yousef.

H.4 Pre and Post-intervention Online Surveys the Pilot Study: Mobile App-based Intervention

iSurvey

UNIVERSITY OF Southampton

Accessibility toolbar

Pre-intervention Survey: Mobile App-based Behaviour Change Intervention to Measure and Promote Critical Thinking and Research Skills Among University Students

Welcome!

Thank you very much for your interest in taking this questionnaire, I appreciate your time and valuable participation, **it should take about 10 minutes**.

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile intervention to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 23503)

After completing the pre and post online questionnaires and the experiment, you will gain **£15** at the end. If you wish to take part, you will need to provide your email address at the end of the pre online survey. This will be kept separately to the answers to your questions, so there will be no way of linking your email address to your answers and you will be contacted later by email to receive the award.

Participant Information Sheet is available from this link: https://drive.google.com/file/d/0B4WPjxV-42nmajlVSkFWVUVZbkk/view?usp=sharing

☐ Please tick (check) this box to indicate that you consent to taking part in this survey

Click here to start this survey

FIGURE H.1: Consent Form for the Participation in the Pre-intervention Online Survey and the Mobile Intervention

1. Critical Thinking and Research Skills: Clarity, Accuracy, Precision, Significance, Relevance, Depth, Logic and Fairness

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	Statements for Intellectual Critical Thinking Standards	No	Sometimes	Not sure	Usually	Yes
Clarity	When I write reports or essays, I express my thinking clearly in different ways and with multiple supporting examples.	○	○	○	○	○
Accuracy	I support my arguments by making sure that all information is correct and free from errors, based on reliable resources	○	○	○	○	○
Precision	In writing, my words and data are specifically exact and no more details could be added to explain what I mean.	○	○	○	○	○
Significance	In my research work, I focus on the most important ideas and crucial facts that would help to make a meaningful point.	○	○	○	○	○
Relevance	In the literature review, everything included is important, each part makes a difference, and accordingly, I connect my arguments to any reliable relevant information.	○	○	○	○	○
Depth	My arguments are thorough, tending to explore the complexities of the research questions, which are addressed profoundly in my answers.	○	○	○	○	○
Breadth	I consider additional perspectives and different viewpoints when I think or write in my research work, to look at the problem from various ways.	○	○	○	○	○
Logic	My arguments are reasonable, such that the thinking is consistent and the conclusions follow from the evidence, where things make sense step-by-step.	○	○	○	○	○

Figure H.2: Statements of Intellectual Standards in the Pre-intervention Online Survey

Fairness	My arguments are balanced, objective and free from hidden biases by considering both positive and negative outcomes.	◌	◌	◌	◌	◌

2. Elements of Thought: Purpose, Questions, Information, Inferences, Concepts, Assumptions, Point of view, and Implications.

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

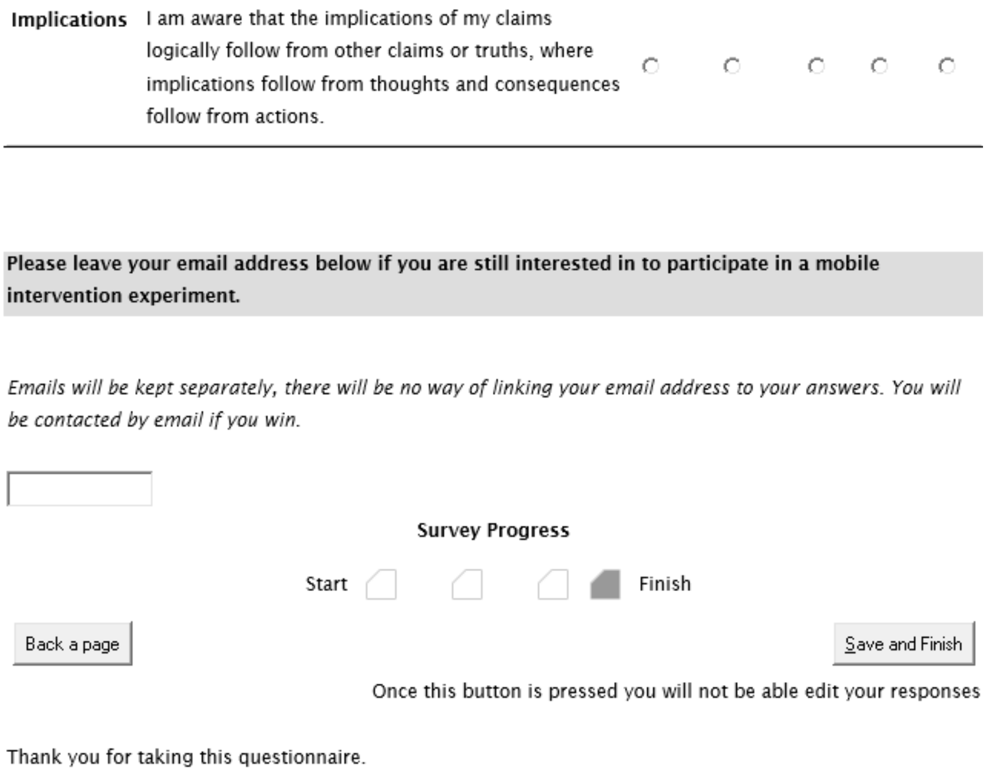
Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	Statements for Elements of Thought	No	Sometimes	Not sure	Usually	Yes
Purpose	I think purposefully when I set my research objectives by trying to determine what the main goal of my work is and why it is important.	◌	◌	◌	◌	◌
Questions	I use my research questions as guidance for my thinking, to figure out how to solve the research problems.	◌	◌	◌	◌	◌
Information	The information I use is correct, accurate and relevant to the purpose and to the questions or issues I am addressing.	◌	◌	◌	◌	◌
Inferences	The inferences and conclusions I make logically follow from the evidence, with no more or less than what is implied in the situation.	◌	◌	◌	◌	◌
Concepts	I justifiably use concepts, ideas, theories, laws, principles, or hypotheses in thinking to make sense of things in my research work.	◌	◌	◌	◌	◌
Assumptions	In assumptions, which are the beliefs I take for granted, either subconsciously or unconsciously, I make sure that they are justified by sound evidence.	◌	◌	◌	◌	◌
Point of view	In my research work, I understand the limitations of my point of view and I fully consider other relevant reasonable viewpoints.	◌	◌	◌	◌	◌

FIGURE H.3: Continue for the Statements of Elements of Thought in the Pre-intervention Online Survey



Implications I am aware that the implications of my claims logically follow from other claims or truths, where implications follow from thoughts and consequences follow from actions.

Please leave your email address below if you are still interested in to participate in a mobile intervention experiment.

Emails will be kept separately, there will be no way of linking your email address to your answers. You will be contacted by email if you win.

Survey Progress

Start Finish

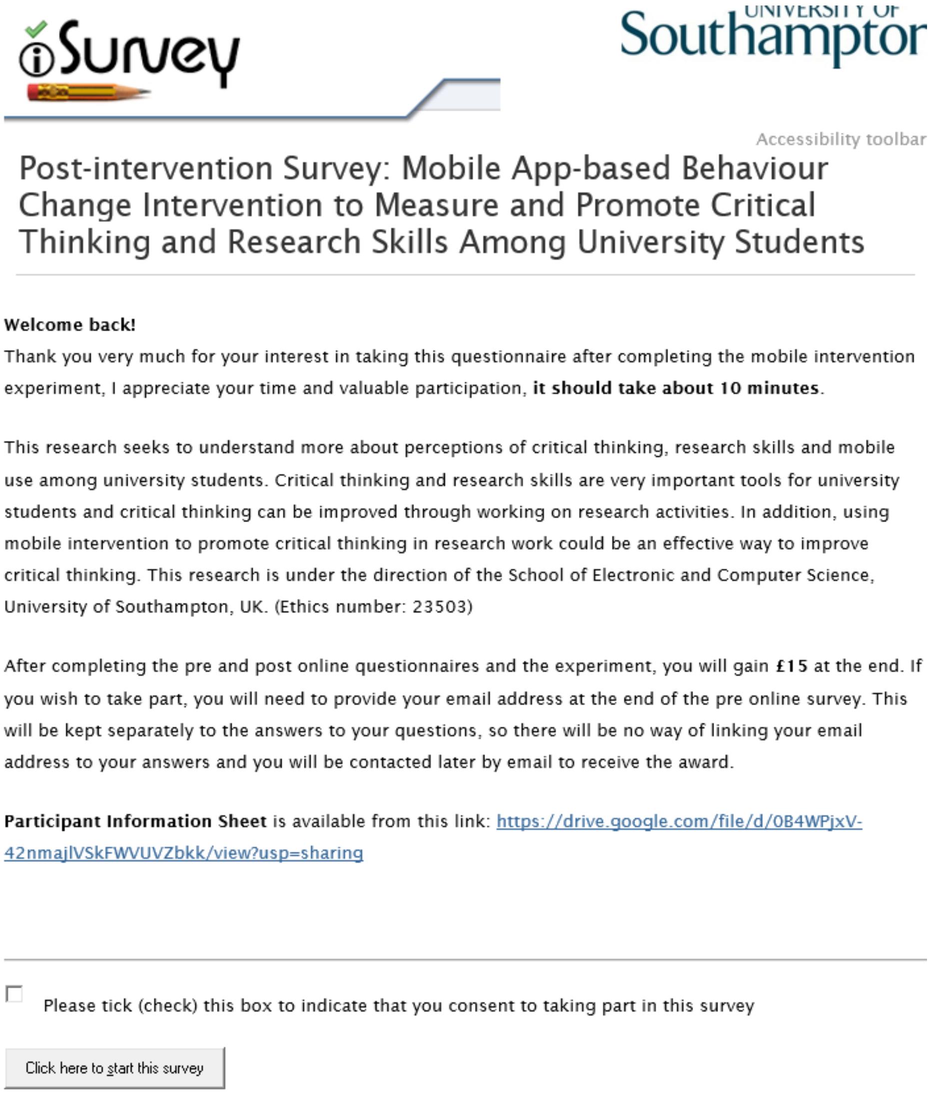
Back a page

Save and Finish

Once this button is pressed you will not be able edit your responses

Thank you for taking this questionnaire.

FIGURE H.4: Continue for the Statements of Elements of Thought in the Pre-intervention Online Survey



iSurvey

UNIVERSITY OF Southampton

Accessibility toolbar

Post-intervention Survey: Mobile App-based Behaviour Change Intervention to Measure and Promote Critical Thinking and Research Skills Among University Students

Welcome back!

Thank you very much for your interest in taking this questionnaire after completing the mobile intervention experiment, I appreciate your time and valuable participation, **it should take about 10 minutes**.

This research seeks to understand more about perceptions of critical thinking, research skills and mobile use among university students. Critical thinking and research skills are very important tools for university students and critical thinking can be improved through working on research activities. In addition, using mobile intervention to promote critical thinking in research work could be an effective way to improve critical thinking. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethics number: 23503)

After completing the pre and post online questionnaires and the experiment, you will gain **£15** at the end. If you wish to take part, you will need to provide your email address at the end of the pre online survey. This will be kept separately to the answers to your questions, so there will be no way of linking your email address to your answers and you will be contacted later by email to receive the award.

Participant Information Sheet is available from this link: https://drive.google.com/file/d/0B4WPjxV-42nmajlVSkFWVUVZbkk/view?usp=sharing

☐ Please tick (check) this box to indicate that you consent to taking part in this survey

Click here to start this survey

Figure H.5: Consent Form for the Participation in the Post-intervention Online Survey

1. Participant's Information

Please provide your email you used in the pre online questionnaire and in the mobile app experiment:

2. Critical Thinking and Research Skills: Clarity, Accuracy, Precision, Significance, Relevance, Depth, Logic and Fairness

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	Statements for Intellectual Critical Thinking Standards	No	Sometimes	Not sure	Usually	Yes
Clarity	When I write reports or essays, I express my thinking clearly in different ways and with multiple supporting examples.	○	○	○	○	○
Accuracy	I support my arguments by making sure that all information is correct and free from errors, based on reliable resources	○	○	○	○	○
Precision	In writing, my words and data are specifically exact and no more details could be added to explain what I mean.	○	○	○	○	○
Significance	In my research work, I focus on the most important ideas and crucial facts that would help to make a meaningful point.	○	○	○	○	○
Relevance	In the literature review, everything included is important, each part makes a difference, and accordingly, I connect my arguments to any reliable relevant information.	○	○	○	○	○
Depth	My arguments are thorough, tending to explore the complexities of the research questions, which are addressed profoundly in my answers.	○	○	○	○	○

Figure H.6: Statements of Intellectual Standards in the Post-intervention Online Survey

Breadth	I consider additional perspectives and different viewpoints when I think or write in my research work, to look at the problem from various ways.	○	○	○	○	○
Logic	My arguments are reasonable, such that the thinking is consistent and the conclusions follow from the evidence, where things make sense step-by-step.	○	○	○	○	○
Fairness	My arguments are balanced, objective and free from hidden biases by considering both positive and negative outcomes.	○	○	○	○	○

2. Elements of Thought: Purpose, Questions, Information, Inferences, Concepts, Assumptions, Point of view, and Implications.

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	Statements for Elements of Thought	No	Sometimes	Not sure	Usually	Yes
Purpose	I think purposefully when I set my research objectives by trying to determine what the main goal of my work is and why it is important.	○	○	○	○	○
Questions	I use my research questions as guidance for my thinking, to figure out how to solve the research problems.	○	○	○	○	○
Information	The information I use is correct, accurate and relevant to the purpose and to the questions or issues I am addressing.	○	○	○	○	○
Inferences	The inferences and conclusions I make logically follow from the evidence, with no more or less than what is implied in the situation.	○	○	○	○	○
Concepts	I justifiably use concepts, ideas, theories, laws, principles, or hypotheses in thinking to make sense of things in my research work.	○	○	○	○	○

FIGURE H.7: Continue for the Statements of the Elements of Thought in the Post-intervention Online Survey

Assumptions	In assumptions, which are the beliefs I take for granted, either subconsciously or unconsciously, I make sure that they are justified by sound evidence.					
Point of view	In my research work, I understand the limitations of my point of view and I fully consider other relevant reasonable viewpoints.					
Implications	I am aware that the implications of my claims logically follow from other claims or truths, where implications follow from thoughts and consequences follow from actions.					

Usability Evaluation

1. Intervention Components: Purpose, Questions, Information, Inferences, Concepts, Assumptions, Point of view, and Implications.

To be able to answer these questions try to think of any research project you might be currently working on, or maybe the last research project you already worked on recently.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	Statements for Intervention Components	No	Sometimes	Not sure	Usually	Yes
Project Information	When I write reports or essays, I express my thinking clearly in different ways and with multiple supporting examples.					
Activities and Trainings	I tend to try thinking about activities or trainings in my mobile device (using any application or web) to improve my critical thinking and research skills.					
Practise Tasks	Working on simple critical thinking tasks (using text editor) in my mobile device helps to improve my critical thinking and research skills for my research work.					

FIGURE H.8: Continue for the Statements of the Intervention Components in the Post-intervention Online Survey

Short Questionnaires	Short questionnaires during the research project period to test the progress of my critical thinking skills helps to self-reflect on my work.	○	○	○	○	○
Setting Goals and Plans	According to my goals and plans written in my mobile device, I succeed to make positive behaviours to improve my critical thinking and research skills.	○	○	○	○	○
Notifications for Engagement	The mobile notifications help me to stay engaged in the mobile application content and therefore to help me to stay engaged in my critical thinking and the research work.	○	○	○	○	○
Inquiries and Answers	Asking questions about my critical thinking skills helps me to improve my research work.	○	○	○	○	○
Feedback and Instructions	Receiving feedback and direct instructions through the mobile application is a fixable way to improve my knowledge and behaviour in critical thinking and research skills.	○	○	○	○	○

2. System Usability Scale (SUS) Test

To be able to answer these questions try to think of mobile application you used in your research project to improve critical thinking skills.

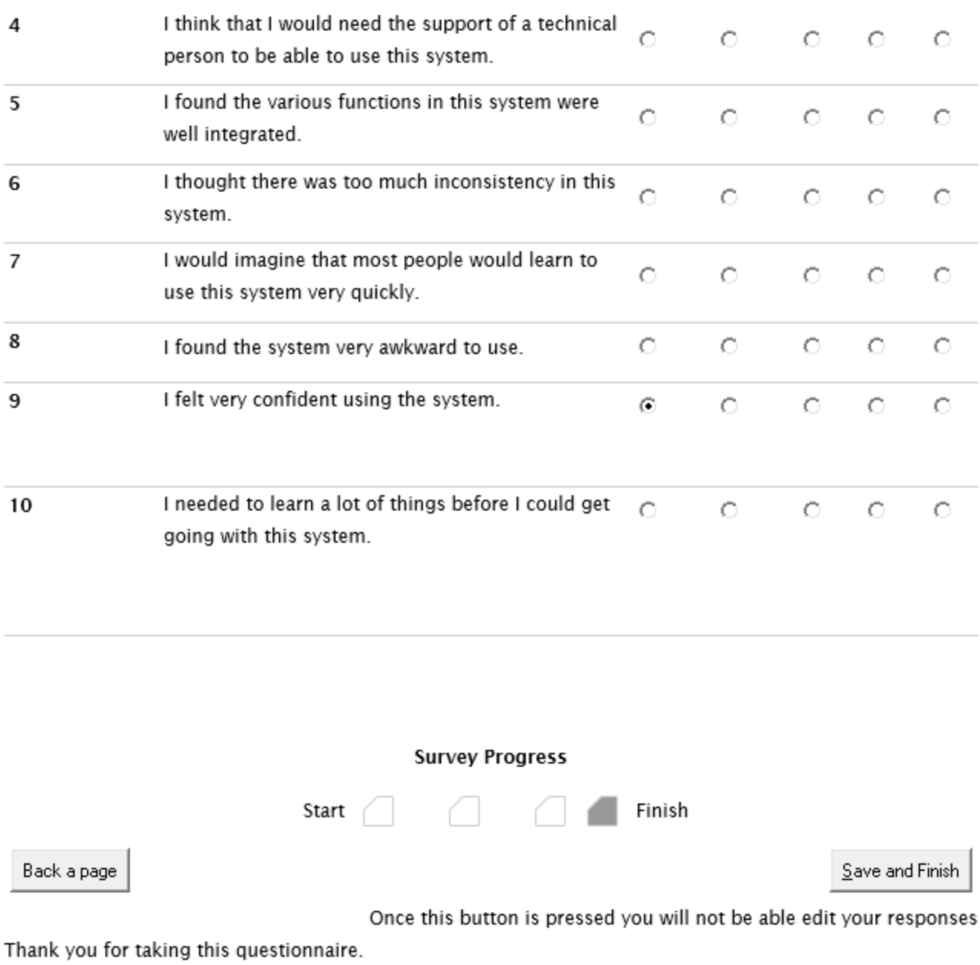
Question 1.

To what extent do you agree or disagree with the following statements?

To be able to make these statements clear for you try to think of any coursework assignment or research project you might be currently working on or you already worked on recently.

	System Usability Scale statements	No	Sometimes	Not sure	Usually	Yes
1	I think that I would like to use this system frequently.	○	○	○	○	○
2	I found the system unnecessarily complex.	○	○	○	○	○
3	I thought the system was easy to use.	○	○	○	○	○

Figure H.9: Continue for the Statements of the System Usability Scale (SUS) Test in the Post-intervention Online Survey



4	I think that I would need the support of a technical person to be able to use this system.	○	○	○	○	○
5	I found the various functions in this system were well integrated.	○	○	○	○	○
6	I thought there was too much inconsistency in this system.	○	○	○	○	○
7	I would imagine that most people would learn to use this system very quickly.	○	○	○	○	○
8	I found the system very awkward to use.	○	○	○	○	○
9	I felt very confident using the system.	◉	○	○	○	○
10	I needed to learn a lot of things before I could get going with this system.	○	○	○	○	○

Survey Progress

Start Finish

Back a page

Save and Finish

Once this button is pressed you will not be able edit your responses

Thank you for taking this questionnaire.

FIGURE H.10: Continue for the Statements of the System Usability Scale (SUS) Test in the Post-intervention Online Survey

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Clarity	Equal variances assumed	.772	.383	-.299	58	.766	-.100	.334	-.770	.570
	Equal variances not assumed			-.299	57.120	.766	-.100	.334	-.770	.570
Accuracy	Equal variances assumed	.028	.868	1.041	58	.302	.333	.320	-.307	.974
	Equal variances not assumed			1.041	57.997	.302	.333	.320	-.307	.974
Precision	Equal variances assumed	.048	.827	-1.106	58	.273	-.333	.301	-.936	.270
	Equal variances not assumed			-1.106	57.996	.273	-.333	.301	-.936	.270
Relevance	Equal variances assumed	.145	.705	-1.547	58	.127	-.500	.323	-1.146	.146
	Equal variances not assumed			-1.547	57.788	.127	-.500	.323	-1.146	.146
Significance	Equal variances assumed	.119	.731	-.904	58	.370	-.300	.332	-.964	.364
	Equal variances not assumed			-.904	57.961	.370	-.300	.332	-.964	.364
Depth	Equal variances assumed	.000	1.000	.469	58	.641	.166	.355	-.544	.877
	Equal variances not assumed			.469	58.000	.641	.166	.355	-.544	.877
Breadth	Equal variances assumed	1.294	.260	-.916	58	.363	-.300	.327	-.955	.355
	Equal variances not assumed			-.916	56.630	.363	-.300	.327	-.955	.355
Logic	Equal variances assumed	.768	.384	-.425	58	.672	-.133	.313	-.761	.494
	Equal variances not assumed			-.425	57.358	.672	-.133	.313	-.761	.494
Fairness	Equal variances assumed	.460	.500	-.649	58	.519	-.200	.308	-.817	.417
	Equal variances not assumed			-.649	57.463	.519	-.200	.308	-.817	.417
Purpose	Equal variances assumed	.034	.853	.412	58	.682	.133	.323	-.514	.781
	Equal variances not assumed			.412	57.990	.682	.133	.323	-.514	.781
Questions	Equal variances assumed	.758	.388	-.909	58	.367	-.300	.330	-.960	.360
	Equal variances not assumed			-.909	56.946	.367	-.300	.330	-.961	.361
Information	Equal variances assumed	.012	.915	-.517	58	.607	-.166	.322	-.812	.479
	Equal variances not assumed			-.517	57.812	.607	-.166	.322	-.812	.479
Inferences	Equal variances assumed	.091	.764	.497	58	.621	.166	.335	-.504	.837
	Equal variances not assumed			.497	57.911	.621	.166	.335	-.504	.837
Concepts	Equal variances assumed	.005	.941	-1.188	58	.240	-.366	.308	-.984	.250
	Equal variances not assumed			-1.188	58.000	.240	-.366	.308	-.984	.250
Assumptions	Equal variances assumed	1.294	.260	-1.465	58	.148	-.433	.295	-1.025	.158
	Equal variances not assumed			-1.465	57.614	.148	-.433	.295	-1.025	.159
Pointofview	Equal variances assumed	.189	.665	-.220	58	.826	-.066	.302	-.671	.538
	Equal variances not assumed			-.220	57.906	.826	-.066	.302	-.671	.538
Implications	Equal variances assumed	.155	.696	-1.071	58	.289	-.333	.311	-.956	.289
	Equal variances not assumed			-1.071	57.639	.289	-.333	.311	-.956	.289

TABLE H.1: Independent t-test for Pre-intervention Surveys for both Groups

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Clarity	Equal variances assumed	3.678	.060	-2.036	58	.046	-.63333	.31104	-1.25594	-.01073
	Equal variances not assumed			-2.036	53.783	.047	-.63333	.31104	-1.25698	-.00969
Accuracy	Equal variances assumed	.001	.969	.544	58	.589	.16667	.30657	-.44700	.78033
	Equal variances not assumed			.544	58.000	.589	.16667	.30657	-.44700	.78033
Precision	Equal variances assumed	.477	.492	-1.071	58	.289	-.33333	.31122	-.95631	.28964
	Equal variances not assumed			-1.071	57.769	.289	-.33333	.31122	-.95636	.28970
Relevance	Equal variances assumed	1.712	.196	-1.785	58	.079	-.53333	.29878	-1.13141	.06475
	Equal variances not assumed			-1.785	56.588	.080	-.53333	.29878	-1.13173	.06507
Significance	Equal variances assumed	.249	.620	-1.056	58	.296	-.36667	.34735	-1.06196	.32863
	Equal variances not assumed			-1.056	57.870	.296	-.36667	.34735	-1.06199	.32866
Depth	Equal variances assumed	.345	.559	-.508	58	.614	-.16667	.32830	-.82382	.49049
	Equal variances not assumed			-.508	57.451	.614	-.16667	.32830	-.82395	.49062
Breadth	Equal variances assumed	.283	.597	-1.456	58	.151	-.46667	.32044	-1.10810	.17476
	Equal variances not assumed			-1.456	57.224	.151	-.46667	.32044	-1.10828	.17495
Logic	Equal variances assumed	.019	.892	-1.416	58	.162	-.46667	.32952	-1.12627	.19294
	Equal variances not assumed			-1.416	57.922	.162	-.46667	.32952	-1.12629	.19295
Fairness	Equal variances assumed	.138	.712	-.215	58	.831	-.06667	.31011	-.68742	.55409
	Equal variances not assumed			-.215	57.975	.831	-.06667	.31011	-.68743	.55409
Purpose	Equal variances assumed	.742	.392	.000	58	1.000	.00000	.32092	-.64239	.64239
	Equal variances not assumed			.000	56.978	1.000	.00000	.32092	-.64263	.64263
Questions	Equal variances assumed	.094	.761	-1.631	58	.108	-.53333	.32707	-1.18803	.12136
	Equal variances not assumed			-1.631	57.704	.108	-.53333	.32707	-1.18810	.12144
Information	Equal variances assumed	.583	.448	.784	58	.436	.26667	.33993	-.41379	.94712
	Equal variances not assumed			.784	57.868	.436	.26667	.33993	-.41382	.94715
Inferences	Equal variances assumed	.551	.461	.201	58	.841	.06667	.33137	-.59665	.72998
	Equal variances not assumed			.201	57.935	.841	.06667	.33137	-.59667	.73000
Concepts	Equal variances assumed	.782	.380	-.734	58	.466	-.23333	.31810	-.87008	.40341
	Equal variances not assumed			-.734	57.489	.466	-.23333	.31810	-.87020	.40353
Assumptions	Equal variances assumed	.011	.918	-.509	58	.613	-.16667	.32736	-.82195	.48862
	Equal variances not assumed			-.509	57.958	.613	-.16667	.32736	-.82196	.48863
Pointofview	Equal variances assumed	.144	.705	-2.321	58	.024	-.73333	.31599	-1.36585	-.10082
	Equal variances not assumed			-2.321	57.869	.024	-.73333	.31599	-1.36588	-.10079
Implications	Equal variances assumed	.601	.441	-.506	58	.615	-.16667	.32946	-.82615	.49282
	Equal variances not assumed			-.506	57.152	.615	-.16667	.32946	-.82636	.49303

TABLE H.2: Independent t-test for Post-intervention Surveys for both Groups

Appendix I

Experts' Assessment for Mobile Texts: Participant Information Sheet and Google Form

I.1 Participant Information Sheet

Study Title: Experts' Assessment for Critical Thinking Skills in Students' Answers.

Ethics number: 46528

You are being invited to take part in the above research study. To help you decide whether you would like to take part or not, it is important that you understand why the research is being done and what it will involve. Please read the information below carefully and ask questions if anything is not clear or you would like more information before you decide to take part in this research. You may like to discuss it with others but it is up to you to decide whether or not to take part. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This study is part of my PhD work. The aim of this study is to formally assess (by experts) the critical thinking skills in the students' answers/texts provided in the mobile application from a previous experiment conducted in 2017 (Ethical approval: 30055) by the same researcher. This study will provide an understanding of whether the critical thinking tasks in mobile application help to enhance critical thinking skills in their research projects for students or not. A Google form will be used to gather data from the participants which will be an assessment in the form of comments/texts and marks/numbers (from 1-5). There are two main sections in Google form. First, anonymous answers for the project information and critical thinking tasks which are the texts provided by the students in the mobile application. Second, an assessing questionnaire with multiple choices to assess the students' work by marking the student's answers (from 1 to 5) based on the 9 critical thinking statements. This research is under the direction of the School of Electronic and Computer Science, University of Southampton, UK. (Ethical approval: 46528).

Why have I been chosen?

This study focuses on understanding the impact of using critical thinking tasks in the mobile application to improve critical thinking for students in their research projects. You are invited to participate as an expert in critical thinking and research projects to review and assess anonymous answers provided by students via mobile application. Your assessment, feedback and opinion will help to gain better understanding for the students' critical thinking. Only two experts are needed to participate individually this study.

What will happen to me if I take part?

A Google form will be used by you as an assessor to evaluate critical thinking in the anonymous answers of 10 students which may take 1 hour or less. The assessment will be in the form of comments/texts and marks/numbers (ratings from 1-5). There are two main sections in the Google form. First, anonymous answers for the critical thinking tasks which are the texts provided by the students in the mobile application. Second, an assessing questionnaire with multiple choices to assess the students' work by marking the student's answers (from 1 to 5) based on the 9 critical thinking statements.

Are there any benefits in my taking part?

Your review and feedback as an expert by assessing critical thinking in the provided answers will help me to gather objective and useful information for my research. This study may also help improve our current understanding of the area using mobile applications to support critical thinking for students in their research projects. Your participation is highly appreciated.

Are there any risks involved?

No.

Will my participation be confidential?

Yes. Your information will be stored and used on secure systems and will be used for the purpose of this study only, your responses are voluntary, and will not be linked to your username. All responses will be compiled and analyzed together. Your participation and the information I collect about you during the course of the research will be kept strictly confidential. Only my supervisor may be given access to data about you for monitoring purposes and/or to carry out an audit of the study to ensure that the research is complying with applicable regulations. Individuals from regulatory authorities (people who check that we are carrying out the study correctly) may require access to your data. All of these people have a duty to keep your information, as a research participant, strictly confidential. The data will be collected are from you are comments/texts and ratings in the assessing questionnaire from 1 (lowest) to 5 (highest) that will be inserted in the Google form. The data will be downloaded and stored on a password protected in my university desktop and can only be accessed by researcher and supervisor. All information provided by participants will be kept confidential by linked anonymity by using random numbers. The data will be destroyed by upon successful completion of the researcher programme (foreseen as the end of the academic year, 2019) by erasure from the hard drive.

What happens if I change my mind?

You have the right to change your mind and withdraw at any time without giving a reason and without your participant rights being affected.

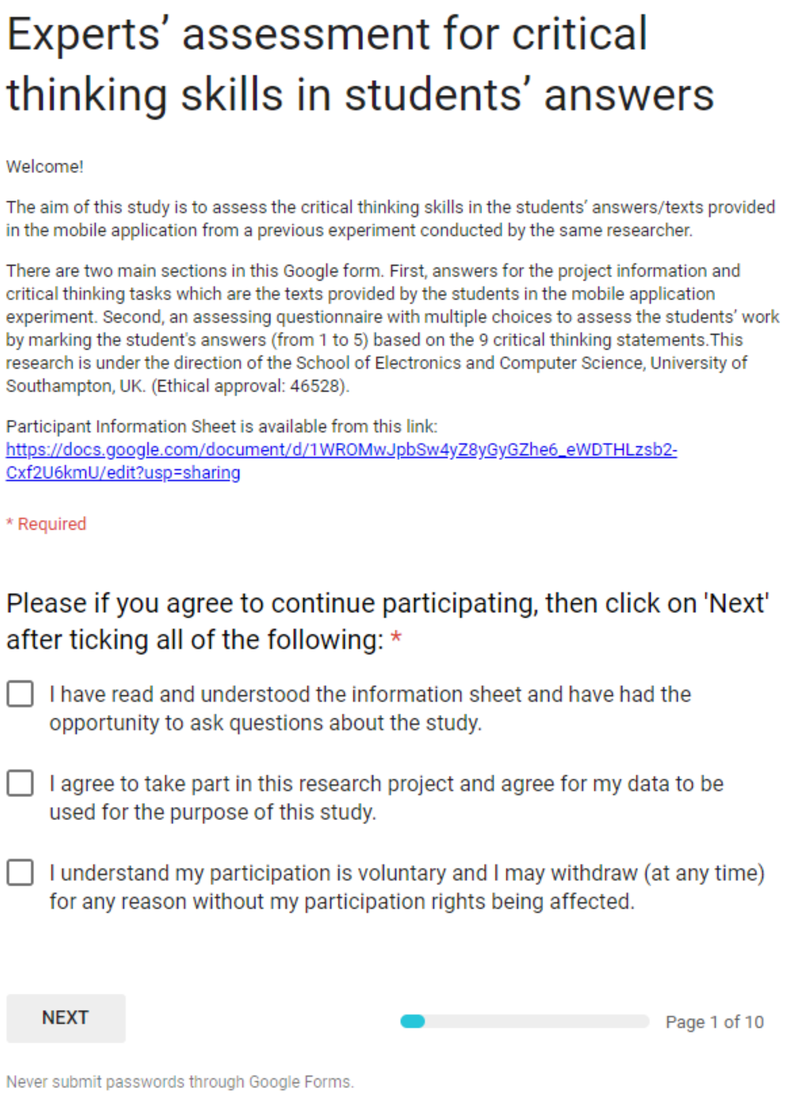
What happens if something goes wrong?

In the unlikely case of concern or complaint, please contact Research Governance Manager (02380 595058, rgoinfo@soton.ac.uk).

Where can I get more information?

For further details, please contact either myself (yaa1e15@soton.ac.uk) or my study supervisors, Dr Mark Weal (mjw@ecs.soton.ac.uk) and Dr David Millard (dem@ecs.soto.ac.uk).

I.2 Google Form: Experts' Assessment for Critical Thinking Skills in Students' Answers



Experts' assessment for critical thinking skills in students' answers

Welcome!

The aim of this study is to assess the critical thinking skills in the students' answers/texts provided in the mobile application from a previous experiment conducted by the same researcher.

There are two main sections in this Google form. First, answers for the project information and critical thinking tasks which are the texts provided by the students in the mobile application experiment. Second, an assessing questionnaire with multiple choices to assess the students' work by marking the student's answers (from 1 to 5) based on the 9 critical thinking statements.This research is under the direction of the School of Electronics and Computer Science, University of Southampton, UK. (Ethical approval: 46528).

Participant Information Sheet is available from this link:
https://docs.google.com/document/d/1WROMwJpbSw4yZ8yGyGZhe6_eWDTHLzsb2-Cxf2U6kmU/edit?usp=sharing

* Required

Please if you agree to continue participating, then click on 'Next' after ticking all of the following: *

- [ ] I have read and understood the information sheet and have had the opportunity to ask questions about the study.
- [ ] I agree to take part in this research project and agree for my data to be used for the purpose of this study.
- [ ] I understand my participation is voluntary and I may withdraw (at any time) for any reason without my participation rights being affected.

NEXT

Page 1 of 10

Never submit passwords through Google Forms.

Figure I.1: Consent Form for the Participation in the Pre-intervention Online Survey and the Mobile Intervention

1. First section: Answers for the student

In this part of the Google form, you will see the anonymous student's answers/texts that were extracted from the mobile application. You will need to read those answers to be able to assess the critical thinking in them based on the questionnaire in the next section of this form. The students' numbers in this form are random which were provided by the researcher to keep the answers of the students anonymous.

(Student number: 001) (The answers for the task 1) (The answers for the task 2) (The answers for the task 3)

2. Second section: Assessing questionnaire

After reading the provided answers above for student number (001), please assess the student's critical thinking by clicking on one choice from 1 (lowest) to 5 (highest) for each statement below.

	Statements for Intellectual Critical Thinking Standards	1 (lowest)	2	3	4	5 (highest)
Clarity	The answers express thinking clearly in different ways with multiple supporting examples.	○	○	○	○	○
Accuracy	The arguments in the answers are supported by making sure that all information is correct and free from errors based on the reliable resources.	○	○	○	○	○
Precision	The words in answers and data used are specifically exact and no more details could be added to explain what the participant means.	○	○	○	○	○
Significance	The answers essentially focuses on the most important ideas and crucial facts that would help to make a meaningful point.	○	○	○	○	○
Relevance	Ideas included in the answers are important, that each part makes a difference and accordingly they connect the arguments to the reliable relevant information.	○	○	○	○	○
Depth	The arguments provided in the answers are thorough by tending to explore the complexities in the research questions which are addressed profoundly in the answers.	○	○	○	○	○
Breadth	Additional perspectives and different viewpoints were considered in the answers to look at the problem from various ways.	○	○	○	○	○
Logic	The arguments in the answers are reasonable that the thinking is consistent and the conclusions follow from the evidence where things make sense step-by-step.	○	○	○	○	○
Fairness	Fairness: The arguments in the answers are balanced, objective and free from hidden biases by considering both positive and negative outcomes.	○	○	○	○	○

2. Expert's comments on the work of the student number 001

Your feedback here

FIGURE I.2: Statements of Intellectual Standards in the Pre-intervention Online Survey