UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Investigating Digital Learning in University Science Education

by Le Quan Ly

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Doctor of Philosophy

under the supervision of
Dr Kirsty Young and Dr Annie Agnew

University of Technology Sydney
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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Le Quan Ly, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the Faculty of Arts and Social Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Dedication

This thesis is dedicated to my grandmother and my parents.

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Glossary of Terms and Abbreviations

ABS: Australian Bureau of Statistics

AECT: Association for Educational Communications and Technology

AI: Artificial Intelligence

AR: Augmented Reality

CSCL: Computer-supported Collaborative Learning

GenAI: Generative Artificial Intelligence

HE: Higher Education

ICT: Information Communication Technologies

LMS: Learning Management System

Mobile device: Includes smartphones, laptops and tablets

MOOC: Massive Open Online Course

NSW: New South Wales

OECD: Organisation for Economic Co-operation and Development

OER: Open Educational Resources

School: Year K-12

STEM: Science, Technology, Engineering and Mathematics

TEL: Technology-Enhanced Learning

TPACK: Technological, Pedagogical and Content Knowledge

UNESCO: United Nations Educational, Scientific and Cultural Organisation

University: A higher education institution that offers undergraduate and postgraduate degrees

VR: Virtual Reality

Abstract

The use of mobile devices, such as laptops, tablets and smartphones, to support learning has become an integral part of contemporary education. However, incorporating these mobile technologies effectively requires thoughtful consideration of pedagogical approaches. In undergraduate science education, the use of distinctive mobile pedagogies, specifically personalisation, authenticity and collaboration as conceptualised in the iPAC mobile framework (Kearney et al., 2012), and the perceived levels of digital pedagogical innovation (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005), remain relatively underexplored.

This empirical study, grounded in sociocultural theory, investigated how distinctive mobile pedagogies (or practices) are used in undergraduate science digital learning activities and the extent to which these activities are perceived as pedagogically innovative. A two-phase mixed methods approach was employed. Phase One involved a global survey of 132 university science teachers to gain a broad understanding of teachers' mobile practices. Phase Two comprised six case studies from four universities in New South Wales, Australia to deepen insights through teachers', learning designers' and students' perspectives. Data from both phases were collected, analysed and interpreted through the sociocultural lens of the iPAC mobile framework and digital pedagogical innovation criteria to gain nuanced insights from multiple perspectives.

Findings highlighted science educators' emphasis on co-creation as a mobile pedagogical approach, with students actively collaborating in data sharing and content production. The data also underscored student agency and conversational aspects of mobile learning through both teacher-led and student-driven initiatives. Mobile practices supporting authentic learning were most evident when students used discipline-specific apps to perform realistic tasks in real-world settings. While customisation has the potential to tailor individual learning needs, this mobile practice was not widely adopted in undergraduate science education.

This study contributes new insights into the use of distinctive and innovative mobile practices in undergraduate science education. It highlights the dynamic interplay of agency, conversation and co-creation in shaping students' learning experiences. This research advocates for a shift toward mobile approaches that support more customised, authentic and networked science learning by

extending into less formal off-campus settings and involving external facilitators. The findings suggest that university science educators consider a reimagination of their mobile practices in response to the evolving digital landscape and the expectations of current and future learners.

Chapter 1
Introduction to the Thesis

Despite widespread adoption of mobile technologies in education, their full pedagogical potential for undergraduate science education remains relatively underexplored. This study has addressed this gap by investigating the use of distinctive mobile practices – personalisation, authenticity and collaboration – as conceptualised in Kearney et al.'s (2012) iPAC mobile framework and perceptions of digital pedagogical innovation. This chapter presents the rationale and key motivation behind this inquiry, positioning it within the broader landscape of global priorities for science education and the growing calls for pedagogical innovations. It introduces the definition of mobile learning and sociocultural underpinnings of the study. It then presents the research design and aims, highlighting the study's significance in advancing knowledge of innovative mobile practices in undergraduate science education and, more broadly, in higher education (HE).

1.1 Rationale for the Study

In recent decades, mobile technologies have become profoundly embedded in daily life, transforming the ways we communicate, work, and study. The number of mobile devices – mobile phones, tablets and laptops – is projected to exceed 18 billion globally by 2025 (Statista, 2021). Recent statistics indicate that over 70% of the global population owns a mobile phone (Datareportal, 2025) and 96% are covered by mobile-broadband networks (ITU, 2024).

Such technological expansion has driven the advancement of mobile learning (m-learning). This approach leverages the connectivity, networking and portability of mobile devices (Bernacki et al., 2020; Crompton & Burke, 2020) in ways that can support learning across formal and informal settings (Sharples, 2015; Toh et al., 2013; Wong et al., 2021). The use of mobile devices has catalysed the expansion of mobile approaches across multiple educational levels and disciplines (for examples: Bano et al., 2018; Crompton & Burke, 2018; Crompton et al., 2017; Kaliisa & Picard, 2017; Pimmer et al., 2016). More particularly, it has provided opportunities for personalised, authentic and collaborative learning experiences (Kearney et al., 2012). However, the impact of mobile devices could either

support or hinder the student learning process, depending on how they are used (Turvey & Pachler, 2018).

In parallel with this expansion, global and national educational policies have positioned innovation as key to economic and societal development. For example, the Organisation for Economic Co-operation and Development (OECD) has highlighted the need to prepare students to meet the demands for high-skilled workers and lifelong learning (OECD, 2021, 2024a, 2025; OECD/EU, 2019; Schleicher, 2022; Vincent-Lancrin, 2023). The Digital Education Action Plan (2021–2027) of the European Commission (2020) has also emphasised the importance of identifying and sharing effective digital education practices among stakeholders. Similarly, the United Nations 2030 Agenda for Sustainable Development (2015b) has advocated for the use of m-learning to promote quality education for all learners. It also recognised innovation as central to its Sustainable Development Goal 9, which focuses on building infrastructure, fostering industry, and encouraging innovation (2015a).

In Australia's National Science Statement (2024), science and innovation are positioned as central to shaping the national science policy and to transforming industry. Yet, Australia has faced shortages of STEM-skilled graduates, raising concerns about the readiness of the future workforce (Office of the Chief Scientist, 2020). To thrive in the "global innovation race", as outlined in the Australia 2030: Prosperity Through Innovation report (2017), the education system must equip students with strong STEM capabilities, including disciplinary knowledge, digital literacy, problem-solving, and critical thinking. This skills gap is particularly pronounced among undergraduate science students, posing challenges not only for individual career prospects but also broader societal and economic growth.

While college and university students constitute the largest demographic of internet, mobile device and social media users (Pew Research Center, 2024), their scepticism about the value of higher education is alarming. According to the Global Learner Survey (2020), respondents in the United States and United Kingdom questioned the need for a university degree for career success, and 72% of global respondents reported that vocational education is more practical to prepare them for the workforce.

There is a growing consensus that traditional teacher-led pedagogies are often insufficient for preparing students to meet the demands of the evolving digital

landscape (McDiarmid & Zhao, 2022). Despite the widespread optimism around digital learning to transform education (Conole, 2014; Laurillard, 2008), there remains a paucity of evidence of digital pedagogical innovations (Criollo-C et al., 2021; Crompton & Burke, 2018, 2020; Traxler, 2018). Education systems need to evolve if they are to support learners in developing the skills needed in an economy that highly values such innovations (Kukulska-Hulme et al., 2024; Law, 2008; OECD, 2025).

One of the key limitations of current m-learning research in science education is its predominant focus on the school level (Bano et al., 2018; Crompton et al., 2016; C. Liu et al., 2020; Zydney & Warner, 2016). In contrast, systematic literature reviews focusing on mobile pedagogies in higher education have highlighted the lack of studies focused on the undergraduate level and the science discipline (Crompton & Burke, 2018; Goundar & Kumar, 2022; Krull & Duart, 2017; Naveed et al., 2023; Pimmer et al., 2016; Sophonhiranrak, 2021). As will be discussed in Chapter 2, most m-learning research studies in science higher education have included limited perspectives (usually of teachers or students only) or adopted narrow study designs, typically overlooking the value of qualitative insights and the interplay of multiple perspectives.

Crucially, the perspectives of learning designers in higher education, who are often referred to as instructional designers, academic developers or educational technologists, have become increasingly important, especially since the COVID-19 pandemic. These practitioners typically work with university subject matter experts (such as subject coordinators) to develop and implement the digital pedagogies that support students' achievement of subject learning outcomes (Heggart & Dickson-Deane, 2022; Mitchell et al., 2017). Despite their vital roles in shaping teaching practices and pedagogical innovation, their perspectives remain underexplored in m-learning research in science higher education.

To address these gaps, this study investigated the perceptions of teachers, learning designers, and students involved in undergraduate science education. Since each of these groups plays a unique role in the development, implementation and experience of mobile pedagogies, exploring their perspectives has provided comprehensive insights into m-learning. Rather than superficially evaluating mobile practices as "right" or "wrong", this study focused on how mobile-mediated science learning activities have been perceived and implemented in terms of pedagogical innovation. In doing so, it contributes

nuanced insights into how mobile practices can support educational transformation.

1.2 The Researcher's Impetus for This Study

My interest in this research stems from my personal and professional experiences. After completing a Bachelor of Science, I began teaching as a sessional academic at a college to support students enrolled in the Diploma of Science. I also worked in the pathology and clinical trial industries while studying part-time for a Master of Science in medical biotechnology.

Over three years of working in both education and industry, I found myself drawn to teaching, especially the exploration of contemporary digital pedagogies. When an opportunity arose in 2016, I applied for the role of academic coordinator, and I have been working in this role ever since. This role requires regular interaction with teachers, learning designers, and students. During the COVID-19 pandemic lockdown, I wondered how other university science teachers in Australia and around the world were using mobile technologies in their practices; how learning designers were supporting these practices; and how science students were experiencing them. These questions motivated me to begin my doctoral journey, with the hope that my research would contribute to a deeper understanding of mobile practices in undergraduate science education.

1.3 Definition of Mobile Learning

The definition of mobile learning (m-learning) has long been debated among researchers (Traxler, 2011). According to Basak et al. (2018), digital learning (d-learning) encompasses various forms of technology-supported learning, including electronic learning (e-learning) and mobile learning (p. 195, see Figure 1.1). Traxler (2005) indicated that m-learning is “difficult to define, conceptualise and discuss” (p. 261), highlighting the lack of consensus on how it should be defined. Over the years, researchers have approached the definition of m-learning from various perspectives, resulting in multiple interpretations.

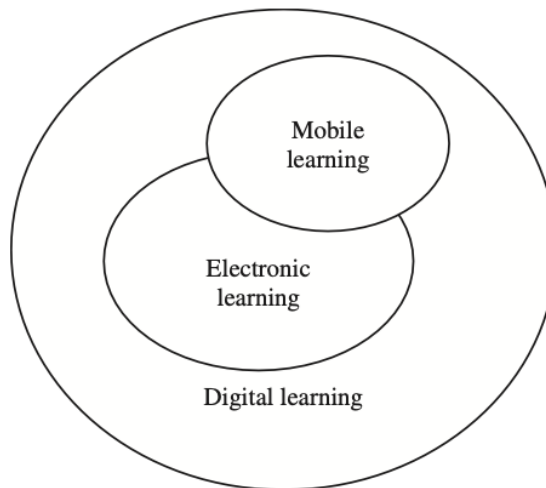
According to Johnson (2021), d-learning is “an overarching term that captures all kinds of technology-supported learning” (p. 2). Within this, e-learning refers to “learning supported by digital electronic tools and media” and m-learning is “e-learning using mobile devices and wireless transmission” (Hoppe et al., 2003, p. 255). Based on these definitions, m-learning can be regarded as a form of e-

learning that uses digital electronic tools and media, specifically through mobile devices and wireless transmission, to support and enhance learning activities.

Figure 1.1

Relationship Between D-learning, E-learning and M-learning

(adopted from Basak et al. 2018, p. 195)



Echoing Hoppe et al. (2003), Traxler (2005) elaborated on the types of mobile devices and their affordances that enable m-learning to extend beyond physical limitations. Traxler (2005) defined m-learning as:

> any educational provision where the sole or dominant technologies are handheld or palmtop devices. This definition may mean that mobile learning could include mobile phones, smartphones, personal digital assistants (PDAs) and their peripherals, perhaps tablet PCs and perhaps laptops PCs, but not desktops in carts or other similar solutions. Perhaps the definition should address also the growing number of experiments with dedicated mobile devices such as game consoles and iPods, and it should encompass both mainstream industrial technologies and one-off experimental technologies. (p. 262-263)

On the other hand, Sharples et al. (2007), with an emphasis on social interaction, defined m-learning as “the process of coming to know through conversations across multiple contexts amongst people and personal interactive technologies” (p. 225). By this definition, m-learning occurs through engagement with both content and peers across diverse settings, highlighting the social nature of

technology-mediated learning. Emphasising the social dimension illustrates how the use of mobile technologies can both facilitate access to knowledge and promote active and communal forms of learning.

On the United States Advanced Distributed Learning website (n.d.), m-learning is defined as "leveraging ubiquitous mobile technology for the adoption or augmentation of knowledge, behaviours, or skills through education, training, or performance support". This definition accommodates the expanding range of m-learning scenarios and the future advancements of mobile devices.

The present study aligns more closely with Crompton's (2013a) definition of m-learning as "learning across multiple contexts through social and content interactions using personal electronic devices" (p. 4). This definition describes how learning occurs across locations and through social engagement, mediated by mobile devices. As all mobile devices are digital, this study uses the term "m-learning" to refer to all learning mediated by mobile devices.

1.4 Theoretical Underpinnings

This study is grounded in the sociocultural theory (Vygotsky, 1978), which emphasises the vital roles of social interactions, conversations, and the use of tools in the learning process (Wertsch, 1998). According to this perspective, learning is mediated by interactions with "more knowledgeable others" to make sense of new information. Mediation can occur through physical artefacts such as textbooks or symbolic tools such as language, signs and symbols. A core concept of this theory is the "human mind is *mediated*" (Lantolf, 2000, p. 1), meaning a student's learning and development processes are mediated by their psychological self, social environment, and cultural tools.

A key concept within the sociocultural theory is the Zone of Proximal Development (ZPD), which Vygotsky (1978) defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). This theory highlights the differences between what learners can accomplish on their own and what they can achieve with support from more knowledgeable others, such as teachers or peers. Vygotsky's assertion, "The only good learning is that which is in advance of development" (p. 89), highlights the importance of instructions and social interactions with peers in helping learners to acquire skills that they can later use independently. Learning is thus most effective when it occurs within

the ZPD, as it promotes cognitive growth and supports learners' development of more advanced understandings.

The implementation of digital technologies into education further amplifies this mediation process by supporting and potentially transforming learning activities and by recognising how learning itself might be interpreted (Säljö, 2010). Technology tools such as mobile devices can be modified based on how they are used, and in turn, their design can influence the way people use them (Glassman, 2001; Salomon & Perkins, 1998). The effective use of technology includes understanding its usage from a technical perspective, its impacts on society, and the relationships between users and tools (Wertsch, 1991). In science education contexts, this sociocultural lens can highlight the significance of interpersonal social interactions and the use of digital tools (Lemke, 2001). Such interactions might take the form of student collaborations in a laboratory activity, or dialogue during a physics tutorial.

While sociocultural theory has provided a broad lens to interrogate digital learning in science education generally, more specific frameworks underpinned by this theory are needed to scrutinise the mobile practices and pedagogical innovations that have been introduced into the field more recently. For this study, I adopted the iPAC mobile pedagogical framework (Kearney et al., 2012), which identifies three distinctive mobile pedagogies (and sub-constructs): personalisation (agency and customisation), authenticity (task and context), and collaboration (co-creation and conversation). Throughout this thesis, the term "mobile pedagogies" is used interchangeably with "mobile practices", and either term refers to these constructs and their associated subconstructs. Additionally, I incorporated Burden, Kearney, Schuck, & Hall's (2019) and Law et al.'s (2005) digital pedagogical innovation criteria, which include the purpose of learning; the contexts of learning; the roles of teachers and their relationship with students; and the roles of students. By combining these frameworks, I aimed to illuminate the distinctive mobile practices used in university science education and the extent to which multiple participants might perceive the m-learning activities as pedagogically innovative. Together, these sociocultural theoretical perspectives formed the conceptual foundation for this study. Chapter 2 provides a detailed justification for their selection.

1.5 Research Design and Aims

To date, no known empirical study has specifically examined perceptions of distinctive mobile practices and digital pedagogical innovations in undergraduate science education from the collective viewpoints of teachers, learning designers, and students. The findings of this study should contribute to the implementing of innovative mobile practices to support students' science learning.

This study addresses gaps in the literature on m-learning and mobile pedagogical innovation by examining how university science teachers employed distinctive mobile practices in their teaching. It also incorporated the views of learning designers and students regarding these practices. Additionally, it explored the extent to which these stakeholders perceived their m-learning activities as pedagogically innovative.

This research was grounded in a pragmatic paradigm, and it adopted a mixed methods design, with a prime focus on case studies. The pragmatic paradigm was chosen because of its focus on addressing practical problems and valuing both singular and multiple realities in empirical investigations (Saunders et al., 2016). The mixed methods approach integrated both quantitative and qualitative data to strengthen the integrity of the findings (Creswell, 2009; Creswell & Creswell, 2018; Tashakkori et al., 2021).

This study consisted of two phases. Phase One utilised a global survey instrument to investigate the perspectives of university science teachers worldwide. Phase Two drew on in-depth case studies from Australian universities, with each case involving researcher observations; surveys of teachers and students; interviews with teacher(s) and a learning designer; and student focus group(s). Case studies were considered suitable for capturing the breadth and depth of multiple perspectives on mobile practices and pedagogical innovations. The findings of Phases One and Two surveys were adapted and modified based on the validated iPAC teacher survey (Kearney et al., 2019) and student survey (Burke et al., 2022) to align with the undergraduate science context.

1.6 The Research Questions

The overarching research question guiding this study was intentionally broad to set the scene for the capture of a wide range of contemporary mobile practices in undergraduate science education.

Overarching Research Question: How are mobile technologies being used in undergraduate science education to support teaching and learning?

Four subsidiary research questions were developed to address the research aims. They involved different stakeholder groups, with their findings providing complementary insights through the triangulation of both quantitative and qualitative components of this study. These questions are unweighted and are in no way ranked according to their importance. As the study developed, new insights emerged, but it is acknowledged that some aspects of these questions may remain unanswered. The purpose of each subsidiary research question will now be explained:

RQ1: How are university science teachers using distinctive mobile pedagogies?

The aim of both phases of this study was to explore how the participating university science teachers implemented distinctive mobile pedagogies (as detailed in the iPAC Framework). They nominated specific science learning activities mediated by mobile devices. This question is investigated through a global survey (Phase One) and in-depth Australian case studies (Phase Two). Understanding how they employed distinctive mobile practices may support other teachers and learning designers to leverage mobile technologies to enrich students' learning experiences.

RQ2: How do learning designers view these mobile pedagogies?

An aim of Phase Two was to examine the viewpoints of learning designers regarding teachers' mobile practices. Despite significant staff reductions in many universities during the COVID-19 pandemic (Zhou, 2020), there has been an increased demand for learning designers. They normally work closely with subject coordinators or teachers in developing and creating strategies to enhance students' learning experiences, typically with the use of digital technologies. Understanding their views may provide empirical evidence for improving learning design practices, thus facilitating better support for teachers and students.

RQ3: How do students experience these mobile pedagogies?

Another aim of Phase Two was to explore students' experiences of their teachers' mobile practices and thereby inform the development of contemporary mobile pedagogies (Burke et al., 2022). Including "student voice" in empirical research is crucial to understanding student learning needs and potentially improving educational outcomes (Cook-Sather, 2014; Cook-Sather & Matthews,

2023; Mockler & Groundwater-Smith, 2014). This study positions students as one of the key stakeholder groups, along with teachers and learning designers, whose insights can inform the m-learning process.

RQ4: To what extent are educators' mobile learning activities perceived as pedagogically innovative?

As mentioned in Section 2.5.2, despite early optimism about the evolution of mobile pedagogies (Kearney et al., 2012; Lindsay, 2016; McHaney, 2023; Norris & Soloway, 2011; Norris & Soloway, 2015; Pegrum et al., 2018), their adoption had so far not led to the expected levels of pedagogical innovations (Burden, Kearney, Schuck, & Hall, 2019; Kearney, Burden, et al., 2019; Selwyn, 2017). This research question was addressed in both phases of the study to investigate mobile pedagogical innovation in undergraduate science education. Its aim was to investigate from multiple perspectives the extent of digital pedagogical innovation in the participants' nominated learning activities.

1.7 Significance of the Study

This thesis offers a novel contribution to the field of m-learning in the context of undergraduate science education, as captured through the perspectives of multiple stakeholders.

The increasing use of mobile technologies in education has highlighted the need for research that critically examines their pedagogical impacts. Drawing on both global and local Australian perspectives, the study adopted a mixed methods research design to investigate the contemporary perspectives of three key stakeholder groups – teachers, learning designers, and students – on how mobile technologies are used in undergraduate science education and the extent to which they are perceived as pedagogically innovative.

Researchers have suggested that the quality of technology-mediated learning with mobile devices is closely linked to the design and implementation of mobile practices (see examples in Bernacki et al., 2020; Burke et al., 2022; Burke et al., 2025; Ke & Hsu, 2015; Sung et al., 2016). Exploring the potential of such approaches in this study has led to an enhanced understanding of students' m-learning experiences, and it thus contributes to improving learning outcomes for undergraduate science students.

This study is also significant because it is underpinned by two sociocultural frameworks: the iPAC mobile pedagogical framework (Kearney et al., 2012), and the digital pedagogical innovation criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005). These frameworks allowed existing knowledge of distinctive and innovative mobile practices to be extended to the underexplored context of undergraduate science education.

While many studies in this domain have tended to accentuate positive outcomes, this thesis also acknowledges what is missing in practice. The study responded to calls from educational technology researchers to report both achievements and challenges in the implementation of m-learning (Crompton & Burke, 2018; Persson & Nouri, 2018) and to learn from these challenges as a means of advancing the field (Crompton et al., 2017; Pegrum, 2019).

Overall, the findings of this study should support the both the implementation of new and effective mobile practices across diverse undergraduate science learning activities and the professional development of practitioners and researchers.

1.8 Organisation of the Thesis

The remaining six chapters of this thesis are organised in the following way.

Chapter 2 presents a comprehensive literature review relevant to this study. It begins with an overview of the field of educational technology, including its history, current trends, barriers to technology adoption, and undergraduate students' use of digital technologies for learning. The chapter then introduces related literature on mobile learning, key mobile pedagogical frameworks, science education and reviews of m-learning in higher education, with a particular focus on mobile pedagogies for undergraduate science. It next examines concepts of innovation in education and related digital pedagogical innovation frameworks. Together, the choices of mobile framework and pedagogical innovation criteria in this study are justified. The chapter also identifies gaps in the existing literature to establish the need for the current study.

Chapter 3 outlines the research methodology, justifying the use of a mixed-methods design underpinned by a pragmatism paradigm. It introduces the research methods used in this two-phased study: surveys, observation, semi-structured interviews and focus groups. The participants, background of case studies, data analysis, study rigour and ethical considerations are also presented.

Chapter 4 reports the findings from the Phase One global survey by presenting the quantitative and qualitative data. It reports on analysis of data from the closed- and open-ended questions in the forms of tables, figures, and texts.

Chapter 5 draws on the multiple data sources from four Australian universities to present the findings of the Phase Two case studies. Based on thematic analysis, it identifies how science teachers implemented mobile practices, the learning designers viewed them, and the students experienced them.

Chapter 6 critically discusses insights from both phases in relation to the research questions and with reference to the chosen theoretical frameworks and the existing literature. The discussion centres on teachers', learning designers' and students' perspectives on the mobile technology-mediated activities. It analyses the extent of pedagogical innovation as perceived by these participants. It also presents practical implications, acknowledges the study's limitations, and proposes future research directions.

Chapter 7 concludes the thesis by summarising the key findings and responding to the research questions. It also highlights the significance of this study and its contributions to the literature in the field of educational technology.

Chapter 2
Literature Review

This chapter provides a comprehensive review of the literature on the adoption of educational technology, focusing on mobile learning and its application in undergraduate science education. It contributes to addressing the research questions:

1. How are university science teachers using distinctive mobile pedagogies?
2. How do learning designers view these mobile pedagogies?
3. How do students experience these mobile pedagogies?
4. To what extent are educators' mobile learning activities perceived as pedagogically innovative?

The chapter begins by introducing the field of education technology, tracing its historical development and its impact on current trends in digital learning. It then explores the barriers to current technology adoption and undergraduate students' use of digital technologies for learning.

Relevant literature has been examined in relation to the features of m-learning, exploring its role in facilitating third space learning. Several mobile pedagogical frameworks are introduced, leading to a justification of the iPAC framework (Kearney et al., 2012) for the present study. The review then details the purposes of science education and examines the implementation of digital pedagogies in undergraduate science education. The key findings of other m-learning reviews in science education are summarised, offering insights into current practices and research trends.

Additionally, the chapter reviews related studies on m-learning in higher education more broadly before narrowing the focus to mobile pedagogies specific to undergraduate science education. The review also introduces the concepts of digital and mobile pedagogical innovations and relevant frameworks to justify the choices of Burden, Kearney, Schuck, & Hall's (2019) and Law et al.'s (2005) criteria. The chapter concludes by identifying the research gaps in existing studies and the need for the present study to investigate distinctive mobile practices and perceptions of pedagogical innovation from the perspectives of multiple stakeholders.

2.1 The Field of Education Technology

2.1.1 Overview of Education Technology

Technological developments have greatly impacted institutions and individuals, shaping their interactions with information, knowledge and work processes (Selwyn, 2016). The term "education technology" is widely used in education and is defined by the Association for Educational Communications and Technology (AECT) as "the study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources" (Januszewski & Molenda, 2008, p. 1). This definition highlights the role of technology in enriching educational practices.

To meet learners' needs and maintain competitiveness in global educational markets, universities and academic staff have adopted innovative technology-enhanced pedagogical approaches, both inside and outside the classroom (Stacey & Gerbic, 2008). Technology-mediated learning is also known as "educational technology", "computers in education", "e-learning" and "learning technologies". In the United Kingdom and Europe, the term "Technology Enhanced Learning" (TEL) has been widely used in the past decades (Bayne, 2015).

Several recent reviews have examined the current state and development of educational technology, identifying research trends such as critical thinking in e-learning environments (Chou et al., 2019), digital games for older adults (Wang et al., 2019), m-learning in nursing education (Chang et al., 2018), and the relationship between teachers' pedagogical beliefs and technology use (Tondeur et al., 2017). Collectively, these studies highlight the diverse applications of educational technology across a range of fields and contexts.

2.1.2 A Brief History of Educational Technology

The field of educational technology has a long history (Spector, 2015). In the first half of the 20th century, radio, films, and television played important roles in delivering educational content. Computers emerged during the period when behaviourism was the prevailing learning theory. Skinner (1958) introduced the concept of "teaching machines" in the 1950s, paving the way for the development of computer-assisted instruction (CAI) over the following two decades. In the 1960s, Alan Kay developed the Dynabook, which was considered a predecessor to modern portable educational devices. The 1990s witnessed the progressive development of interactive multimedia and communication software, leading to

the advent of the internet. In 1993, Seymour Papert introduced the LEGO Mindstorms robot building kit, enabling children to build hands-on programmable robots (Papert, 1993). This period marked a shift to constructivist theories underpinning education technology designs and applications, emphasising the enhancement of critical thinking, problem-solving and creativity in the use of learning with technologies.

With the development of the World Wide Web, Berners-Lee (1997) introduced Web 1.0, a network of interconnected sites utilising the Hypertext Transfer Protocol (HTTP) to facilitate users' online access and information sharing. The latest evolution, Web 4.0, combines multiple dimensions such as the Internet of Things, Big Data, Artificial Intelligence (AI) and new models of communication between machines (Almeida, 2017). To manage the distribution of online teaching and learning content, numerous Learning Management Systems (LMSs) were developed in the 1990s. LMSs currently used in universities include Moodle, Canvas and Blackboard Learn. Other online educational technologies impacting learning include cloud computing, gamification, Massive Open Online Courses (MOOCs), social networking, virtual reality (VR) and augmented reality (AR) and learning analytics connected to the Internet.

In the early 2000s, the rise of mobile devices marked the next shift in education technology, with mobile learning (m-learning) becoming a recognised term in the field (Crompton, 2013a). Mobile phones, tablets and mobile applications are now prominent tools for university student learning that support increasingly flexible interactions and communications with teachers and peers, both within and outside university schedules (Aresta et al., 2015; Stevenson & Hedberg, 2017). In recent years, the surge in AI and its tools has substantially impacted many sectors, including education (Chu et al., 2022; Crompton & Burke, 2023). The current study has explored how mobile technologies might continue to enhance undergraduate science education.

2.1.3 Current Trends in Digital Learning

Digital technologies are reshaping relationships between teachers and students, influencing how teaching and learning resources are utilised. It is therefore important for teachers to thoughtfully incorporate appropriate digital pedagogies to assist students in using digital technologies effectively to achieve learning objectives (Bećirović, 2023). The COVID-19 pandemic that began in early 2020 has accelerated the development of digital pedagogies, as institutions

transitioned from face-to-face to online learning environments (Anderson, 2020; Houlden & Veletsianos, 2020). In addition, many universities have since adopted online and blended learning models to address reduced funding, increased student enrolment, and technological advancements (Rosenbusch, 2020).

Bećirović (2023) identified digital pedagogy as consisting of the following factors associated with technology-enhanced learning processes:

> attitudes and motivation to adopt and use advanced technologies; digital literacy and digital competencies of instructors and students; Open Educational Resources (OER); student engagement; multicultural education; privacy and personal data protection; barriers to successful technology use; and a variety of teaching and learning strategies. (p. 2)

From a sociocultural perspective (see Section 1.4), educators can create personalised, authentic, and collaborative learning experiences by adapting mobile devices to dynamic learning contexts (Kearney et al., 2012). As will be seen later in this chapter, digital approaches not only foster a seamless flow of knowledge, but they also challenge conventional pedagogical practices, encouraging innovation and the development of new teaching strategies (Sharples, 2015).

Digital technologies have also positively impacted both student engagement and learning outcomes (Anuyahong & Pucharoen, 2023; Pinto & Leite, 2020). Examples of commonly used digital technologies to support HE students' learning include LMS (e.g., Canvas, Moodle and Blackboard); Information Communication Technologies (ICT); publish and share tools (e.g., video technologies for lecture, podcasts, blogs, e-books, and e-portfolios); social networking (e.g., Facebook and Twitter); assessment and feedback; and 3D virtual worlds (Pinto & Leite, 2020).

While initially driven by the pandemic, the recent shift to digital learning has resulted in university teachers increasingly opting for synchronous hybrid or blended learning modes supported by rich-media technologies such as video or web conferencing, which allow online students to participate in face-to-face class simultaneously (Bower et al., 2015; Raes, 2022; Zydney et al., 2019). Synchronous hybrid learning also offers organisational benefits, such as increased enrolment numbers and access to education from anywhere and at any time, as well as pedagogical benefits such as access to experts outside of

the university and broader learning opportunities for all students (Raes et al., 2020).

Raes et al. (2020) have also addressed the pedagogical and technological challenges of synchronous hybrid learning from both teachers' and students' perspectives. Teachers need to adjust their pedagogical approaches to ensure onsite and offsite students receive comparable learning experiences. Technological challenges for remote students include a possible sense of disconnect compared to their on-campus peers and audio quality issues. To address these challenges, these authors also proposed guidelines focusing on training and support, clear communication, activating learner engagement, and curriculum alignment.

Key Trends in Higher Education: The 2024 *Horizon Report* (EDUCAUSE, 2024) identified the key trends shaping contemporary higher education within five categories: social, technological, economic, environmental, and political (STEEP). Socially, public perception of higher education's value is declining, coinciding with changing student demographics and increased demand for access to learning anytime and anywhere. Technologically, increasing concerns about cybersecurity and privacy accompany the growing use of learning analytics aimed at enhancing personalised and adaptive learning experiences; nevertheless, the digital divide persists, with unequal access to digital devices.

Economically, universities face the challenge of developing curricula that can adapt quickly to the demands of the workforce; there are also issues with employee retention and the impact of student debt on enrolment decisions. Environmentally, higher education institutions continue to commit to sustainability, with rising concerns about the environmental impacts of big data tools and the demand for green skills in the workforce. Politically, the political polarisation in the United States continues to affect higher education, with government policies playing an increasingly significant role. As emerging technologies evolve, there is a demand for policies to address their impact. For the first time in the history of the *Horizon Report*, panellists highlighted AI trends across all STEEP categories, indicating that AI's significant and widespread impacts, for example, transforming communication, reshaping education, influencing the economy and workforce, challenging climate and sustainability inaction, and emerging as a political tool.

2.1.4 Barriers to Current Technology Adoption

Despite the widespread awareness of digital technologies in education, teachers often lack preparedness to implement them effectively (Burden & Kearney, 2017; Stare et al., 2023; Starkey, 2020). This challenge persists long after the key message from the first EDUCAUSE Review article: "To improve m-learning effectiveness, students and instructors need help adopting more effective learning and teaching practices across content areas" (Denoyelles & Chen, 2013). Building on this, Skantz-Åberg et al. (2022) reviewed the concept of teachers' professional digital competence and identified technological and pedagogical competences as the most prominent aspects that need to be developed for effective educational technology adoption.

Q. Liu et al. (2020) identified several contextual factors that influence academics' adoption of learning technologies in higher education: bureaucracy; politics and purpose; research prioritisation; culture; and discipline. The characteristics of tertiary institutions are often captured by the term *loosely coupled systems* (Weick, 1976), which describes how different components of an institution connect to a larger system but preserve their own identities. Such structures tend to reduce the likelihood of responding to minor changes and preference for localised rather than university-wide adaptions (Weick, 1976).

Teachers at both schools and universities face the challenge of selecting appropriate digital resources – subject-specific and generic – that can facilitate their students' learning. These decision-making processes can vary significantly across institutions and are dependent on their available technical support. Barriers to technology adoption can be influenced by intrinsic and extrinsic factors (Drent & Meelissen, 2008; Errington, 2004; Jääskelä et al., 2017). Ertmer (1999) categorised the barriers and enablers of teachers' integration of technologies as extrinsic first order (i.e., access to support, training and technology provision) and intrinsic second order (i.e., teacher pedagogical beliefs, attitudes, self-efficacy). First-order barriers have become less prevalent because of the available support of policymakers and institution leaders in the adoption of digital practices (Ertmer et al., 2012; Tondeur et al., 2017). However, second-order barriers are rooted in teachers' beliefs and attitudes, which can be resistant to change. This highlights the importance of embedding the use of technologies in the professional development programs for both experienced and early-career educators.

To successfully incorporate technology into their teaching, it is crucial for educators to understand the purposes and affordances of various pedagogies. An effective strategy is the use of educational frameworks that demonstrate how pedagogical and technological knowledge can be integrated. Examples of such frameworks are the Technological, Pedagogical and Content Knowledge (TPACK) framework (Koehler & Mishra, 2009), which demonstrates how technological, pedagogical and content knowledge are intertwined; and the iPAC mobile pedagogical framework (Kearney et al., 2012), which highlights the personalisation, authenticity and collaboration in learning mediated by the use of mobile devices. Other frameworks include the Substitution, Augmentation, Modification, Redefinition (SAMR) model (as cited in Puentedura, 2013) with four levels of technology integration to enhance student learning, and the High Possibility Classrooms model (Hunter, 2015), which provides a scaffold for the incorporation of technology in education contexts. Such frameworks allow teachers to gain valuable strategies to integrate pedagogical and technological knowledge, thereby enhancing educational experiences and addressing the second-order barriers that hinder the adoption of digital practices.

2.1.5 Undergraduate Students' Use of Digital Technologies for Learning

University students are generally more likely to be permitted to use their mobile devices on campus to support their learning than younger school students. The ownership of mobile devices among university students has increased, with many having more than one device (Crompton & Burke, 2018; Kumar et al., 2021). University students find institutional online tools valuable for learning tasks, accessing self-service systems and resources using a variety of mobile devices on campus for learning (Gierdowski, 2019). However, the use of digital technologies for learning varies across disciplines and is influenced by factors such as perceived usefulness, digital media self-efficacy, and social integration (Pumptow & Brahm, 2023). Henderson et al. (2017) examined university students' perceptions of what constitutes "useful" digital technology and identified key features such as time and place flexibility, ease of task organisation, and management. This emphasis on usability was supported by Findik-Coskuncay et al. (2018), who stated that students generally prefer LMS systems that enhance "enjoyment, satisfaction and interactivity and control factors" (p. 25).

Despite the prevalence of mobile devices, many undergraduate students lack awareness of their potential for academic purposes (Woodcock et al., 2012; Yasan-Ak & Yildirim, 2024). Researchers have argued that it would be inaccurate

for teachers to assume that students possess prior knowledge to fully utilise the learning opportunities provided by mobile devices (Fuller & France, 2019). Therefore, providing tailored online learning orientations to specific platforms and software can help students navigate these systems efficiently, thereby reducing confusion and frustration (Singh et al., 2022).

2.2 Mobile Learning (M-Learning)

2.2.1 Features of M-Learning

There are unique features and characteristics of m-learning that make it distinctive from other forms of digital learning. A signature feature is the possibility for learners to learn from anywhere with a mobile device, a concept often referred to as "untethered" learning (Schuck & Maher, 2018; Traxler, 2009). This untethered feature allows learning to occur without being "tied" to a specific location, encapsulating the idea of "learning anywhere". Furthermore, m-learning enables students to break free from the constraint of university schedules, offering the possibility of "learning anytime" due to the instant connectivity provided by mobile devices. This is not achievable with non-mobile devices that require Wi-Fi and a fixed location for access. As data plans become more affordable and student ownership of mobile devices increases, the accessibility and flexibility of m-learning continue to expand.

The proliferation of mobile devices, including mobile phones, tablets and laptops, along with their associated mobile applications, has flourished rapidly at school and tertiary educational levels. Researchers have examined m-learning across a wide range of educational contexts, such as secondary PK-12 education (Crompton et al., 2017; Crompton et al., 2019) and higher education (Crompton & Burke, 2018; Kaliisa et al., 2019; Kaliisa & Picard, 2017; Naciri et al., 2020; Pimmer et al., 2016) and across different fields, such as mathematics (Crompton & Burke, 2015), languages and literacies (Pegrum, 2019), nursing (Chang et al., 2018), science (Crompton et al., 2016), science and mathematics (Bano et al., 2018), special education (Kearney et al., 2022), and social studies (Diacopoulos & Crompton, 2020).

Benefits and Challenges of M-learning. Mobile technologies have the potential to transform and reshape learning practices (Mayer, 2014, as cited in Bernacki et al., 2020). Several scholars have espoused the benefits of m-learning, particularly learner autonomy and opportunities for collaboration, and sharing with others (Chee et al., 2017; Kearney et al., 2012; Oon et al., 2023; Schuck et al.,

2017). The portability of mobile devices allows users to access learning resources "anytime, anywhere", and the built-in features such as cameras and microphones enable them to capture photos and videos for learning purposes. Rashid and Asghar (2016) highlighted the benefits of undergraduate students' use of email, internet, and social media to foster self-directed learning and student engagement. Similarly, Al-Hariri and Al-Hattami (2017) discovered positive correlations between second-year students' use of digital technologies and student achievement in health colleges, with laptops and phones being the most frequently used devices. Rysbayeva et al. (2022) explored the attitudes of engineering faculty students toward m-learning and found that most students used mobile apps frequently. While m-learning presented some disadvantages, such as information pollution, the need for support, and high costs, these authors found that students perceived it as useful for increasing motivation and facilitating learning.

Mobile devices allow university students to move away from fixed computing spaces and towards a more mobile and wireless paradigm, potentially transforming any space into a learning space. France et al. (2020) developed a pathway, with questions aimed at assisting teachers in evaluating whether m-learning interventions are appropriate and add value to learning.

M-learning also presents several challenges. For instance, while laptops are widely used in classrooms (Elliott-Dorans, 2018; Patterson & Patterson, 2017), Hall et al. (2020) found that their use could negatively influence the learning of neighbouring students due to off-task usage. Carter et al. (2017) reported lower final exam scores among students who used computers during class compared to those who did not. Similarly, Patterson and Patterson (2017) evaluated the effect of classroom laptop use on academic performance and identified negative impacts on grades, particularly among male students and those with lower academic performance. The Students, Digital Devices and Success report (OECD, 2024b) also indicated that overuse of digital devices for leisure purposes in classrooms can adversely affect academic performance. It also poses risks such as cyberbullying, exposure to inappropriate content, and privacy issues.

2.2.2 M-learning in the Third Space

This section introduces the concept of Third Space, a metaphor emphasising inclusive and dynamic educational environments where diverse cultures and

knowledge can interact. It then explores the critical role of m-learning in facilitating seamless learning in the Third Space.

What is Third Space? The concept of third space has gained considerable attention in educational settings, with several influential authors contributing to its understanding. Gutiérrez et al. (1995) suggested the Third Space as

> A framework for redefining what counts as effective classroom practice. Effective practice, in this sense, exists in contexts in which various cultures, discourses, and knowledges are made available to all classroom participants, and thus become resources for mediating learning. (p. 467)

Third Spaces have been described as environments where diverse cultures can come together to negotiate and share understandings (Bhabha,1996; Gutiérrez, 2008; Soja,1996; Zeichner, 2010), and as welcoming, accessible and inclusive spaces where people can interact with each other, such as in a coffee shop or communal place where everyone is welcome (Oldenburg, 1989).

In learning contexts, a Third Space serves as a connection between the dominant cultures, such as the university and student cultures, enabling learners within this space to redefine established knowledge (Kearney et al., 2020). It also offers opportunities to disrupt conventional pedagogical practices and create new ones. For Schuck et al. (2017), a Third Space is

> an emergent shared space, providing an opportunity to develop contemporary learning skills and knowledge, a space that extends beyond traditional, institutional learning with rigid, temporal schedules to also include the spaces of more spontaneous, often incidental learning, unconstrained by classroom walls and set schedules, and sometimes free from teachers and prescribed curricula. (p. 123)

This definition extends learning activities to more informal settings initiated by students. By providing a space for diverse voices and perspectives, the Third Space is where students can have their knowledge and experiences recognised and integrated into the broader learning environment.

Building on the notion of Third Space as an inclusive environment, m-learning is potentially a powerful tool for bridging physical and virtual contexts, allowing learners to engage in seamless, ubiquitous learning experiences that transcend traditional boundaries of time and place (Burden & Kearney, 2016; Kearney et al.,

2020; Schuck et al., 2017; Toh et al., 2017). Seamless learning refers to "when a person experiences a continuity of learning, and consciously bridges the multifaceted learning efforts, across a combination of locations, times, technologies or social settings" (Sharples et al., 2012, as cited in Wong et al., 2021, p. 269).

Mobile devices can remove or blur traditional boundaries between the classroom and the external world by offering new learning opportunities beyond the confines of the classroom, workshop or lecture theatre (Cristol & Gimbert, 2013; Melzer et al., 2009; Zeichner, 2010). By harnessing the power of social interaction across formal and informal contexts (Sharples, 2015), m-learning experiences can thus significantly enhance ubiquitous learning across the Third Space. Further research into designing m-learning is essential for uncovering its full potential to disrupt and redefine traditional pedagogical practices and to foster learning experiences no longer defined by time, place or space.

2.2.3 Mobile Pedagogical Frameworks

Mobile pedagogical frameworks provide strategies and guidance for integrating m-learning into educational practices. Several notable frameworks, such as the M-COPE (Dennen & Hao, 2014), the Mobile Learning Ecology Framework (Khaddage et al., 2015) and the Design for Transformative Mobile Learning frameworks (Cochrane et al., 2017), offer valuable perspectives on m-learning. Such frameworks often adopt a process orientation, rather than focusing exclusively on the signature pedagogical features of m-learning.

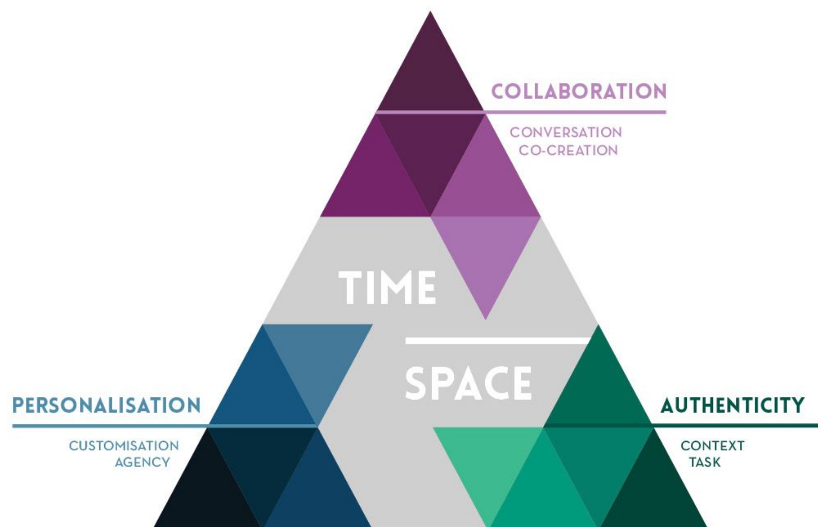
The M-COPE framework consists of five critical factors to be integrated with the instructional design model: mobile affordances, conditions, outcomes, pedagogy, and ethics (Dennen & Hao, 2014). The Mobile Learning Ecology Framework identifies four barriers to m-learning adoption: pedagogical challenges, technological challenges, policy challenges, and research challenges (Khaddage et al., 2015). The Design for Transformative Mobile Learning Framework aims to assess how mobile device usage can transform the learning environment and foster a shift in the development of student-generated contexts; it outlines the following six success factors for mobile deployments (Cochrane et al., 2017):

1. The pedagogical integration of the technology into the course and assessment;
2. Lecturer modelling of the pedagogical use of the tools;
3. Creating a supportive learning community;

4. Appropriate choice of mobile devices and Web 2.0 social software;
5. Technological and pedagogical support;
6. Creating sustained interaction that facilitates the development of ontological shifts, both for the lecturers and the students.

Originally known as the Mobile Pedagogical Framework (MPF), the iPAC framework was developed by Kearney et al. (2012) and further developed through an almost decade-long research agenda (Kearney et al., 2020). It was chosen as the most appropriate choice for the current study because it highlights three distinctive characteristics of m-learning from a pedagogical standpoint – personalisation, authenticity, and collaboration – in which learners' experiences are influenced by time and space (Figure 2.1).

Figure 2.1
The iPAC Mobile Pedagogical Framework
(Kearney et al., 2020, p.120)



The personalisation construct, which consists of two sub-constructs – customisation and student agency – captures pedagogical features such as students' choices, learning autonomy, and customisation. The customisation sub-construct highlights the "just-in-time, just-for-me" nature of m-learning that can provide students with a stronger sense of ownership by tailoring their digital activities and tools based on their individual learning needs. The agency sub-construct indicates a student's capacity to control and act independently when

using mobile devices to learn. A student can choose the place (physical or online), the pace, and the time they want to learn and thus enjoy a high level of autonomy in what they learn.

The authenticity construct consists of context and task. It addresses a learner's participatory, contextualised, and situated learning opportunities that are highly relevant to real-world settings and have personal meaning for them. Authentic learning emerges from the dynamic interplay between the student, the task and the learning environment (Barab et al., 2000). Learners participate in relevant learning tasks in real-life contexts by using digital tools or apps to collect data or generate learning content similar to professional practices.

The collaboration construct highlights the immediate connectivity aspects of m-learning, encompassing the conversation and co-creation sub-constructs (see examples of collaborative learning in Section 2.4.2). Koschmann (1994) introduced the concept of computer-supported collaborative learning (CSCL) to emphasise the role of technology in supporting peer learning. Crook (1999) further categorised student collaboration into four types:

1. *At* computers: where two or more learners work together at a computer
2. *Around* a computer: groups of students work together around computers in a common place
3. *Through* a computer: students worked separately in time and space through computer networks
4. *In relation to* computers: learners referred to previously shared learning experiences at the computer.

Using mobile devices, students can form rich connections with peers through multi-modal communication, information sharing and digital content production. By leveraging spatial and temporal boundaries (indicating by "time-space" in the middle of the representation shown in Figure 2.1), they can experience the unique characteristics of m-learning.

The iPAC framework provides a comprehensive and robust theoretical foundation to examine the dynamic interplay of personalisation, authenticity, and collaboration in m-learning practices. This holistic approach enriches our understanding of how these elements contribute to effective m-learning experiences for undergraduate science students in the present study. Its theoretical and practical values have been validated through more than 50

empirical studies (Kearney et a., 2020), albeit in teacher education and formal education in school and college settings (e.g., Bano et al., 2017; Burden & Kearney, 2017; Burke et al., 2025; Haering et al., 2021; Kearney et al., 2022; Kinash et al., 2012; Lindsay, 2016; Parmigiani & Giusto, 2016; Torres Diaz et al., 2015; Townsend, 2015; Viberg et al., 2018).

In this study, the iPAC framework was adopted because its sociocultural orientation and mobile pedagogical dimensions were appropriate for research in which personalisation, authenticity, and collaboration play central roles.

2.3 Science Education

This section begins with a brief overview of the purposes of science education. It then narrows its focus to undergraduate science education and the use of digital pedagogies. It proceeds to reviews of m-learning in science education together with related literature on m-learning in higher education and mobile pedagogies in undergraduate science education.

2.3.1 The Purposes of Science Education

Understanding the nature of science is important for recognising its power in shaping our ways of thinking and acting. It relies on rigorous evidence and effective communication to create shared meanings. According to Corrigan and Smith (2015):

> Science embodies a way of thinking and acting, a knowledge-seeking enterprise that is continuous and purposeful, generated by a need to understand, make sense of and communicate thinking about phenomena and experiences. In this context, science is a process of human endeavour, a human attempt to create explanations for what is observed and experienced; it is entrenched in human experience, reflects cultural diversity and is built upon individual perceptions and understandings. To this end it is a type of thinking which depends upon the rigorous pursuit of evidence for validity of ideas and seeks to effectively communicate findings to a wider audience to establish a shared meaning and understanding. (p. 102)

There is a widespread agreement among educators and the general public that the purpose of science education is to foster students' scientific literacy, enabling them to engage with scientific concepts and processes (Tytler, 2007). According

to Goodrum et al. (2001), scientifically literate individuals are curious to understand the world around them; they participate in scientific debates, critically assess scientific claims, formulate questions, draw conclusions using evidence, and make informed choices related to environmental and personal issues. These characteristics imply the type of science learning anticipated in compulsory schooling and in post-compulsory studies in science-related fields.

By encouraging students to identify issues, ask questions and test hypotheses, science educators aim to foster skills that are transferable to the STEM disciplines – Science, Technology, Engineering, and Mathematics (Bybee, 2010) and connect what they learn with real-world scenarios (Goodrum & Rennie, 2007). Furthermore, Fensham (2015) has argued that fostering trust in science should be a priority goal in science education; his analysis of how science is represented in Australian media found a scarcity of content that encouraged trust in science and, instead, a prevalence of uncertainty.

Science education has received unprecedented global attention because it is crucial for tackling social, economic and environmental challenges (Pei & Zheng, 2021). It is also closely linked with the transformative potential of digital education (Bidarra & Rusman, 2017; Rapanta et al., 2021). However, traditional teacher-centric pedagogies often fall short of engaging students in exploring scientific knowledge and preparing them for the rapidly evolving technological landscape (McDiarmid & Zhao, 2022). As a result, students may find it challenging to connect scientific concepts to real-world problems. The European Commission (2025) has also identified a need for more policy efforts and research into STEM education to tackle challenges such as low student proficiency levels, teacher shortages, and the widening talent gap.

Bidarra and Rusman (2017) argued that despite the widespread use of digital devices for communication and entertainment, empirical evidence regarding their effectiveness in making science learning meaningful is limited. They emphasised the importance of promoting science as a foundation element for understanding real-world practices, particularly for engaging low achievers in developing essential skills and competences to foster a deeper appreciation for science as a fundamental aspect of every day basic-life skills. Furthermore, they highlighted the need to create environments that are more learner centred by exploring emerging pedagogical approaches for “participative learners” and integrating new methods of media consumption and production from global resources.

2.3.2 Undergraduate Science Education

STEM education and research are increasingly being recognised as fundamental to national growth, economic competitiveness and societal well-being. In their international review of STEM education, Freeman et al. (2019) emphasised the need for the STEM disciplines in tertiary science education to effectively prepare students with the skills necessary for the future. Science & Technology Australia (2023) has also pointed out the rising demand for STEM skills in the workforce, as STEM degrees are highly valued by employers.

University undergraduate science programs aim to equip students with the knowledge and skills essential for professional science practice or further studies such as honours or postgraduate degrees. In Australia, the Tertiary Education Quality and Standards Agency (TEQSA) is responsible for assuring and regulating the quality of all higher education providers (2022). According to the Australian Bureau of Statistics (2008), the main fields of science study include mathematical sciences, physical sciences, chemical sciences, earth sciences, environmental sciences, and biological sciences. Most established universities with a Science Faculty offer bachelor's degrees tailored to these fields, with typically durations of three to four years. These degrees are designed to develop students' practical skills and theoretical understanding, ensuring graduates are career ready. Students generally begin with core subjects such as chemistry, biology, physics, statistics and mathematics before progressing to more specialised subjects in subsequent semesters, based on their chosen pathway. Undergraduate science curricula typically comprise both compulsory and elective coursework, supported by learning activities such as lectures, tutorials, laboratories, and optional research projects.

University teaching is different from school education in several important ways. University teachers are subject-matter experts, but their formal pedagogical education is often limited (Brownell & Tanner, 2012; Schussler et al., 2015). Gehrtz et al. (2022) found that while STEM undergraduate course teachers may lack the pedagogical expertise of school teachers, they generally possess a deep understanding of their subject matter and are often engaged in research activities. In fact, some academic prioritise research performance over teaching (Parker, 2008; Stensaker et al., 2017).

Shulman (1987) argued that effective teaching of a subject necessitates more than just content knowledge and general pedagogical knowledge; it requires a

combination of content mastery and teaching skills. Coccorese et al. (2024) found a positive correlation between teaching quality and research productivity an Italian university, but they also found that teachers who pursued greater research quality may neglect their teaching. Although teachers tend to believe that teaching is positively related to research, the input of time required in academic research can affect their teaching. Such limitations may hinder university teachers from implementing new mobile pedagogies, and contribute to the resistance toward extensive changes in their practices (Anderson, 2020). Notably, Sarkar et al. (2024) indicated that efforts to improve teaching quality at the university level have been sporadic and inconsistent, suggesting the need for further investigation into the ways university teachers can cultivate both subject content and pedagogical knowledge to enrich their students' learning experiences.

2.3.3 Digital Pedagogies in Undergraduate Science Education

Digital pedagogy in science education is "the art of teaching and learning science with contemporary educational technologies" (Kearney & Nielsen, 2019, p. 213). Integrating technology in science education can enhance learning outcomes by allowing students to engage in practices similar to those of professional scientists, such as collecting, sharing and analysing data through modelling tools; assessing evidence; and collaborating with others (Edelson, 1998).

Video-based laboratories have gained popularity as a way to provide authentic learning experiences that foster student engagement and interaction (Beichner, 1996; Rodrigues et al., 2001). Videos allow teachers and students to record their experiments, thus facilitating data collection and analysis. From a social constructivist perspective, there has been a shift of focus to classroom learning in which teachers co-construct knowledge with students. Students can challenge their prior knowledge and build new knowledge through artefacts they produce during the learning process. As will be discussed later in this chapter, examples of social constructivist digital pedagogies include collaborative learning, inquiry-based learning, and student-generated digital media.

Science education researchers have been exploring effective strategies to incorporate digital technologies into the curriculum (Bidarra & Rusman, 2017). Commonly used digital pedagogies in science education include flipped learning (Chen et al., 2022), virtual labs and simulations (Chan et al., 2021; Reeves &

Crippen, 2021), augmented reality (Arici et al., 2019; Hidayat & Wardat, 2024; Xu et al., 2022), and virtual reality (Matovu et al., 2023).

Flipped Learning. This blended learning approach involves teachers pre-recording traditional lecture content for students to watch and study before they attend class, thereby allowing for more interactive discussions during class time (Roehl et al., 2013). Research indicates that flipped learning can positively impact students' learning achievement, motivation, engagement, and interaction across different educational fields (Strelan et al., 2020; Zainuddin & Halili, 2016). Chen et al. (2022) conducted a review of flipped learning in science education and found it has been predominantly used in chemistry, physics, biology, natural science and ecology. They found instructional videos and online learning systems were typically employed for pre-class activities; problem-based learning was the most commonly adopted approach for in-class activities; and examinations were often administered post-class to assess learning outcomes.

Virtual Labs and Simulations. This approach leverages digital tools to enhance traditional instruction and conceptual understanding, allowing students to conduct lab experiments in a simulated environment (Rutten et al., 2012). Virtual experiments in science and engineering education can add value to physical experiments by connecting observable and unobservable phenomena, enabling learners to perform multiple experiments in a shorter timeframe (De Jong et al., 2013). In their review, Chan et al. (2021) found that virtual chemical laboratories can be more effective than traditional lecture, text and video teaching approaches and offering equal or greater learning outcomes compared to hands-on practical classes. Furthermore, combining traditional and virtual lab learning approaches yielded better educational results.

Augmented Reality (AR) and Virtual Reality (VR): With the development of wearable devices, the use of AR and VR in education has increased exponentially in recent years (Al-Ansi et al., 2023; Tan et al., 2022). AR technology superimposes digital content onto the surrounding real-world environment (Garzón, 2021; Hantono et al., 2018), while VR technology immerses users in simulated environments by leveraging computer graphics and motion sensor technologies to track users' body movement in real time (Burdea, 2003; Slater & Sanchez-Vives, 2016). Xu et al. (2022) identified that AR had medium-to-large positive effect on academic achievement in science-related courses. Furthermore, the science discipline (e.g., earth sciences) and AR types

(e.g., marker-based AR) also served as significant moderators of student achievement. Matovu et al. (2023) reviewed 64 studies of the ways science teachers designed, implemented and evaluated immersive VR and found that sensory and actional features of VR were frequently used to enhance students' visualisation of abstract science concepts. Despite the generally positive users' experiences in regard to engagement and motivation, the review also highlighted mixed learning outcomes.

Implementing technology into science education is encouraged as a way to construct knowledge, promote active learning, support instructional delivery and student presentations, and generate communication and research (Burden & Kearney, 2016; Sarican & Akgunduz, 2018). To ensure the successful implementation of digital practices, it is important to understand both the benefits and limitations of d-learning (Maatuk et al., 2022; McDiarmid & Zhao, 2022). Furthermore, it is essential for university teachers to master the use of digital technologies and to understand various digital pedagogies as a core component of their practices (Basilotta-Gómez-Pablos et al., 2022).

2.3.4 Reviews of M-learning in Science Education

Given the increasing interest in m-learning, researchers have used systematic literature reviews (SLRs) to examine its application in science education and to develop a collective view of the research landscape across multiple educational levels (Bano et al., 2018; Burden & Kearney, 2016; Crompton et al., 2016; Garzón & Lampropoulos, 2023; C. Liu et al., 2020; Zydney & Warner, 2016). These reviews have collectively enhanced our understanding of m-learning in science teaching and also identified opportunities for future studies.

Crompton et al. (2016) reviewed 49 publications exclusive to science education across all educational levels and found that most research focused on the elementary level (5 to 11 years) in informal settings (53%), with only 13% of the studies addressing HE. These studies often employed mixed methods and emphasised designing mobile systems, evaluating m-learning effects, and investigating the affective domain. Crompton et al. highlighted the need for more m-learning research in science disciplines at other educational levels to help teachers embrace digital practices. This is one of the key intentions of this doctoral study.

Zydney and Warner's (2016) review of science mobile apps identified common design features, including technology-based scaffolding, location-aware

functionality, and digital tools for knowledge construction. Most of the studies reviewed focused on elementary school education. They found eight out of 37 studies had used situated learning theory to design m-learning environments and that students' scientific knowledge was the most commonly measured outcome. They suggested that future studies should leverage newer mobile technologies, isolate the testing of specific app design features, and better align theories, design and outcome measures. They also recommended scholars explore science topics various involving various cognitive attributes and skills, along with diverse populations.

C. Liu et al. (2020) examined mobile inquiry-based learning (mIBL) in school science education and identified five types of mIBL: authentic, abductive, collaborative, collective whole-class inquiry, and game-based inquiry. They also categorised the benefits and constraints of mIBL into micro, meso and macro-level themes, emphasising the importance of aligning mIBL types with learning outcomes and educators' needs (see Table 2.1).

Table 2.1
Benefits and Constraints of mIBL in Science Education
(adopted from C. Liu et al. (2020))

Levels	Themes
Micro	efficiency, effectiveness, learnability, perceived usefulness and cognitive load
Meso	attitude, attention, motivation, learning performance, group work and cognitive processes
Macro	motivation

Bano et al. (2018) reviewed 49 studies focused on the effectiveness of using apps in school science and mathematics education. Most had used qualitative research methods (63%), and far fewer had used mixed methods (6%). The most frequently used pedagogical approaches were collaborative, inquiry-based, and problem-based learning in formal settings. The authors recommended adopting mixed methods designs and exploring seamless learning across a range formal settings (institution-based settings such as university lecture, tutorial and laboratories classrooms); semi-formal settings (out-of-classroom and predetermined by teachers such as museum and field trips); and informal settings

(everyday spaces chosen by students such as buses, cafes and beach). In line with this recommendation, the present study adopted quantitative and qualitative approaches to collect and analyse data from multiple stakeholders.

Garzón and Lampropoulos (2023) conducted a meta-analysis to assess the effect of the use of mobile devices on K–12 science students' learning. Their results showed that m-learning can positively affect students' learning outcomes, particularly in primary education environmental science subjects. The situated learning and semi-formal settings were found to enhance students' learning. Furthermore, Widowati and Tyas (2024) conducted a bibliometric analysis of research trends in mobile inquiry-based learning within science education, focusing on publications in Scopus from 2015 to 2023. Their findings indicate an increase in the volume of global research in this field, specifically from Indonesia and primarily in the form of articles and conference papers.

2.4 Reviews of Related Literature on M-learning

This section provides an overview of key trends and insights from existing body of research within the context of m-learning. The first sub-section focuses on SLRs of m-learning in higher education and the second sub-section provides an overview of mobile pedagogies used in undergraduate science education.

2.4.1 M-Learning in Higher Education

In higher education, SLRs of m-learning have primarily focused on multiple disciplines. Pimmer et al. (2016) reviewed 36 publications on mobile and ubiquitous learning in HE and found that mobile technologies supported instructionist approaches but were less effective in enabling transformative learning designs. Hybrid learning designs, where students create multimodal representations outside the classroom, could connect learning in formal and informal learning environments. It is worth noting that the studies in their review (from 2000 to 2013) mainly evaluated smaller portable devices such as smartphones and PDAs and did not include tablet PCs.

In their review, Krull and Duart (2017) reported an increase in HE m-learning research with a focus on mobile applications and systems, with mobile phones the most commonly used devices among the selected studies. Crompton and Burke (2018) found that most m-learning research in HE focused on the impact of m-learning on student achievement and undergraduate students in formal settings. They raised concern about the lack of research focus on the type of

pedagogical practice (20%) and science subject domain (10% combined with engineering). They suggested expanding digital pedagogy-focused research into other subject areas and gathering perspectives from multiple stakeholders in less formal settings. Addressing these gaps is another driving factor for the present study.

Sophonhiranrak's (2021) review on the features, barriers and influencing factors of using mobile devices in HE found that mobile devices can serve as instruments for diverse activities such as assessment submission, reflection, and sharing knowledge. Building on this research, Goundar and Kumar (2022) systematic mapping showed a growing interest in research related to a diverse range of m-learning applications in higher education, such as learning management systems, vodcasts and podcasts, game-based learning, collaborative learning, and language learning. Naveed et al. (2023) analysis of 167 m-learning studies across various disciplines in HE identified behaviourism, constructivism, cognitivism, and sociocultural theory as key theories used to explore m-learning. Their review highlighted factors that can impact m-learning adoption such as personal preference, intention, attitude, usage, utility, and ease of use. Most of studies in their review were conducted in developing countries, primarily focusing on student participants and employing quantitative research designs.

Overall, these reviews have broadened our understanding of m-learning in higher education and highlighted the research gaps in undergraduate science education from multiple perspectives.

2.4.2 Mobile Pedagogies in Undergraduate Science Education

This section explores research on m-learning studies specific to undergraduate science education. The emphasis is on their adopted mobile pedagogical approaches, which are derived from this researcher's co-authored SLR on m-learning in university science education (Ly & Kearney, 2024), written as part of this doctoral project. The emergent m-learning approaches included collaborative, inquiry-based, field-based, context-aware, game-based, connectivist, instructionist, and problem-based learning. Notably, these approaches often overlap, and many studies discussed multiple strategies in science learning activities.

Collaborative Learning. Collaborative learning involves students working in groups to achieve shared learning objectives (Jeong & Hmelo-Silver, 2016). The

use of mobile devices facilitates multimodal connections with peers or resources (Fu & Hwang, 2018; Lowell & Tagare, 2023) through meaningful conversations, co-creation of artefacts, and exchanging ideas. Technology-enhanced collaborative learning had been used in combination with other approaches in the reviewed studies.

Baldock et al. (2021) highlighted the potential use of iPads and Apple Pencils in a chemistry course to promote active learning through a combination of asynchronous and synchronous learning strategies. Digital tools such as OneNote, Google Slides and Socrative were instrumental in fostering problem-solving and group discussions. Faculty report from teachers and survey responses from students indicated that m-learning had enhanced students' learning. However, the provision of iPads and Apple Pencils by their university pointed to a disparity that may restrict the collaborative potential of such technologies in institutions where such resources are not readily available.

Powell and Mason (2013) conducted a mixed-methods study of the effectiveness of mobile-delivered podcasts in enhancing students' learning in inquiry-based chemistry laboratory activities. The results indicated that although students who used podcasts had engaged more with their peers and had fewer interactions with instructors, their academic performance did not differ significantly from the traditional lecture group. Furthermore, the study's focus on specific groups of students and teaching assistants limited the generalisability of the findings, thus indicating a need for further research.

Inquiry-based Learning. The inquiry-based approach in science education has emphasised student engagement through investigation, hypothesis testing, and problem-solving (Pedaste et al., 2012). It has been shown to maintain student interest and effectively support their science learning journey towards scientific literacy (Furtak et al., 2012; Tytler et al., 2008).

Chen et al.'s (2017) integration of iBeacon context-aware technology within the 5E Learning Cycle framework (Engage, Explore, Explain, Elaborate and Evaluate) illustrates the potential of m-learning to enhance museum learning experiences. They found that such technologies can facilitate student engagement with exhibits and promote deeper learning and prolonged participation. However, the limited sample size and the inclusion of students from various disciplines raised concerns about the generalisability of the results, suggesting the need larger numbers and more homogenous participants in future

studies. Similarly, Pirinen et al. (2024) adopted an open-inquiry approach to teaching digital signal processing using the Phyphox mobile app and a Jupyter interactive notebook. Although their study found positive engagement outcomes from a student questionnaire, the noticeably small sample size (n=4) limited the reliability and applicability of the findings, suggesting a need for more comprehensive studies to evaluate how the mobile-assisted inquiry approach can be applied in larger student populations.

Field-based learning. Fieldwork has a crucial role in environmental biosciences by providing students with essential practical skills (Goulder et al., 2013). Utilising smartphones or tablets into the learning process can enrich students' field experiences (Welsh & France, 2012). Often incorporating collaborative and inquiry-based learning, field-based learning allows students to engage more deeply and practically with their learning activities.

Grounded in the self-determination theory, the studies conducted by Jeno et al. (2020, 2022, 2017) have offered valuable insights into how the use of the ArtsApp can influence students' motivation and achievement in learning biology. The use of mobile apps enhanced intrinsic motivation, achievement (Jeno et al., 2017), and perceived competence among students, particularly when designed to support intrinsic goal-framing (Jeno et al., 2020). While students generally found the app useful, some expressed a preference for familiar tools such as textbooks (Jeno et al., 2022). Across these studies, limitations included small sample sizes and a focus on biology students, which raises questions about the generalisation of their findings in other science disciplines. While these studies adopted either quantitative or qualitative methods, a mixed-methods approach could have addressed the research questions in a more nuanced way.

Unger et al. (2021) evaluated the iNaturalist app's effectiveness in outdoor biology activities using a student survey and found that it improved student engagement and achieved high identification accuracy with terrestrial organisms. Nevertheless, this study was limited by the small sample size and variability in photographic quality. Schwarzenbach et al. (2022) also used a survey to explore students' experiences with the "Actionbound" app for hydrology and climatology field-based learning in Zurich, Switzerland. The app guided users to various points of interest, providing videos, photos, audio and text information, along with assignment questions that offered immediate feedback. While the app engaged students and supported them to learn at their own pace, the reliance only on

student survey and the relatively low follow-up response rate indicated a need for further studies.

Thomas and Fellowes (2017) evaluated the effectiveness of mobile apps for bird species identification with 91 undergraduate students in the United Kingdom, using pre- and post-tests and questionnaires. They reported while both the mobile app and traditional textbook improved identification skills, no significant difference was identified between the two approaches. Despite this, the students enjoyed using mobile devices for learning, suggesting that the effectiveness of m-learning may vary depending on the context.

In summary, these studies highlight the potential of mobile technologies to enhance field-based education in various science disciplines. They also presented challenges related to generalisability, comparative effectiveness and the need for larger and more diverse participant samples.

Context-aware Learning. Context-aware technology can detect learners' presence in relation to surrounding objects and people, thereby allowing the learning resources to be adaptable (Traxler & Kukulska-Hulme, 2015). This approach has been employed in several field-based studies to enrich learners' experiences in both indoor and outdoor settings.

Wang et al. (2015) investigated the use of a context-aware knowledge map (CAKM) system, which utilised radio frequency identification technology in a museum setting. In their study, students were randomly assigned to one of the three knowledge retrieval interfaces: CAKM, knowledge map (KM), and traditional keyword groups. They completed a learning achievement test and a questionnaire on their learning experience. The findings indicated that CAKM group achieved higher learning efficiency and accuracy compared to the traditional approach. Wang et al. (2020) conducted an experimental study on a context-aware plant ecology learning system (CAPELS), which integrated locations, climate data, and plant identifications. Teaching experts evaluated the system's quality and its effectiveness in enhancing learners' motivation. The results showed that students using CAPELS outperformed those relying only on textbooks in plant leaf identification, indicating that m-learning can enhance student motivation and learning effectiveness. Although both studies demonstrated the benefits of context-aware mobile systems in supporting student learning, their findings are constrained by small sample size and reliance on student participants and quantitative design.

Game-based learning. This approach integrates learning into game environments where learners can acquire knowledge and skills through competitions and challenges (Qian & Clark, 2016). Various studies have examined the efficacy of game-based apps, primarily in chemistry education.

Winter et al. (2016) described the development and implementation of the Chairs! mobile app, which helps chemistry students learn the ring flip of cyclohexane. They found that the mobile game improved student engagement and learning outcomes. Similarly, Jones et al. (2018) investigated the Chirality-2 app's ability to support organic chemistry learning. This app allowed users to earn chemistry-type medals, track their progress, post their scores or learn collaboratively in class or at home through competition. Based on the survey responses, the app provided an engaging platform for learning, yet it was most effective when combined with classroom discussions and teacher guidance, suggesting it should be used as a complementary teaching tool rather than a replacement. Fonseca et al. (2021) used a student survey to highlight the effectiveness of the MILAGE LEARN+ app in enhancing chemistry students' motivation, learning processes, and outcomes. However, the relatively small sample size and lack of qualitative data across these studies suggest the need for future research to validate and extend their findings.

In a larger mixed-methods study, Garcia and Barrientos (2023) surveyed 677 students from education, information technology, and chemistry programs across six universities in the Philippines to explore their attitudes towards mobile chemistry games (MCG). They sought to identify design lessons for MCG by comparing them with non-science m-learning games (MLG). Findings revealed significant differences in gameplay experiences in terms of competence and relatedness. While only chemistry students showed confidence in gameplay and stronger connection to the subject, most students held negative attitudes toward MCG. This result points to a need for further investigation into how game-based design can more effectively enhance learning across diverse student cohorts.

Guided by the spaced education theoretical framework (Kelley & Whatson, 2013), Pechenkina et al. (2017) examined the impact of an gamified in-house app that was designed to deliver multiple-choice quizzes after lectures and before the tutorials to accounting and science students. They found the use of apps was associated with higher retention rate and improved academic achievement. These authors highlighted the practical implications for universities (attrition cost),

teachers (content, easy-to-use teaching tool and automated collection of usage analytics) and students (learning, immediate feedback and revision tool). Despite the large sample size, the reliance on quantitative data in this study limited the scope of its findings. Future studies would benefit from adopting a mixed-methods approach to capture a more holistic view of multiple perspectives on game-based learning.

Connectivist Learning. In connectivist learning, mobile technologies are leveraged to facilitate peer connection, information exchange, and resource access (Siemens, 2004). This approach was discussed in three studies mentioned earlier in this section (Baldock et al., 2021; Fonseca et al., 2021; Jones et al., 2018).

Using quantitative methods, Bidarra and Sousa (2020) investigated how students in online physics and statistics courses used mobile devices in their personal learning environments. Drawing on responses from a questionnaire, they found that students widely adopted m-learning regardless of gender, age or course type. Although no correlation was found between social media use and prolonged study effort, students valued digital media for its connectivity and flexibility. However, the findings were limited to distance learning and may not be generalise to other educational contexts.

Escamilla-Fajardo et al. (2021) conducted a quasi-experimental mixed methods study and found that the use of TikTok could promote student motivation, creativity and engagement. Their study would have benefited from a larger sample size and multiple stakeholders' perspectives to increase the validity and reliability of the results.

Instructionist Learning. This form of learning focuses on teacher-centric practices with measurable outcomes. It relies on a structured and prescriptive pedagogy and often lacks interactive elements (Johnson, 2005).

Fernandez (2020) investigated the use of iPads and Apple Pencils for chemistry students. The responses from a student survey (n=8) revealed that the use of mobile devices enhanced the students' understanding of the topics and increased their engagement in class. Roman et al. (2021) also used a student survey to explore the effectiveness of Socrative in chemistry lectures and laboratory activities over two academic years. They found the use of apps improved students' performance and motivation and created more interactive learning environment.

Employing activity theory in an exploratory case study, Lee et al. (2021) used observations and interviews with teachers and students to investigate the affordances of Microsoft digital pens and tablets in chemistry education. The themes that emerged from their data analysis included focused learning, reflective thinking, flexibility, peer collaboration, and emerging learning. An important finding suggested that universities should consider factors such as students' technological devices and emerging learning processes when evaluating the benefits and challenges of m-learning.

Problem-based Learning. Problem-based learning (PBL) centres on students' actively learning in real-world scenarios with peers to discover and construct knowledge for problem-solving activities facilitated by a teacher (Barrows, 1996; Hmelo-Silver, 2004). Despite its common use in science education (Ayyildiz & Tarhan, 2018; Lee et al., 2017; Tandogan & Orhan, 2007), only a limited number of problem-based learning research studies could be found for the current review.

Morris et al. (2016), for example, conducted a 3-year study on students' perceptions of using pre-configured Apple iPads in neuroanatomy practical classes and their impact on learning outcomes. The pedagogical approaches underpinning their study emphasised student autonomy, problem-solving, and independent learning. Students completed an online questionnaire at the end of the practical class and answered four neuroanatomy-related quiz questions in the final exam. The study found the students had utilised mobile devices to support their learning, such as information retrieval and research, without significant training; however, the reliance on student surveys limited the depth of its findings. Further studies into the impact of technology-mediated problem-based learning should enhance understanding of its benefits.

In summary, the reviewed studies highlight the possible benefits for undergraduate science students of m-learning that uses a variety of pedagogical approaches. However, their results indicate that future researchers could enhance the impact of similar research by employing more diverse methodological approaches and including multiple stakeholders. The connection between mobile pedagogies and pedagogical innovation will be further explored in the next section.

2.5 Innovation

The concept of *innovation* in education is multifaceted and often loosely applied. Definitions vary. For instance, Reisman (2017) "Innovative pedagogy has as a

goal to prepare individuals to be creative, face changes, manage and analyse information, and work with knowledge" (p. 19) while Lindfors and Hilmola (2016) described it as inventive and novel ways to generate solutions. The present study adopts Kearney et al.'s (2019) definition of innovation as "new ideas or practices that are impactful and valuable to individuals or communities" (p. 143). Innovations can range in scale from small to large, but they must extend beyond surface-level changes to introduce new ideas that significantly impact communities or individuals (Fenwick, 2016; Lindfors & Hilmola, 2016). For Cranmer and Lewin (2017), innovations must provide value and highlight the importance of contexts; what is perceived as innovative in one context may not be perceived the same way in another. Hence, interpretations of "innovation" ultimately depend on individual perspectives and contexts (Caldwell, 2018).

Roger's (2003) diffusion of innovation theory further highlights four elements that influence the adoption of new ideas: innovation, communication channels, time, and the social system. He also categorised adopters into five groups: innovators, early adopters, early majority, late majority, and laggards, emphasising how individual and contextual factors affect the variations of adoption.

2.5.1 Digital Pedagogical Innovation

In exploring innovative classroom practices, Law et al. (2005) identified six dimensions of innovative digital learning with ICT: the intended curriculum goals of innovative practices; the pedagogical role(s) of the teacher; the role(s) of the students; the nature and sophistication of the ICT used; the multidimensional learning outcomes exhibited; and the connectedness of the classroom. Law (2003) employed these dimensions to assess and categorise the extent of digital pedagogical innovations, ranging from "traditional", "some new elements", "emergent", "innovative" to "most innovative" (p. 174). These dimensions provide a useful way to evaluate innovative digital pedagogies.

The *Innovating Pedagogy* report from the Open University in the United Kingdom identified "new pedagogies mak[ing] use of technologies to go further, to open up new possibilities" (Ferguson et al., 2017, p. 8). In the 2024 report, Kukulska-Hulme et al. (2024) identified 10 innovative digital pedagogical approaches as a guide for educators and policymakers. Examples included speculative worlds (i.e., reimagine and design a more equitable future), pedagogies of peace (i.e., promote societal harmony through peace-promoting practices), and learning in conversation with generative AI (i.e., a dialogic, real-time virtual learning method).

While new digital pedagogies continue to emerge, digital practices need to be flexible and adaptable to meet learners' needs and contexts (Bidarra & Rusman, 2017).

Sustaining and Disruptive Innovation. Digital pedagogy innovations can be categorised as sustaining and disruptive (Christensen et al., 2008; Fenwick, 2016; Kearney, Burden, et al., 2019). Sustaining innovations are characterised as using digital devices with practices modified to meet existing curriculum objectives while enhancing their effectiveness (Christensen et al., 2008; Cranmer & Lewin, 2017). For example, students might use digital lab notebooks instead of paper manuals to record experimental results in science labs. However, the activity remains largely traditional within university lab settings, where students are expected to follow pre-designed experiment procedures to achieve predetermined learning goals.

In contrast, some innovative pedagogical practices are considered disruptive or radical innovation (Christensen, 1997; Christensen et al., 2008; Cranmer & Lewin, 2017). According to Selwyn (2017), disruptive innovation is "not about using technology to do the same things differently, but using technology to do fundamentally different things" (p. 32). When applied to m-learning, these innovations leverage the features of mobile devices to create new pedagogical approaches that significantly alter learning experiences compared to traditional practices. Law (2008) argued that disruptive digital pedagogical innovations can lead to new purposes of learning, new contexts of learning, and new teacher roles and relationships with students, and thus potentially change the roles of students: "the innovation as a whole can be considered a disruption to prevalent practices" (p. 428).

Disruptive digital pedagogies correspond to the Redefinition level in Puentedura's (2013) SAMR model, yet their implementation has been limited. Currently, the use of digital technologies in education tends to align more with traditional pedagogical approaches, with minimal curriculum changes. In the SAMR model, most educational applications remain at Substitution level (the lowest level), where technology has simply replaced traditional tools without transforming teaching practices. Rogers (2003) highlighted the importance of incremental innovation through small-scale interventions, a viewpoint supported by other scholars who also recognise the challenges associated with scaling disruptive innovations (Kampylis et al., 2013).

Christensen et al. (2013) discussed a misconception regarding disruptive innovation – the notion that “disruptive innovations are good and sustaining innovations are bad” (p. 1). They argued that such an interpretation is inaccurate because sustaining innovations are essential to a healthy and robust sector as organisations try to improve their products or services (including education). They noted that disruptive innovations do not necessarily provide better products to customers (or students in the context of education) in established markets (universities or schools in the context of education).

Although the use of educational technology has long been promoted as transformative (Conole, 2014; Laurillard, 2008), evidence of digital pedagogical revolutions in HE remains limited (Criollo-C et al., 2021; Henderson et al., 2017; Kirkwood & Price, 2013). Cochrane (2014) emphasised the need for new technical and pedagogical support strategies, as well as the creation of supportive communities of practice, as key factors for digital pedagogical transformation. Henderson et al. (2017) also noted that despite the distinct features of digital technologies that support students’ learning, they “are clearly not ‘transforming’ the nature of university teaching and learning, or even substantially disrupting the ‘student experience’” (p. 1577-1578). They suggested that rather than being overly enthusiastic about what digital technologies can do, university teachers should gain insights into the realities of students’ experiences with digital learning.

Although educators may incorporate digital practices into their curriculum design, this implementation does not necessarily equate to innovative or transformative pedagogies. Given the constrained parameters of universities and schools, the expectations of more disruptive digital pedagogical innovations are viewed as unrealistic and unlikely to be successful (Cranmer & Lewin, 2017). Hence, Burden, Kearney, Schuck and Hall (2019) suggested a “sweet spot” – somewhere between sustaining and radical innovation, where “feasible” mobile pedagogical innovation is more likely to be achievable and scalable.

2.5.2 Mobile Pedagogical Innovation

Innovative mobile pedagogies have the potential to transform existing paradigms and open new opportunities for learning by leveraging the unique features of mobile devices, such as portability and connectivity, to achieve teaching and learning outcomes that are unattainable otherwise (Chee et al., 2017; Traxler, 2010b). They also enable learning experiences beyond the boundaries of the

classroom (Schuck et al., 2017). In STEM education, mobile approaches, particularly those focused on problem-solving and real-world applications, have been shown to have a larger effect on student performance (Tlili et al., 2024). This is largely attributed to the interactive capabilities of mobile devices, such as hands-on simulations and experiments, which can help students understand complex scientific concepts and foster essential skills such as communication, problem-solving and creativity (Sung et al., 2016). They can also positively impact teachers' perceptions of student learning experiences (Burke et al., 2025).

Despite promising findings and long-standing expectations that mobile pedagogies could transform education (Kearney et al., 2012; Lindsay, 2016; McHaney, 2023; Norris & Soloway, 2011; Norris & Soloway, 2015; Pegrum et al., 2018), the adoption of mobile technologies has not brought about the anticipated levels of radical pedagogical innovations (Burden, Kearney, Schuck, & Hall, 2019; Kearney, Burden, et al., 2019; Selwyn, 2017). Nor have educators fully harnessed their potential; instead, they have often woven these tools into conventional, teacher-centred approaches (Cochrane & Antonczak, 2014; Pimmer et al., 2016; Traxler, 2021). There remains insufficient evidence about whether the use of mobile devices can transform learning experiences or merely replicate existing practices (Crompton & Burke, 2018, 2020; Selwyn, 2017; Traxler, 2018). Enduring transformations will require not only the introduction of technology into learning activities but also improvements in the theory and practice of teaching, learning, and assessment (Sharples, 2019). The present study's investigation of mobile pedagogical innovation in undergraduate science education aligns with this need.

Related Studies on Mobile Pedagogical Innovations. Scholars have begun to further explore the impact of innovative mobile pedagogies, albeit primarily at school levels. Burke et al. (2025) employed structural equation modelling to investigate the impact of iPAC mobile pedagogies and mobile innovation (or m-innovation) on K–12 teachers' perceptions of student learning experiences. They found that teachers who exhibited enhanced agency during customised and authentic m-learning activities were more likely to view their mobile practices as innovative and improve students' learning.

Burden, Kearney, Schuck, and Hall (2019) analysed 57 papers on innovative mobile pedagogies in schools and identified only three studies (Akom et al., 2016; Barak & Ziv, 2013; Toh et al., 2017) that examined disruptive digital

pedagogical innovations unachievable without the use of mobile devices. Those studies had disrupted traditional teacher-student interactions by involving community engagement in project-based learning, namely, the inclusion of family members in inquiry projects (Toh et al., 2017) and the collecting and sharing data with the public in a health promotion project (Akom et al., 2016). Students learned across formal school and local environments as they created location-based interactive learning objects (LILOs) on a mobile platform named “Wandering” and shared their work on social media (Barak & Ziv, 2013). These technology-mediated activities involved a radical shift in student agency, granting them high autonomy over the location, time and pace of their learning, with free choices of apps and how they used them to co-created apps and LILOs. Barak and Ziv (2013) also emphasised the value of personalised learning experiences, where students could learn with their smartphones and teachers could “release control” and allow students to explore and learn from their mistakes.

Despite these insights into the application of innovative mobile practices in schools, there remains a limited body of research related to higher education. Criollo-C et al. (2021) conducted a systematic mapping of innovative mobile practices across multiple disciplines, examining five educational innovation dimensions: purposes of learning; contexts of learning; roles of the teacher and learner; and evidence of results. They identified 27 relevant publications and found that the role of teachers was the least studied dimension, indicating a need for more teachers’ involvement in adopting innovative mobile practices. In contrast, the purpose of learning was the most explored dimension.

Among the studies reviewed earlier on m-learning in undergraduate science education, only Schwarzenbach et al. (2022) and Escamilla-Fajardo et al. (2021) focused on the innovative mobile pedagogies in their research. The remaining studies did not consider digital pedagogical innovation or only mentioned it superficially (Garcia & Barrientos, 2023; Wang et al., 2015). The present study aims to fill this research gap by adopting a combination of Kearney et al.’s (2012) iPAC mobile pedagogical framework and criteria of digital pedagogical innovation (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005) to examine mobile practices specifically within undergraduate science education from multiple perspectives.

2.5.3 Digital Pedagogical Innovation Frameworks

The innovative pedagogical criteria (Burden, Kearney, Schuck, & Hall, 2019) adopted in this study were derived from Law et al.'s (2005) digital pedagogical innovation dimensions (see Section 2.5). Underpinned by sociocultural theory, these criteria can be utilised to evaluate the following aspects of pedagogical innovation in m-learning contexts:

- The purpose of the m-learning activity: measures the innovativeness of the learning activity and whether it could occur without the use of digital devices. This could include the curriculum design, lesson plans, learning objectives and/or nature of the task.
- Context of learning: captures the flexibility of m-learning contexts, such as location, time and learning modes (e.g., face-to-face or online).
- Roles of teachers and their relationship with students: examines whether the roles of teachers and their relationship with students differ from traditional approaches and include external participants such as family or community members.
- Roles of students: assesses students' choices in what (e.g., the learning objectives, the apps) and how they learn using mobile devices (e.g., their preferred place, time or pace)

Other models also explore digital pedagogical innovation. Mioduser et al. (2003) introduced a two-axis schema for analysing domains and levels of pedagogical innovation in schools using ICT. The vertical axis consists of the domain of innovation: time and space configurations, student roles, teachers, and the curriculum, while the horizontal axis covers levels of innovation: assimilation, transition, and transformation. Mioduser et al.'s (2003) schema broadly examines innovation across ICT domains, while Burden, Kearney, Schuck, & Hall's (2019) and Law et al.'s (2005) criteria were specifically designed for digital pedagogical innovation. Although the Science Learning Activities Model (SLAM) framework (Bidarra & Rusman, 2017) provides valuable insights into designing participatory and innovative science learning activities through interactive technologies (e.g., mobile applications, AR and VR), it primarily focuses on the context, technology and pedagogy of learning rather than exclusively addressing pedagogical innovation.

By adopting Burden, Kearney, Schuck, & Hall's (2019) and Law et al.'s (2005) criteria for pedagogical innovation, the current study aimed to obtain empirical insights into university science teachers', learning designers', and students' perceptions of innovative mobile practices and thus contribute to a more comprehensive understanding of m-learning affordances in undergraduate science education.

2.6 Chapter Summary

This literature review has provided a comprehensive overview of the implementation of educational technology, focusing particularly on m-learning within undergraduate science education. It has justified the selection of the iPAC mobile pedagogical framework and criteria of digital pedagogical innovation for the present study, highlighting their importance in analysing mobile practices from a sociocultural perspective. The research questions of the present study address the following gaps informed by the literature.

First, research on m-learning in schools indicated that science was the most commonly subject studied (Crompton et al., 2017; Crompton et al., 2019; Liu et al., 2014). However, this literature review suggests a limited of empirical research on distinctive mobile practices in undergraduate science, thus highlighting a notable research gap.

Second, the existing research on m-learning practices in undergraduate science education has primarily adopted quantitative methods to study the digital pedagogical phenomena at specific time points. To provide a more nuanced and "thick descriptive" (Lincoln & Guba, 1985) understanding of distinctive mobile practices, the current study employed a mixed methods approach that included surveys, interviews, focus groups, and observations.

Third, the literature presented in this chapter reflects a research trend for studies to typically include only one or two types of "stakeholders" – usually students or teachers. The present study has a broader scope: it collected data from multiple perspectives, namely, science teachers, learning designers, and students across multiple universities, thus enriching the findings through data triangulation.

Fourth, researchers on m-learning in science higher education have often not drawn on strong theoretical frameworks. The present study, underpinned by the sociocultural theory, incorporated the iPAC mobile pedagogical framework (Kearney et al., 2012) and innovative digital pedagogical criteria (Burden,

Kearney, Schuck, & Hall, 2019; Law et al., 2005) to gain evidence-based insights into m-learning phenomena in undergraduate science education.

Fifth, many of the reviewed undergraduate m-learning studies examined a specific science discipline or included non-science subjects. This study aligns with the recommendations of scholars advocating for the exploration of m-learning affordances in a broader range of higher education science disciplines (Crompton & Burke, 2018; Pimmer et al., 2016).

Sixth, given that students' experiences with mobile pedagogies are influenced by diverse contexts (Kearney et al., 2020), this study investigate from a sociocultural perspective the potential of distinctive mobile practices in diverse learning activities in undergraduate science education.

Seventh, many of the studies reviewed in this chapter are more than five years old. This raises questions about the ongoing applicability of their findings. This investigation of the affordances of mobile devices for learning aligns with calls for continuous research into the dynamic nature of the digital landscape.

To my knowledge, this is the first empirical study to examine the use of distinctive mobile pedagogies and perceptions of digital pedagogical innovation in undergraduate science education from global universities, with a particular focus on Australia and insights from multiple stakeholders.

The next chapter describes the research design of this study, including its methodology and strategies for data collection and analysis.

Chapter 3
Research Methodology

This study examines the use of distinctive mobile practices in undergraduate science education from the perspectives of teachers, students and learning designers. It also investigates how these educators' mobile learning activities were perceived as pedagogically innovative. This chapter begins by justifying the pragmatic paradigm and research design adopted for this study. It then details the researcher's role and the research methods, followed by participant information and the background of the case studies. Finally, it presents the data analysis procedures, along with considerations of study rigour and ethics.

3.1 Philosophical Positioning

This section discusses the philosophical positioning and rationale for adopting a mixed methods approach to address the following primary research question and four subsidiary research questions:

Primary research question:

How are mobile technologies being used in undergraduate science education to support teaching and learning?

Four subsidiary research questions:

RQ1: How are university science teachers using distinctive mobile pedagogies?
RQ2: How do learning designers view these mobile pedagogies?
RQ3: How do students experience these mobile pedagogies?
RQ4: To what extent are educators' mobile learning activities perceived as pedagogically innovative?

Selecting an appropriate paradigm is crucial for shaping the focus of a study and the reporting of its findings (Shannon-Baker, 2016). This study is underpinned by a pragmatism research paradigm, which focuses on finding "what works" and identifying what solutions can address problems (Creswell, 2009; Patton, 1990). Pragmatism is particularly relevant to this study because it offers a middle ground beyond the "paradigm wars" and overcomes the limitations of both positivist and interpretive paradigms. While positivism views the social world as objective and quantifiable, interpretivism assumes a subjective and intricate social world

(Cohen et al., 2017), pragmatism avoids debates about truth and reality. Instead, it recognises the value of both singular and multiple realities in empirical investigations aimed at addressing practical problems (Saunders et al., 2016).

This perspective enables the researcher to "find out what I [the researcher] want to know" (Hanson, 2008, p. 109). Pragmatism provides an epistemological foundation that supports mixed methods research by integrating quantitative and qualitative data. It offers a lens through which researchers can focus on data that is relevant to current and future knowledge. By supporting a mixed methods approach, pragmatism yields more nuanced insights than a single method might produce.

In this study, quantitative data elicited through a survey were used to identify broad patterns in teachers' mobile practices, and qualitative data provided deeper insights (from multiple perspectives) into the phenomenon, gathered through the case studies. This study recognises the value of mixed methods rather than adhering rigidly to a single methodological tradition (Patton, 2002). Some scholars have advocated embracing multiple worldviews through mixed methods to broaden understanding (Hall, 2013; Shannon-Baker, 2016; Sommer Harrits, 2011). Pragmatism empowers researchers to choose the most suitable methods to explore a particular theory, phenomenon or question (Feilzer, 2010) and facilitate a "properly integrated methodology for the social sciences'' (Morgan, 2007, p. 73). This is especially important in studies that examine the connection between theory and practice, and the dynamic nature of the social research environment.

Given that this study explores the perspectives of science teachers, learning designers, and students on mobile practices and pedagogical innovation in undergraduate science education, both globally and in Australia, pragmatism is well-suited for capturing the richness of these experiences. Ultimately, pragmatism provides a strong philosophical foundation for addressing the complex and evolving nature of mobile pedagogies and innovation, ensuring that findings are both theoretically grounded and practically informed.

3.2 Research Design

This study adopted a concurrent mixed method design, integrating both quantitative and qualitative data to develop a comprehensive understanding of the research problem (Creswell, 2009; Creswell & Creswell, 2018; Tashakkori et al., 2021). As no single method alone is sufficient to capture all the details and

trends in a situation (Greene et al., 1989; Tashakkori & Teddlie, 1998), combining multiple methods can strengthen findings through triangulation and enhance validity (Johnson & Christensen, 2008). Triangulation in this study allows for cross-validation of data from across various sources (Patton, 1999) to provide a more inclusive analysis of the findings (Gelo et al., 2008).

There were two phases in this study. Phase One utilised a global survey of university science teachers while Phase Two featured six case studies from universities in New South Wales, Australia. Each phase targeted different groups of participants. The case studies formed the core component of this research, with the Phase One survey providing broader global perspectives on mobile practices. This design was informed by a sociocultural perspective (detailed in Section 1.4), which emphasises learning as a socially mediated process through interactions and conversations (Vygotsky, 1978). This study also utilised the iPAC mobile pedagogical framework (Kearney et al., 2012) and criteria for innovative digital practices (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005) to guide both data collection and analysis.

Mixed methods design has been effectively employed by other scholars to investigate the complexity of learning with mobile devices in similar research areas (see Chapter 2 literature review). Unlike prior studies that employed relatively narrow study designs, the present study adopted multiple phases and methodologies to explore distinctive and innovative mobile practices in undergraduate science education from global and Australian perspectives. Table 3.1 presents the timeline and alignment between the research questions, study phases, research methods and participants.

Table 3.1

Overview of the Research Plan

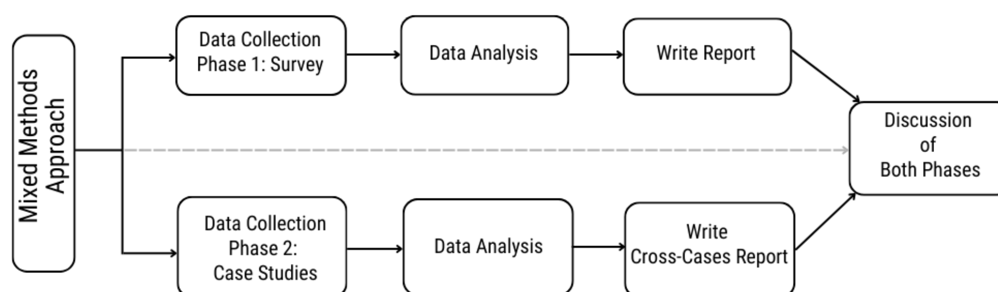
Timeline	**Overarching RQ:** How are mobile technologies being used in undergraduate science education to support teaching and learning?	Phases	Research methods	Participants
Jan – Sep 2023 (8 months)	**RQ1:** How are university science teachers using distinctive mobile pedagogies? **RQ4:** To what extent are educators' mobile learning activities perceived as pedagogically innovative?	1	Global survey	Teachers
Semester 1 & 2/2023 (6 months)	**RQ1:** How are university science teachers using distinctive mobile pedagogies? **RQ2:** How do learning designers view these mobile pedagogies? **RQ3:** How do students experience these mobile pedagogies? **RQ4:** To what extent are educators' mobile learning activities perceived as pedagogically innovative?	2	Six Case studies (NSW, Australia), including: • Observations • Teacher and student surveys • Semi-structured Interviews • Focus groups	Teachers, learning designers, students

Note. For more information, see Section 3.4 for research methods, Section 3.7 for data analysis and Section 3.8 for study rigour

Figure 3.1 presents an overview of the two-phase, mixed-methods study design, integrating both quantitative and qualitative approaches to answer the research questions. Data from each phase were collected, analysed and reported independently, with cross-case analysis conducted in Phase Two. Synthesising findings from both phases aimed to gain a comprehensive multidimensional understanding of distinctive and innovative mobile practices in undergraduate science education.

Figure 3.1

Illustration of the Study Design



Note. For more information, see Section 3.4 for research methods, Section 3.7 for data analysis and Section 3.8 for study rigour

The next sub-sections introduce the survey and case study methodologies used in this study.

3.2.1 Phase One: Survey Methodology

Survey research is widely used in education to gather data from a target population to understand "their characteristics, opinions, attitudes, or previous experiences" (Leedy & Ormrod, 2005, p. 183). Quantitative methodology refers to techniques for collecting, analysing and interpreting numerical data (Tashakkori et al., 2021), operating on the assumption that social phenomena can be measured quantitatively through scientific method and hypothesis testing. Quantitative research is typically confirmatory and guided by prior theories and established knowledge related to the investigated phenomenon (Tashakkori et al., 2021). Surveys, as methodological tools, systematically collect numerical data to predict the attributes or behaviours of the population of interest.

This study used a global survey to explore teachers' mobile practices by adapting the validated teacher survey developed by Kearney et al. (2019) to ensure methodological rigour. The survey involved administering a set of pre-determined questions in a standardised format to a representative sample of university science teachers (see Section 3.5.1 for participant selection criteria). This approach aligns with the core assumptions of quantitative research that structured, numerical data can reveal statistical patterns.

3.2.2 Phase Two: Case Study Methodology

The case study is a well-established qualitative methodology for in-depth investigation of real-life phenomena (Denscombe, 2007; Yin, 2009). It is suited to generating comprehensive insights of complex issues and to developing new knowledge (Bogdan & Biklen, 1982). Case study research often involves multiple data collection methods (Bryman, 2012; Dörnyei, 2007) to understand the characteristics of the phenomenon under investigation (Denscombe, 2007; Silverman & Seale, 2005). This makes it particularly compatible with the mixed methods designs and the pragmatic paradigm informing this study.

Depending on the research focus, case studies may involve single or multiple case designs (Stake, 2005; Yin, 2002). While single-case studies may capture unique instances, multiple-case studies enabled comparative analysis across contexts, enhancing the robustness of the findings (Herriott & Firestone, 1983; Yin, 2018) and strengthening the validity through data triangulation (Stake, 2006). Within multiple-case designs, each case can be either a holistic or embedded structure (Yin, 2018). A holistic design of each case has a single unit of analysis, while an embedded design focuses on subunits within each case. Phase Two of this study employed a holistic multiple-case design to investigate the use of mobile practices in undergraduate science education across six cases from four New South Wales universities. These cases were bounded by the university location and the participants' m-learning experiences. Instead of presenting individual case reports, findings are presented as a consolidated analysis to streamline reporting and avoid redundancy (see Chapter 5).

Limitations of Multiple Case Studies

Despite their strength, multiple case studies also present several limitations. Findings from individual cases, or even a collection of cases, are inherently context-specific, making generalisation more difficult compared to experimental studies (Greene & David, 1984). However, well-designed case studies can provide rich contextual details, allowing other researchers and practitioners to evaluate the transferability to their context. Further, conducting multiple case studies is resource-intensive, demanding substantial time, effort and costs for data collection, analysis and reporting (Anderson et al., 2014). Additionally, inclusion of multiple cases may not offer the same level of detail as single-case studies, due to time constraints (Gerring, 2007; Hunziker & Blankenagel, 2024). In this study, challenges arose during the early phase of participant recruitment,

resulting in variations among the number of cases per university, largely due to varying responsiveness across institutions.

The Value of Cross-Case Analysis

Cross-case analysis provides a systematic way to identify similarities and differences across cases, enhancing the robustness of research findings (Hunziker & Blankenagel, 2024). This approach was particularly suitable for this study's goal of exploring mobile practices across diverse undergraduate science learning activities. Each case was first analysed independently, then synthesised to identify common themes. This approach can strengthen the development of theory by highlighting the patterns and variations between cases (Ridder, 2017).

The cross-case synthesis was instrumental in drawing meaningful comparisons between cases while maintaining the focus on the specific phenomena under investigation (Yin, 2018). To explore perceptions of mobile practices in the nominated learning activities, thematic analysis (see Section 3.7.2) guided the coding and theme development, ensuring each theme was supported by multiple triangulated data sources. This allowed the study to examine both shared practices and context-specific variations across different science subjects, activities, and participant groups.

3.3 The Role of the Researcher

The researcher's role and positionality are crucial to maintaining the integrity and quality of the research process (Holmes, 2020). To ensure research is conducted ethically and meticulously with an awareness of its limitations, it is important to be transparent about the researcher's background, assumptions and potential biases. I am both an insider and an outsider in my research area. As an insider, I am an academic coordinator within a diploma of science program, and being a science graduate from an Australian university enabled me to relate to participants' perspectives. Nonetheless, I am also an outsider, as I was external to the faculties of science involved in my study during the research period. Acknowledging this dual positionality, I remained open to the diverse perspectives shared by participants and took proactive steps to ensure ethical and professional boundaries. As described by Cohen et al. (2011, as cited in Holmes, 2020, p. 2), reflexivity refers to "researchers should acknowledge and disclose their selves in their research, seeking to understand their part in it, or influence on it". Throughout this study, I constantly engaged in reflexivity by critically reflecting on my assumptions about the data interpretations and actively

seeking alternative interpretations by engaging with relevant literature and discussion with supervisors.

3.4 Research Methods

This section outlines the research methods employed in both phases of this study. Phase One involved a survey targeting university science teachers worldwide. Phase Two adopted a multiple-case study approach incorporating observations, surveys, interviews and focus groups. Participant information sheets were available for all research methods (refer to the list of appendices). Table 3.2 presents an overview of the research methods, including the study phases, participants sample size, research methods with further details.

Table 3.2
Overview of the Research Methods

Phases	Participants and sample size	Research methods	Further details
1. Global survey	University science teachers (n=132)	Teacher survey	anonymous - teachers' views of digital pedagogies adopted in ONE recent science learning activities
2. Case studies NSW, Australia (n=6)	a) University science teachers (n=10)	Observations	Research observed the nominated learning activities
		Teacher survey (n=10)	One survey per teacher. (two cases with two teachers each - Cases 2 and 5)
		Semi-structured Interview (n=10)	One interview per teacher using the iPAC and innovation sliders
	b) Undergraduate science students (147 students who provided consent for observation)	Student survey (n=126)	Anonymous - students' views of mobile pedagogies in the observed activity
		Focus group (n=19), total students (n=44)	with use of iPAC and innovation sliders, students' artefacts as stimulus e.g., photos, screenshots
	c) Learning designers (n=8)	Semi-structured Interview (n=8)	one interview per learning designer using the iPAC and innovation sliders as stimulus

Note. For more information on case studies, refer to Section 3.5.3 for participant information, Section 3.6 for case study's background information. Table 5.1 provides an overview of Phase Two case studies.

The following subsections outline each of the study's research methods and how it was applied, including their benefits and limitations, as well as the recruitment process for data collection. More specific information about each case and a breakdown of participants in each case is available in Section 3.6.

3.4.1 Phase One Survey Tools

Survey research involves collecting, analysing and interpreting data from a specific group to gain their opinions and perceptions of the topic under investigation (Varghese et al., 2025). This study adapted the validated iPAC teacher survey (Kearney et al., 2019), originally designed for mainstream teachers to elicit university science teachers' perspectives regarding a recently implemented science activity in which students used a mobile device to support learning. The activity could range from a brief task to more extended activities spanning several days, implemented either in and/or outside the classroom.

For the current study, the iPAC survey was modified over several iterations to ensure clarity and relevance to undergraduate science education contexts, without changing the core items of the survey. To better align the initial version with typical university science students' learning tasks, the researcher adjusted the background information items including the years of teaching, science discipline areas, the undergraduate levels, and the types of examples in the core items. The original survey's "piped through" inclusion of discipline and cohort information (e.g., biology and 1st year) within the main stem of the core iPAC items was removed to reduce redundancy and survey length. These decisions were informed by consultations with three science subject coordinators and regular supervisory feedback to ensure the survey language and examples were suitable for university science teachers.

Further validation was achieved through frequent discussions with two of the iPAC framework's co-designers, ensuring alignment with the subconstructs and underpinning sociocultural theory (Kearney et al., 2012). To support global applicability, additional feedback was obtained from a pilot of five university science teachers from different science disciplines (three English-speaking and two Chinese-speaking) across four countries. Their input informed final refinements to survey examples and the user interface, improving clarity across international university science education contexts.

The final version of the survey was available in English and simplified Chinese (see Appendices C and D). The aim of providing the survey in both languages

was to achieve higher response rates in countries where these languages are widely used. Furthermore, the researcher's fluency in English and Chinese also facilitated accurate translation and consistent data interpretation.

Phase One teacher survey included seven sections with 16 closed-ended and two open-ended questions. The participating teachers were given 5-point Likert scales to indicate their agreement levels (1= Strongly Disagree, 2= Disagree, 3= Neutral, 4= Agree, 5= Strongly Agree) to respond to the core items. The first two sections collected background information about the participants and their chosen m-learning activities. Section 3 focused on the core iPAC constructs – collaboration, agency, and personalisation (Kearney et al., 2012) – where participating teachers reflect on their students' behaviour in the chosen activity. Each construct was divided into two sub-constructs: collaboration (conversation and co-creation), personalisation (agency and customisation), and authenticity (context and task). Section 4 featured five questions about students' overall learning experiences, while Section 5 addressed pedagogical innovation. Section 6 asked about the location of the activity, with the option to choose more than one location. Section 7 of comprised two open-ended questions inquiring about the main application(s) used in the nominated activity and a brief description of how students used them. The open-ended questions provided opportunities for the participating teachers to elaborate or provide further details about their activities.

Benefits and Limitations of the Survey Method

Surveys are effective means of collecting data and perceptions from research participants and often serve as an initial step for further research methods, such as interviews and focus groups (Varghese et al., 2025). In this study, survey data were collected via Qualtrics, which facilitated automated data entry and streamlined the data analysis process. The Phase One survey allowed the researchers to gather a large volume of representative data from a broad and diverse population of university science teachers worldwide. The survey was both efficient and cost-effective in reaching a targeted international academic audience and for providing a straightforward way to obtain both quantitative and qualitative information on recently implemented m-learning activities. This broad reach supported greater generalisability by highlighting trends across a wide range of contexts.

However, the survey method was constrained in this study. While large-scale surveys offer breadth of coverage, they often lack the depth required to explore the complex research topic (Denscombe, 2010) and often cannot capture the unique qualitative traits that defined individual members within the collectivity (Thomas, 2003). Additionally, Denscombe (2010) noted that response rates in such survey can be low, particularly when potential participants were selected randomly and the researcher had no personal contact with them. In this study, despite active recruitment efforts, some participants dropped out due to the survey length, although the majority completed it. Contributing factors may include language barriers and limited internet access in some regions.

Another constraint included the reliance on self-reported data, which introduces the possibility of response bias, as participants may have chosen activities they believed reflected best practices rather than typical examples. Further, variation in university science education systems and standards across countries added complexity to data interpretation. Relying solely on survey tools would have constrained the study's capacity to capture the multifaceted nature of science mobile practices from multiple stakeholders. Therefore, to obtain a richer and nuanced understanding, this study also incorporated interviews, focus groups, and observations.

Phase One Recruitment. A combination of purposive and snowball sampling techniques was employed to recruit participants in this phase. Widely adopted in qualitative research, purposive sampling selects participants as representative samples of the target population (Cohen et al., 2011; Denzin & Lincoln, 2005). It was used in this study to identify participants whose experiences and opinions might reflect the targeted group of university science teachers (Martínez-Mesa et al., 2016). The global survey was disseminated to university science teachers using publicly available contact details found on university websites and in reference lists of the literature reviewed.

The Phase One survey was active from 24 January 2023 to 4 September 2023. The recruitment process involved the following steps:

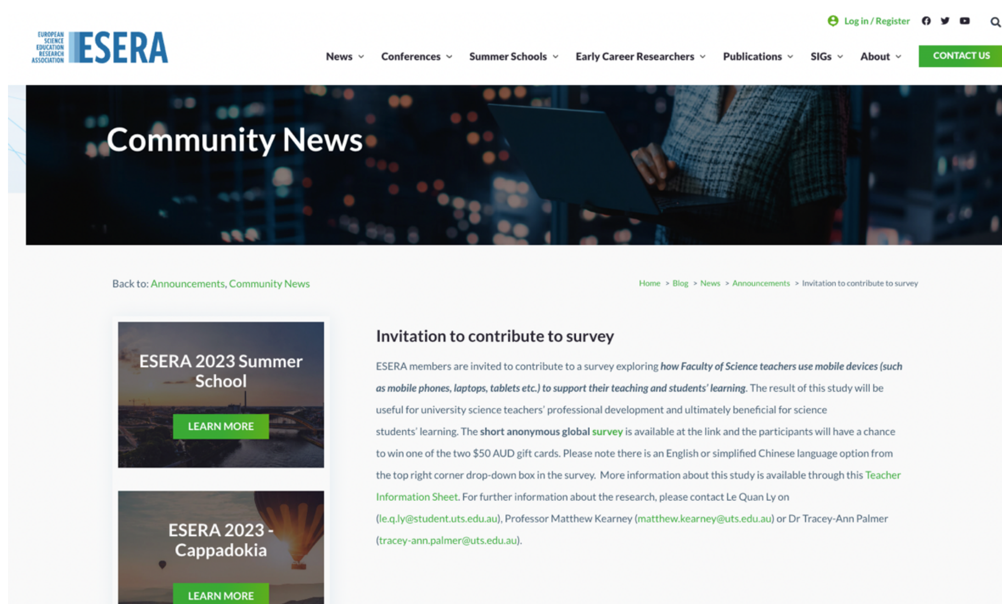
Step 1: identify universities in each country via Google search. E.g., names of universities in Australia.
Step 2: access to the university websites to locate faculty of science teaching staff directories.
Step 3: email survey invitations to prospective participants.

In addition, the survey invitations were distributed to prestigious science education researchers and to organisations such as the National Association of Research in Science Teaching (NARST), European Science Education Research Association (ESERA), the Australasian Society for Computers in Learning in Tertiary Education (ASCILITE) and the Australasian Science Education Research Association (ASERA) to promote the survey campaign.

Snowball sampling, which relies on initial participants referring others (Fogli & Herkenhoff, 2018), was particularly useful in this global survey where a comprehensive database of university science teachers was unavailable. Further dissemination occurred through word-of-mouth referrals and private group chats. To enhance the survey response rate, three online advertising campaigns (initial, reminder, and final) were launched across popular platforms, including LinkedIn, Facebook, Twitter (now known as X), Instagram, WeChat, and WhatsApp. These campaigns utilised the following specific hashtags to capture users' attention: #digital learning, #mobile learning, #m-learning, #digital pedagogy, #mobile pedagogy, #innovative pedagogy, #innovation, #science, #university, and #higher education. Furthermore, these posts were also shared, reposted or retweeted by science teachers and academic influencers. Figures 3.2 and 3.3 are illustrations of the Phase One survey campaign.

Figure 3.2

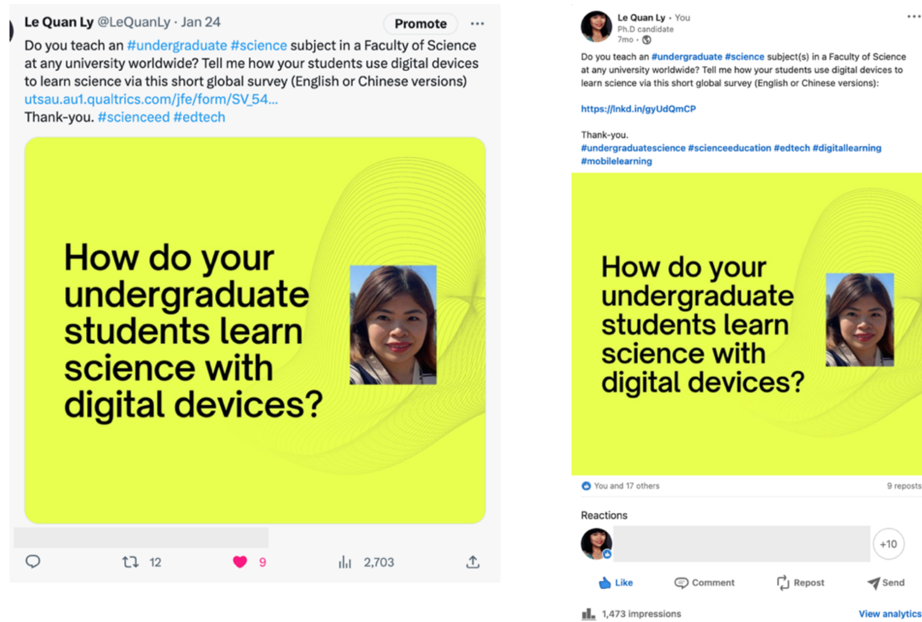
An Example of the Phase One Survey Promotion Campaign



Note. *An example of survey promotion on the ESERA Community News website*

Figure 3.3

Examples of the Survey Dissemination Campaign on Twitter (now X) (left) and LinkedIn (right)



Note. *Phase One advertisements on Twitter (now X) and LinkedIn with post analytics data, including discovery impressions (the total number of times the posts were displayed on screen) and engagements (the total number of audience reactions and reposts).*

Sample Statistics

This sub-section describes the sample of teachers who completed the Phase One survey, along with information about the completion of each section of the survey. A total of 269 teachers began the survey, and invalid responses were removed due to low completion rates or incomplete core items. Table 3.3 presents the number of respondents for the closed-ended questions.

Table 3.3

The Number of Teachers Completing Closed-Ended Items from the Survey

Survey sections	Questions	Number of Teachers
Background items	Q1 - 4	199
Digital learning activity	Q5 - 7	189
iPAC items	Q8 – Q13	146
Overall experience	Q14	143
Innovation	Q15	140
Location of the chosen activity	Q16	140

Of the 269 teachers who started the survey, 199 (74%) responded to the background information questions, and 189 (82%) of these completed the questions related to their learning activities. Sixty-one percent of the teachers responded to all core items. Data analysis was performed on 132 fully completed closed-item survey responses after excluding invalid responses. From these 132 respondents, most (124 for question 17 and 118 for question 18) completed the open-ended questions. In Phase One, the teachers were labelled using hashtags for identification purposes (e.g., Teacher #1).

In alignment with the case study methodology, Phase Two employed multiple data collection methods – observations, surveys, interviews, and focus groups – to capture in-depth, contextualised insights from multiple participants regarding mobile practices in undergraduate science education.

3.4.2 Observations

Observations provide researchers with opportunities to collect in situ, first-hand data from naturally occurring settings (Cohen et al., 2017). They typically involve the researcher watching, listening, and recording what occurred in the observed activities (Thomas, 2003). The direct observation data in this study served as supporting evidence for the surveys, focus group and interview data to triangulate findings. The researcher observed six case studies nominated by science teachers from four universities based on the timetable schedules. Each case consisted of one learning activity, except for Cases 1 and 3, which included two activities each. The teachers informed their students about the researcher's project approximately one to two weeks before the observation to seek students' interest in participating in the activity observed, the optional survey, and the focus group. The aim of these strategies was to assist the researcher in recruiting teachers and students from the same cohort.

Students typically signed the consent form on the day of the observation after the researcher re-introduced the project. The researcher normally sat at the back of the classroom or in an appropriate area to take observation notes on the learning activities using the observation template as a guide (see Appendix K). Since all observations took place before the focus group and interview sessions, the researcher used the scenarios and interactions in the observations to assist participants in recalling their experiences.

In Cases 1a and 5, the subject coordinators invited the researcher to attend the introductory session, which was the first class of the semester. These sessions

were ideal opportunities for the researcher to meet the student cohort, introduce the research project, and seek the students' participation. The researcher then distributed participant information sheets and consent forms for students to sign in the introductory session.

Benefits and Limitations of Observations

Direct observation can play a crucial role in spontaneously capturing phenomena and participants' interactions as they occur (Kumar, 2005; Tashakkori et al., 2021). In this study, it was used to triangulate findings from the surveys, interviews, and focus groups, offering detailed insights into undergraduate science mobile practices. While the observational data were not analysed separately, they provided rich contextual information that complemented other sources and helped interpret the perspectives of the participating teachers, learning designers, and students. They were collected during on-campus sessions, with some of the student surveys and focus groups conducted immediately following the observed activities. A notable exception was a 7-day field trip, which offered extended opportunities for data collection. These observations added depth to the case studies, reinforcing the reliability of findings by capturing what exactly happened in the observed activities.

Even though they can be valuable, observations are context-specific and influenced by factors such as class schedules and the presence of the researcher, which can affect both what is observed and how participants behave (Kumar, 2005). In this study, the observations were bounded by the nominated learning activities and university timetables, which limited the representation of different science disciplines and activity types. The awareness of being observed can also influence participants to alter their behaviour, potentially causing discomfort or self-consciousness and participants may modify their behaviour due to the presence of the researcher. Additionally, it is impossible for a researcher to document everything that happens during a session (Thomas, 2003), potentially missing details. Moreover, observations also require significant time and logistical coordination, making the method labour intensive. To mitigate these, and for a more comprehensive analysis, this study also integrated data from surveys, interviews and focus groups from multiple participants.

3.4.3 Phase Two Survey Tools

As described in more detail in Section 3.4.1, the validated iPAC teacher survey (Kearney et al., 2019) and student survey (Burke et al., 2022) were further

adapted for Phase Two teachers and students to align with the specific context and aims of this phase (see Appendices L and M). Given that the researcher was to directly observe the activities during this phase, the surveys were intentionally shorter compared to those in Phase One and would require approximately 10 minutes for completion. The researcher invited the students to complete the survey during the observation period, and the teachers to complete it prior to their interviews. These surveys enabled the efficient collection of teachers' and students' perspectives on the use of mobile devices within the nominated learning activities. Additionally, the survey results supported the development of the subsequent semi-structured interviews and focus groups.

The validated student survey has previously been utilised by other researchers for examining distinctive mobile practices using the iPAC framework (Burke et al., 2022). The current study strategically adapted both the teacher and student surveys for the contexts of undergraduate science education. This dual application allowed for a structured yet flexible way of collecting data across multiple cases, while maintaining the exploratory focus of the qualitative case study design. Although these surveys retaining the core structures of the original iPAC surveys, their implementation across Phase One (global survey) and Phase Two (case studies) represents a novel methodological extension. This study therefore demonstrates how validated instruments can be thoughtfully modified and applied in new disciplinary and educational research contexts.

Phase Two teacher survey (see Appendix L) consisted of six sections, including 12 closed-ended and two open-ended questions. Section 1 gathered information about the participants' background (years in teaching, experience in using digital teaching, and the digital device types used by their students in the observed activity). Sections 2 to 6 were similar to the core items in the Phase One survey, prompting participants to reflect on their students' use of digital devices in their nominated learning activities.

The student survey (see Appendix M) consisted of five sections with 12 closed and two open-ended questions. Section 1 was the background questions about students' undergraduate years; the types of digital device used in the observed activity: and the confidence levels in using digital devices to learn science. The items in Sections 2 to 5 mirrored the items in the teacher's version, albeit using simpler and more student-friendly language to enhance the readability.

3.4.4 Semi-structured Interviews

Interviews are a valuable method to explore complex issues, allowing a more personal engagement with participants and providing opportunities for clarification (Brown & Dowling, 1998). Semi-structured interviews involve a prepared guide for open-ended questioning. This format allows the researcher to organise the contents while also expanding on them, including new avenues and probing further (Cohen et al., 2007). Flexibility is essential in semi-structured interviews, particularly regarding the order of questions and the need to allow the interviewees to develop and articulate their thoughts in response to the questions initiated by the researcher.

In this study, to streamline interviews within the limited proposed duration (20 minutes), teachers were asked to complete a survey related to the nominated activity prior to the interviews. No survey was required for learning designers because the validated iPAC surveys were specifically designed for teachers and students only.

Prior to the interviews, the teachers and learning designers received the interview questions in advance (see Appendices N and P). These questions were designed to elicit their views on the observed activities. The wording and flow of these interviews were adjusted based on the actual interview interactions, incorporating the iPAC slider (Appendix Q) and innovation slider (Appendix R), based on the work of Kearney et al. (2020), as stimuli for their responses. These tools allowed participants to rate the perceived presence of the iPAC and innovation elements on a 3-point scale (1= low, 2= medium, 3= high) and to explain the rationale behind their ratings. Since the slider information somewhat overlapped with the quantitative data already collected through the validated teacher and student surveys, the slider ratings are not reported in this study. While artefacts from teachers and students were not formally analysed, they were used to enrich the discussions and stimulate further insights.

A total of 18 one-on-one interviews were conducted with 10 teachers and eight learning designers. These took place either on their campuses, online, or at the field trip locations. Each interview took approximately 25 minutes and was recorded for transcription and subsequent data analysis.

Benefits and Limitations of Semi-structured Interviews

Semi-structured interviews can be an effective method for gaining detailed insights into participants' perspectives by enabling probing (Tashakkori et al., 2021) and offering flexibility for the researcher to elicit respondents' perspectives (Thomas, 2003). In this study, semi-structured interviews allowed the participants to elaborate on their mobile practices and the teachers to clarify their survey responses. They also yielded rich data from learning designers, providing additional viewpoints on teachers' mobile practices. Scheduling interviews at participants' convenient times and locations contributed to high response and completion rates. Furthermore, the face-to-face interactivity allowed participants to verify the accuracy and relevance of the data as it was collected (Denscombe, 2010). The use of audio-recordings followed by review of automatic transcription, eliminated the need for manual data entry and streamlined the data analysis process.

Nevertheless, this interview method also presented several limitations that must be acknowledged (Tashakkori et al., 2021). The flexibility of the interview format introduced variability in how follow-up questions were asked, which may have influenced the depth or direction of the participants' responses. Conducting face-to-face interviews with the teachers and learning designers in Phase Two was time-consuming and resource intensive. Each case study had its own unique context and individual perspectives, making it challenging for the researcher to maintain consistency and objectivity across the interviews. Moreover, the data collected reflected what participants said or believed, which might not have always aligned with their actual behaviours (Denscombe, 2010). Despite these challenges, the semi-structured interview method proved valuable for capturing nuanced, contextualised insights that complemented the data from observations, surveys, and focus groups.

3.4.5 Focus Groups

Focus groups are widely used in qualitative research and are valued for their ability for supporting data saturation and facilitate participant interaction, thereby building a rich social context (Onwuegbuzie et al., 2009). The main aim of a focus group is to elicit data through group discussions centred on predetermined topics (Morgan, 1997), while also helping participants to reflect deeper insights into the topics under discussion (Nyumba et al., 2018). In this study, the focus group participants were invited to share their experiences of the observed activity, using

their digital artefacts (e.g., photos and notes – see Figure 3.4) as prompts to elaborate their responses. The researcher guided the discussion using a set of questions (see Appendix O), along with the iPAC and innovation sliders to support reflection on the m-learning activities.

A total of 19 focus groups were conducted, involving 44 undergraduate science students from four NSW universities. These sessions were held either on the university campuses or at field trip locations and lasted for approximately 20 minutes on average. All discussions were audio-recorded for transcription and subsequent analysis. Even when only one student was willing and available to participate, the sessions were still conducted according to the university ethics guidelines.

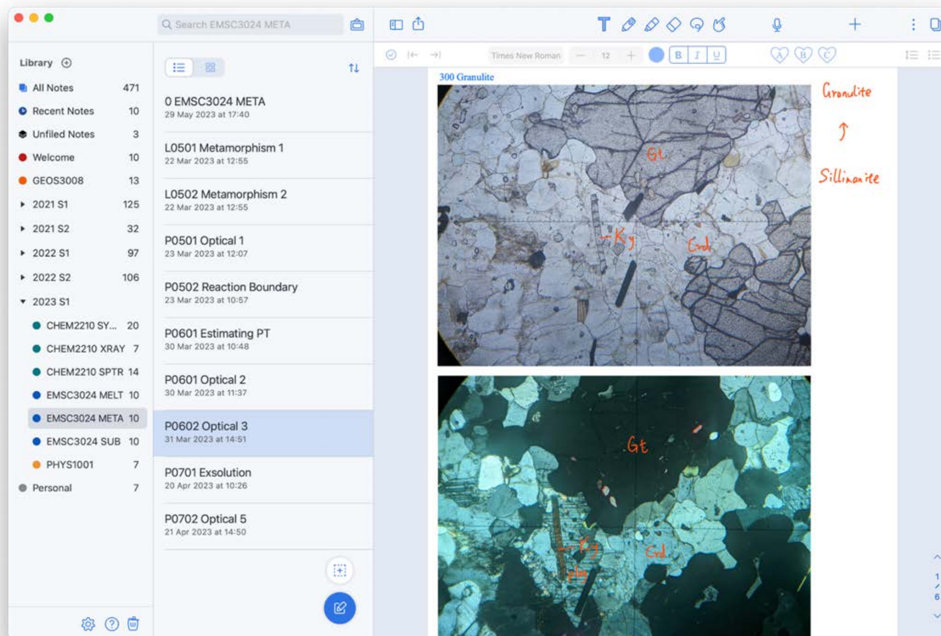
Benefits and Limitations of the Focus Groups

The focus group method offers valuable opportunities to explore participants' ideas in greater depth by uncovering underlying reasons for their thoughts and sparking interactive dialogue among group members (Grix, 2019; Tashakkori et al., 2021). In this study, this method was deemed appropriate for capturing comprehensive insights into the student learning process. The students were prompted to reflect on their experiences during the observed activities, elaborate on their earlier survey responses, and articulate both shared and opposing views on their m-learning experiences, thus reflecting a wide range of common and personal insights.

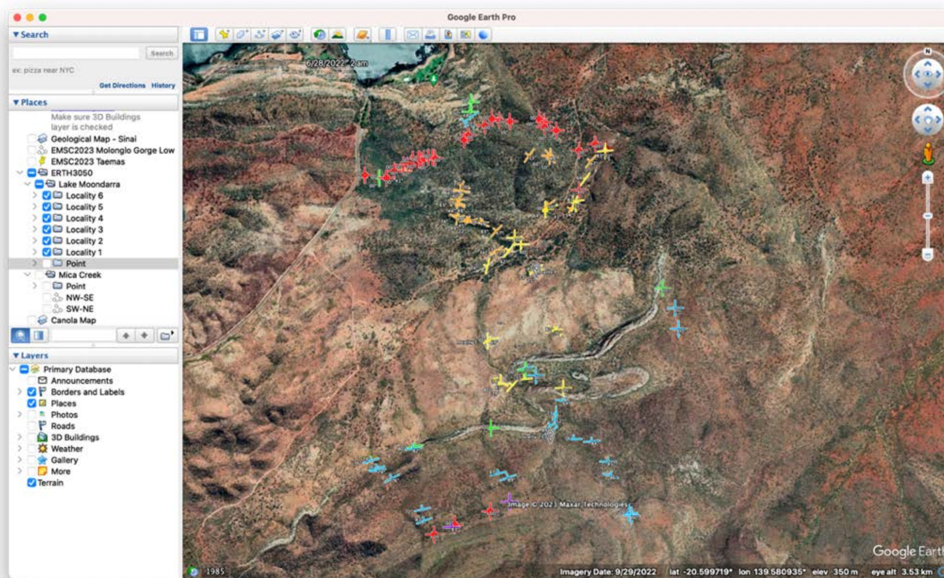
However, focus group limitations include the potential for one or two participants to dominate the conversation and the possibility of researcher bias influencing the discussion (Tashakkori et al., 2021). In this study, while most students were open to sharing their thoughts, a few seemed to have reservations. To mitigate their concerns, the researcher reassured participants that all discussions were strictly confidential, and that their identities would remain anonymous.

Figure 3.4

Examples of Students' Artefacts Collected in Phase Two



a)



b)

Note.

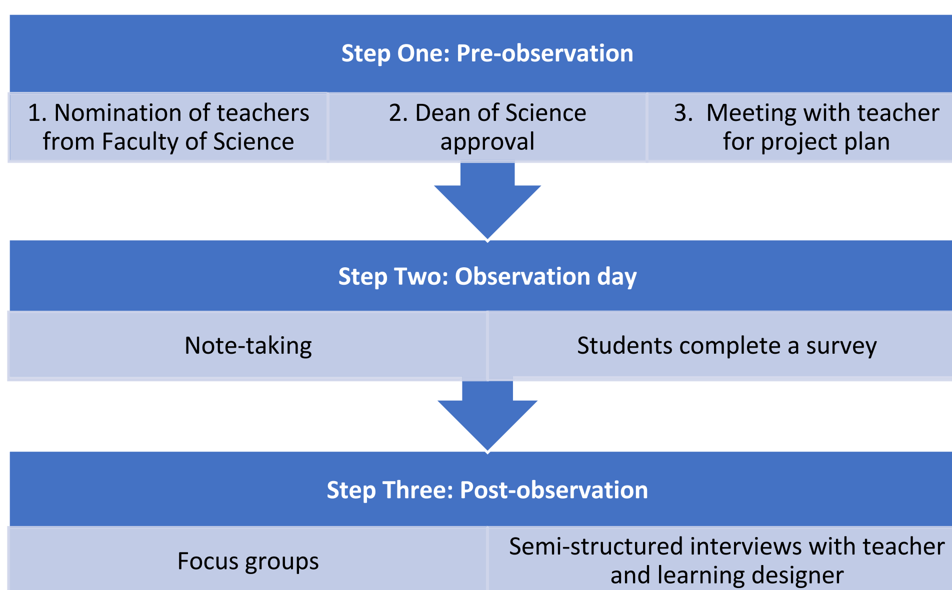
a) student used Notability on iPad to annotate on the microscope thin section photo taken by a phone;

b) student's measurement with a digital compass app on a phone and imported data to Google Earth.

Phase Two Recruitment. Phase Two data were collected from faculties of science at universities in New South Wales, Australia, due to the researcher's familiarity with the academic environment, geographical accessibility and relevance of the study's focus. Figure 3.5 summarises the recruitment strategies, which involved three steps for each university: (1) pre-observation, (2) observation day, and (3) post-observation.

Figure 3.5

Overview of Phase Two Data Collection Procedures



Step 1: Pre-observation: Initial invitations, including participant information sheets and consent forms for the university (see Appendix E), were sent to teaching and learning leadership teams in New South Wales universities that have a science faculty (e.g., Associate Dean Teaching and Learning (T&L), Faculty Associate Deans (T&L), T&L coordinators and Heads of schools). Subsequently, approval from the Dean of Science of each participating university was obtained once the nominated teachers expressed their interests. Follow-up meetings were then organised between the researcher and teachers to discuss the procedures in preparation for the subsequent steps.

Step 2: Observation day: Before the scheduled observe activity, the researcher introduced the study to students and obtained their consent to participate. Students were then invited to complete a survey and participate in an optional focus group. Detailed observation notes were taken using the observation template (see sample in Appendix K).

Step 3: Post-observation: Following the observation, data were collected through student focus groups and semi-structured interviews with teachers and learning designers. Additionally, teachers completed the survey prior to the interviews.

3.5 Participants

This section outlines the participant selection criteria, along with background information on the participants involved in both phases of this study.

3.5.1 Participant Selection Criteria

Participants were drawn from three key stakeholder groups: university science teachers, learning designers, and students. Selection was based on specific criteria described below to ensure participants possessed relevant experience with the use of digital technologies in their practices.

Criteria for selection of Phase One teachers

Teacher participants were to be:

- currently full-time, part-time, sessional or casual academics who teach undergraduate science students within a Faculty of Science or equivalent in any country;
- experienced in using digital technologies in teaching science in university; and
- available to complete the survey.

Criteria for selection of Phase Two participants

a) Teacher participants were to be:

- based at a university in NSW, Australia;
- identified as experienced in digital practices based on recommendations from Deans of Science, Associate Deans of Teaching and Learning (T&L) of science faculties or course coordinators; and
- available to participate in an activity observation, a post-activity survey and a follow-up one-on-one interview.

b) Student participants were to be:

- enrolled in the Faculty of Science or in subject(s) offered by the Faculty of Science in New South Wales, Australia;

- 18 years old or order;
- taught by the nominated teacher participating in Phase Two; and
- available to participate in an activity observation, an optional survey and focus group.

c) Learning designers were to be:

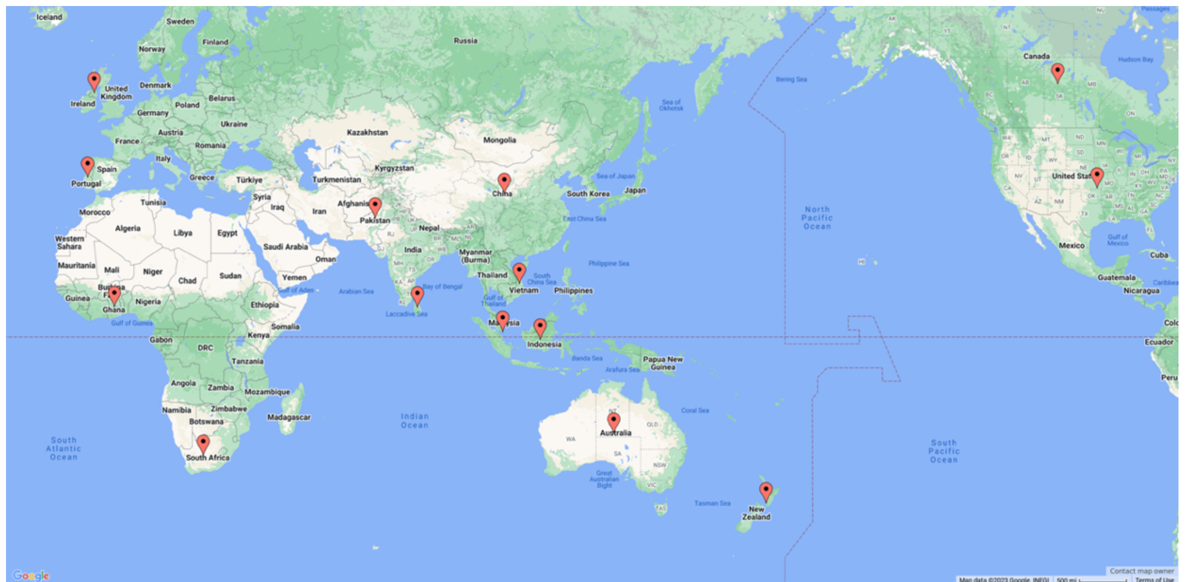
- based in New South Wales, Australia;
- experienced in working with university science teachers to embed digital technologies into the science curriculum;
- nominated by their university and preferably work with undergraduate science teachers; and
- available for a one-on-one interview.

3.5.2 Phase One Participants' Backgrounds

Phase One included 132 university science teachers from various countries around the world. Their distribution is illustrated in Figure 3.6, with red markers indicating their demographics across all continents.

Figure 3.6

Overview of Phase One Teachers Locations (N=132)



Note. The red markers identify the countries of Phase One participants

Table 3.4 presents a detailed breakdown of demographics. Most participants were from Australia (67%), followed by Asia (11%), Europe and UK (10%), Africa (6%) and North America (5%).

Table 3.4

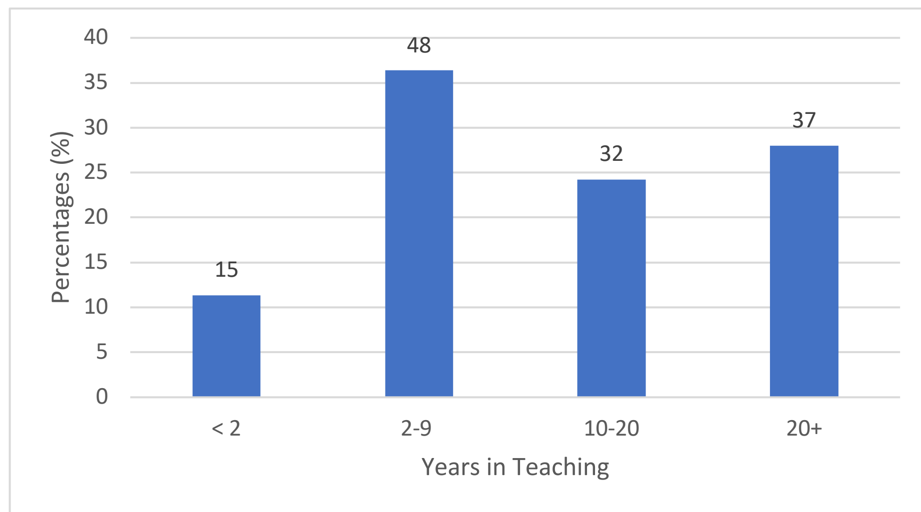
Phase One Teachers: Demographic Distribution (N=132)

Continents	Countries	Frequency	Total	Percentage (%)
North America	Canada	2	6	5
	United States of America	4		
Africa	Ghana	7	8	6
	South Africa	1		
Europe and UK	Portugal	2	13	10
	United Kingdom of Great Britain and Northern Ireland	11		
Australia and New Zealand	Australia	88	90	68
	New Zealand	2		
Asia	China	3	15	11
	Indonesia	5		
	Pakistan	1		
	Singapore	1		
	Sri Lanka	3		
	Viet Nam	2		

Figure 3.7 displays the distribution of participants' years of teaching in university science education, highlighting that most teachers had substantial years of teaching science: 2-9 years (36%), 10-20 years (24%) and more than 20 years (28%).

Figure 3.7

Phase One Teachers: Years of Teaching Science in University (N=132)

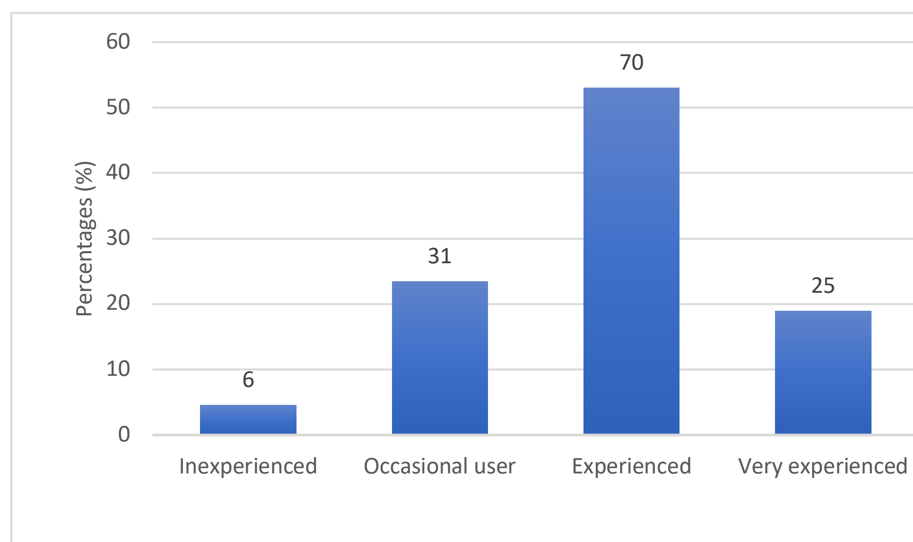


Note. Values above each column indicate the number of teachers in each teaching year groups.

In terms of experience of using digital pedagogies, a significant percentage of teachers perceived themselves as “experienced” (53%) or “very experienced” (19%) in teaching science with digital technologies (see Figure 3.8). Only a small number of teachers reported themselves as inexperienced (5%).

Figure 3.8

Phase One Teachers: Experience in Digital Teaching (N=132)



Note. Values above each column indicates the number of teachers in each experience group.

3.5.3 Phase Two Participants' Backgrounds

Phase Two was conducted over the course of the southern hemisphere autumn and spring semesters of 2023. The participating universities, referred to as Universities A, B, C and D, have strong reputations in higher education and are ranked among the top 10 in the Times Higher Education Australia University Rankings (2025) and within the top 150 globally according to the QS World University Ranking (2025). Participants in each case study included university science teachers, learning designers, and students. The teachers were asked to nominate one or two m-learning activities for in-depth exploration in this study.

Teacher Participants' Backgrounds

Ten university science teachers participated in Phase Two. Table 3.5 summarises each teacher's background information, based on their case study number.

Table 3.5

Phase Two Teachers' Background Information

Case No	Years in teaching	Experience levels	Science disciplines	Undergraduate levels
1a	<2 years	Experienced	geology	third year
1b	2-9 years	Very experienced		
2	< 2 years	Experienced	chemistry	first year
	< 2 years	Experienced		first year
3a	20+ years	Very experienced	physics	first year
3b	2-9 years	Very experienced		first year
4	2-9 years	Occasional user	statistics	first year
5	20+ years	Experienced	chemistry	third year
	10-20 years	Occasional user		third year
6	2-9 years	Very experienced	microbiology	third year

Most Phase Two teachers (70%) had more than two years' experience of teaching science at the undergraduate level. Additionally, 80% reported themselves as experienced or very experienced with digital pedagogies. These teachers either taught 1st-year or 3rd-year science subjects in one of the

following five different science disciplines: geology, chemistry, statistics, physics, and microbiology.

The researcher observed the activity taught by each teacher, who also completed a survey and participated in a semi-structured interview after the observation. In addition, these teachers also provided artefacts such as subject outlines, lesson materials, recordings (Cases 4 and 5) or access to the Canvas course (Case 4). These resources were used to support the development of the case studies.

Learning Designer Participants' Backgrounds

Eight learning designers participated in this study, five of whom also served as subject coordinators and had nominated the learning activities in this study. One participant was the director of the 1st-year science lab. These participants self-nominated or were nominated by the academic leaders to participate in an interview as a "learning designers". They then nominated other teacher(s) or lab demonstrator(s) to be interviewed as "teachers" for this study. As the validated iPAC survey used in this study was specifically designed for teachers and students to evaluate their mobile learning activities, learning designers were not required to complete it.

Student Participants' Backgrounds

A total of 147 undergraduate science students provided consent for the researcher to observe their learning activities as nominated by their teachers. Of these, 126 completed a student survey and 44 participated in focus groups. Table 3.6 provides students' self-reported confidence level with digital learning. Across all cases, most students reported being very confident (49%) or confident (38%) in using mobile devices to support their learning.

Table 3.6

Students' Confidence Levels in Using Digital Learning (N=126)

Case No	Not confident at all (1)	Somewhat confident (2)	Neutral (3)	Confident (4)	Very confident (5)	Total
1a	0	0	3	4	7	14
	0	0	21%	29%	50%	100%
1b	0	0	2	4	7	13
	0	0	15%	31%	54%	100%
2	0	0	1	4	6	11
	0	0	9%	36%	55%	100%
3a	0	0	0	2	3	5
	0	0	0	40%	60%	100%
3b	1	0	0	1	0	2
	50	0	0	50%	0	100%
4	0	0	2	9	14	25
	0	0	8%	36%	56%	100%
5	0	0	0	10	9	19
	0	0	0	53%	47%	100%
6	0	2	5	14	16	37
	0	5%	14%	38%	43%	100%

Note. Confidence levels range from not confident at all (1) to very confident (5)

3.6 Background Information on Phase Two Case Studies

This section provides background information for all Phase Two case studies, highlighting the implementation of mobile devices in six case studies across the four Australian universities. Cases 1 and 3 each included two separate learning activities (e.g., labelled as Cases 1a and 1b). Across all cases, there were five different subjects with varied activity types, including lectures, laboratories, a workshop and a field trip. Activity duration ranged from one hour to seven days. This diversity provided valuable insights into the ways mobile devices were employed in undergraduate science education.

Table 3.7 provides an overview of all cases, including case numbers, universities, subjects, activity types and durations. A naming convention was employed

throughout this phase. Each participant was labelled according to their case number, role and identifier (e.g., Case 2_Teacher 1). For cases with two activities, alphabetical sub-labels were added (e.g., Case 1a_Student 3). In the student survey, participants were labelled with hashtags (e.g., Case 2_Student #1).

Table 3.7

Overview of Phase Two Data Collection

Case No	Universities	Subjects	Activity types	Duration
1a	A	Geology	Field trip	7 days
1b			Workshop	2 hrs
2		Chemistry	Lab	3 hrs
3a		Physics	Lecture	1 hr
3b			Lab	3 hrs
4	B	Statistics	Lecture	2 hrs
5	C	Chemistry	Workshop	2 hrs
6	D	Microbiology	Lab	3 hrs

3.6.1 Case One

This case explored two activities from University A: a field trip (Case 1a) and a laboratory workshop (Case 1b) within a 3rd-year geology subject. This subject included a 1-week program of on-campus tutorials and laboratory workshops, and a 2-week field trip to Broken Hill, a mining city in far west of New South Wales, approximately 14 hours by train from Sydney. According to the subject outline, students were expected to develop advanced geological mapping, stratigraphic correlation, and structural synthesis and apply practical geology knowledge to identify geological problems, design field data collection plans and analyse hypotheses. Additionally, the subject objective include building proficient in using digital technologies to collect geological data and present findings through exercises, reports, and oral presentation assessments.

Although the field trip and laboratory workshop involved the same students, there were two distinct learning activities. The only link between these activities was the use of rock samples from Broken Hill to create microscope slides for the laboratory workshop. The field trip involved three teachers, a technical officer, and 15 students, 14 of whom completed the student survey. Data sources for

Case 1a consisted of one-on-one interviews with a teacher (Case 1a_Teacher), a learning designer (Case 1a_Learning designer), as well as four student focus groups. The laboratory workshop included one teacher, who also served as the learning designer (Case 1b_Teacher/Learning designer) and 16 students, 13 of whom completed the student survey. Data sources comprised an interview with the teacher/learning designer and six student focus groups – three of which consisted of one student each.

Case 1a Background. The researcher observed the first week of the field trip, which began each day with breakfast at 7:00am, followed by group activities from 8:00am to 4:00pm in the field or at the gallery, a communal meeting space within the accommodation area. Each student was equipped with an iPad and essential geology tools for the field activities. In the evenings, students either attended workshops in the gallery or worked on a report to be submitted by the end of the first week.

The technology used by students to collect data in the field was the StraboSpot app (freely available on Android[1] and iOS[2] systems). This app allows users to record lithology data and structural features, such as sketches, diagrams, photos and descriptive notes on their iPads (see Figure 3.9).

The collected fieldwork data was stored within the StraboSpot system and backed up on a server, allowing students to download the data onto their laptops upon returning to the accommodation area where internet access was available. Figures 3.10 and 3.11 provide snapshots of the field trip activities.

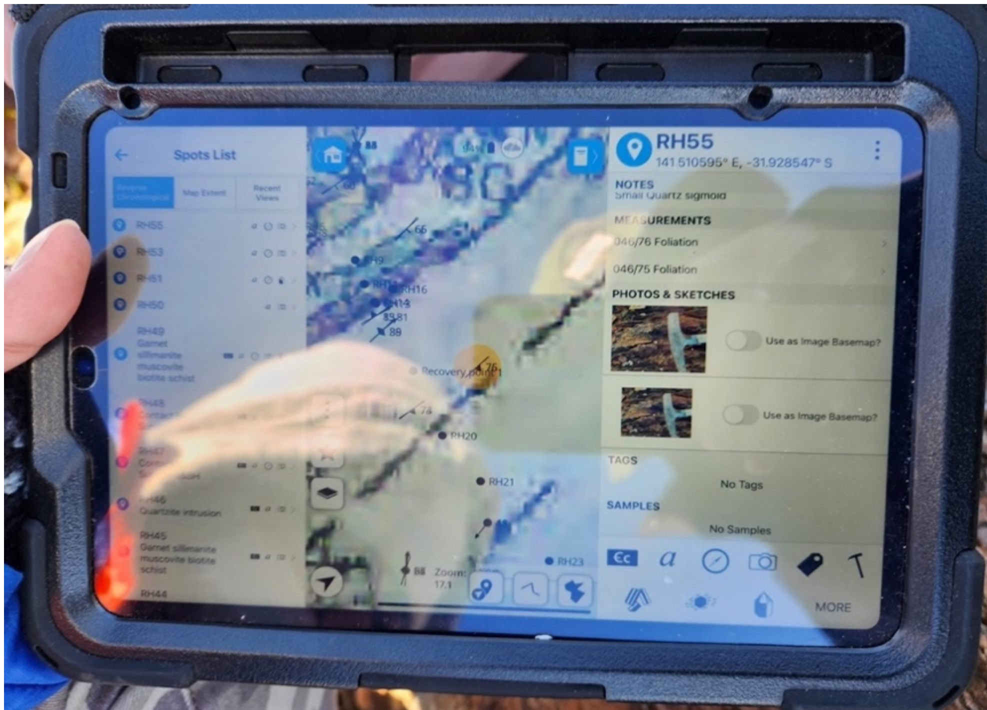
On the first day, the students were introduced to the Broken Hill vicinity and trained to use the StraboSpot app. The second day involved an overview of Broken Hill geology and metamorphic rock field geology, preparing students for the upcoming Round Hill field trip. The third day marked the beginning of fieldwork in the Round Hill area, where students began identifying evidence of intense and localised deformation. Working in groups of three to four, each accompanied by a teacher, students collected data individually on their iPads. Fieldwork continued in the Round Hill area on the fourth and fifth days, with students compiling daily observations into maps for detailed analysis upon their return to the accommodation area. On the sixth day, students synthesised all

[1] Android is a trademark of Google LLC
[2] iOS is a trademark or registered trademark of Cisco in the USA. and other countries and is used under license.

collected data from the previous three days of fieldwork to write a comprehensive report to depict the change in the rock formations over time.

Figure 3.9

The Interface of a Data Point in StraboSpot App



Note. The left section of the app's main screen displays a list of collected data points (spots); the middle section displays the locations of these spots; the right section displays information about spot RH55 altitude, notes, measurements, photos and sketches, tags and sample tools. (used with permission)

Figure 3.10

Groupwork in the Field

Note. *The teacher and students were discussing their collected data (standing), while a student was taking notes (sitting on the left) and performing measurements (sitting on the right) using the StraboSpot app on their iPads. (Used with permission)*

Figure 3.11

StraboSpot Measurement on an iPad

Note. *Students were aligning an iPad onto the rock surface to collect data. (Used with permission)*

Case 1b Background. The campus-based, 2-hour laboratory workshop aimed for the students to decode the microstructures in metamorphic rocks and explore the relationships with petrology and structural geology using thin section slides. The rock used to make the microscope slides was originally from Broken Hill. However, there was no curriculum link between the two activities and students did not explicitly connect their field activities with lab-based learning.

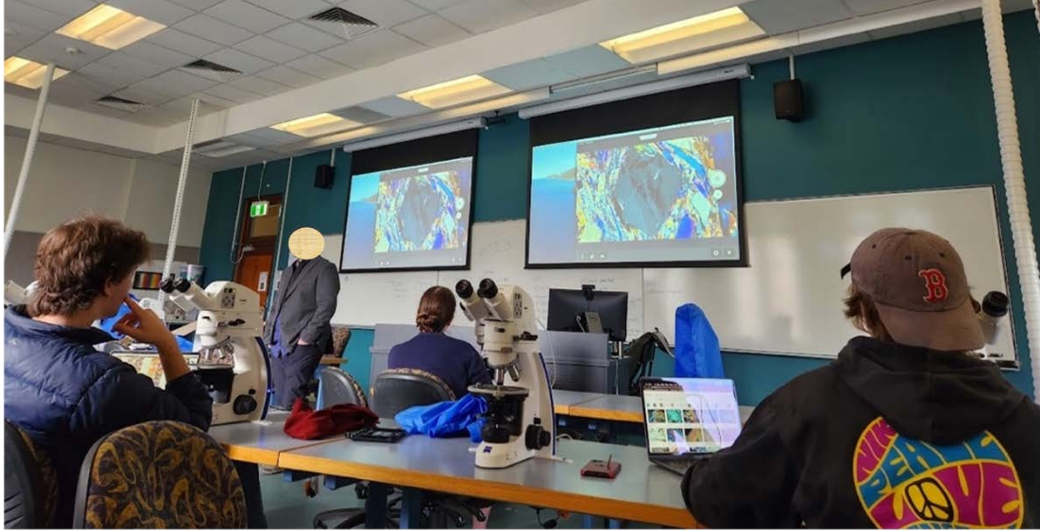
During the workshop, the students conducted mineralogical and textural analyses using microscopes equipped with the ZEISS Labscope digital imaging application, pre-installed on the university iPads. The microscopes were linked to iPads via the university's Wi-Fi network, allowing students to view and record real-time images and videos of microscopic structures. The Labscope application is freely available for download on Android and iOS systems.

At the start of the workshop, the teacher introduced key concepts in metamorphic rock microstructures and explained how to use the Labscope app with the microscopes. Rather than relying on the microscope eyepieces, the students identified minerals and estimated the proportions of available minerals based on their texture directly from the iPad screens. They recorded their observations through photos and videos, transferring files via email or airdrop for analysis in their individual reports later. These students used the Labscope app in diverse ways. They viewed and captured microscope images, displayed their microscope views to the class projector and used smartphones and laptops to access materials and image output from the iPad and microscope.

Throughout the session, the teacher played a pivotal role in guiding whole class discussions and answering student queries. When students encountered notable mineral features or if the teacher identified interesting mineral features, they were encouraged to call out their microscope numbers, allowing their live microscope views to be projected onto the class screen for group discussion and analysis. Figures 3.12 to 3.14 provide visual documentation of the activity.

Figure 3.12

Whole-class Discussion on a Thin Section Slide Shared from a Student's iPad



(used with permission)

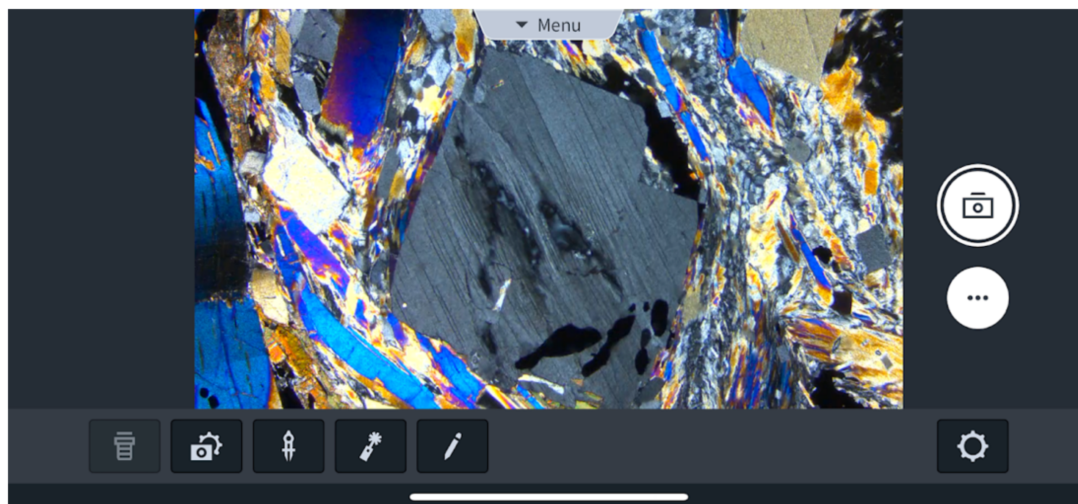
Figure 3.13

A Student Was Setting Up the Microscope and Ipad. A Laptop Was Used to Check Reference Information About Minerals

(used with permission)

Figure 3.14

Microscopic View of a Thin Section Slide from the Labscope Interface on an Ipad



(used with permission)

3.6.2 Case Two

This case examined a 1st-year advanced chemistry practical activity at University A. Data sources for this case included one-on-one interviews with two teachers (Case 2_Teacher 1 and Case 2_Teacher 2), a learning designer (Case 2_Learning designer), and a focus group with one student (Case 2_Student 1). The chemistry laboratory activity took place in a Physical Containment Level 2 (PC2) standard laboratory, involving two teachers and 36 students, of whom 11 completed the student survey.

According to the subject outline, students were expected to develop a deeper understanding of experimental design and advanced analytical skills. Key topics covered included nuclear and radiation chemistry, wave theory, spectroscopy, and equilibrium. The subject incorporated lectures, tutorials and practical classes. The practical component was assessed through continuous evaluation, with students graded on laboratory techniques, digital lab logbook entries, and a post-lab poster submission.

Activity Background. The technology that students used in this case was LabArchives, a cloud-based Electronic Laboratory Notebook (ELN) designed for recording experimental data and results. LabArchives provides tools such as text editors, tables, figures, and photo attachments, allowing students to type, sketch, and upload files on their laptops. The application is compatible with Android and

iOS devices, and it was introduced to students during their first practical class of the semester. LabArchives was integrated with the university's learning management system's gradebook, enabling teachers to provide feedback on students' digital lab note submissions.

At the start of the 3-hour practical activity, the teacher provided a brief introduction to the silver nanoparticles experiment. In the first part of the activity, students followed the lab logbook instructions to conduct various parts of the silver nanoparticle experiment. They collected UV-visible spectrum absorption wavelengths using a spectrometer and used Microsoft Excel to generate visual representations of the data. Although students worked individually in this part, they shared their results via WhatsApp group chats or emails and verbally discussed the findings with lab partners. In the second part, students repeated the experiment with modifications in the preparation steps, as assigned by the teachers. They recorded and shared results via digital notebooks and discussed the modified experimental conditions with their peers.

As outlined in the lab manual and reinforced by teachers during class, students were encouraged to upload photos, data, sketches, diagrams, or videos where relevant. At the end of the practical session, the teachers summarised key experimental findings, and students had up to two weeks to submit their digital lab notebooks.

3.6.3 Case Three

This case examined two activities (Cases 3a and 3b) in a 1st-year physics subject at University A. Both activities took place on the same day: a 1-hour hybrid lecture in the morning (Case 3a) followed by a 3-hour laboratory session in the afternoon (Case 3b). The content covered in the previous week lectures was related to the experiment conducted in the practical.

For Case 3a, data sources included interviews with a teacher (Case 3a_Teacher) and a learning designer (Case 3a_Learning designer) as well as two focus groups – one with two students and another one with one student. These students discussed both the lecture and laboratory activities in the same session. Of the 54 students who attended the on-campus lecture, five completed the student survey.

For Case 3b, data sources included one-on-one interviews with a teacher (Case 3b_Teacher) and a learning designer (Case 3b_Learning designer). Among the

forty students present, two completed the student survey. The focus group students in Case 3b and 3a were the same students. According to the subject outline, students were expected to develop foundational physics knowledge and experimental skills to explain and predict scientific phenomena. Weekly learning activities consisted of lectures, tutorials, and practical sessions.

Case 3a Background. The hybrid lecture focused on the dynamics of rotational motion, covering key concepts such as torque, angular acceleration, rotational work, and angular momentum. The technology used by students in the session was Mentimeter, a real-time polling system for students to vote on problem-solving questions. Echo360 was a platform that allowed online students to join the lecture live-stream. It also automatically uploaded the recording to the learning management system after the class.

During the observed session, the teacher used an Apple Pencil to annotate on an iPad and demonstrations using physical objects. As soon as the Mentimeter poll was launched, there was a burst of conversations where students engaged in lively discussions with peers. Throughout the session, the teacher moved around the lecture hall, interacting with students and discussing their answer choices. Once the poll results were displayed, students started to discuss the questions with their peers and vote for their answers either on the laptops, tablets or mobile phones. The teacher circulated in the lecture hall to interact with students and invite them to explain their reasoning to the class.

Case 3b Background. Some students from Case 3a also participated in the afternoon laboratory activity on the same day. This section discusses Case 3b, which was originally designed in response to the COVID-19 pandemic in 2020 and continued to be used on-campus in 2023. The aim of the physics laboratory activity was for students to investigate the rotational dynamics of a mobile phone by spinning their mobile phones into the air and analysing results using principles of momentum and energy. To prepare for the lab experiments, students were required to complete the pre-work activities on Canvas and submit a group lab report by the end of the practical session as part of the assessment. The observed activity was facilitated by one main lab teacher and three support lab demonstrators.

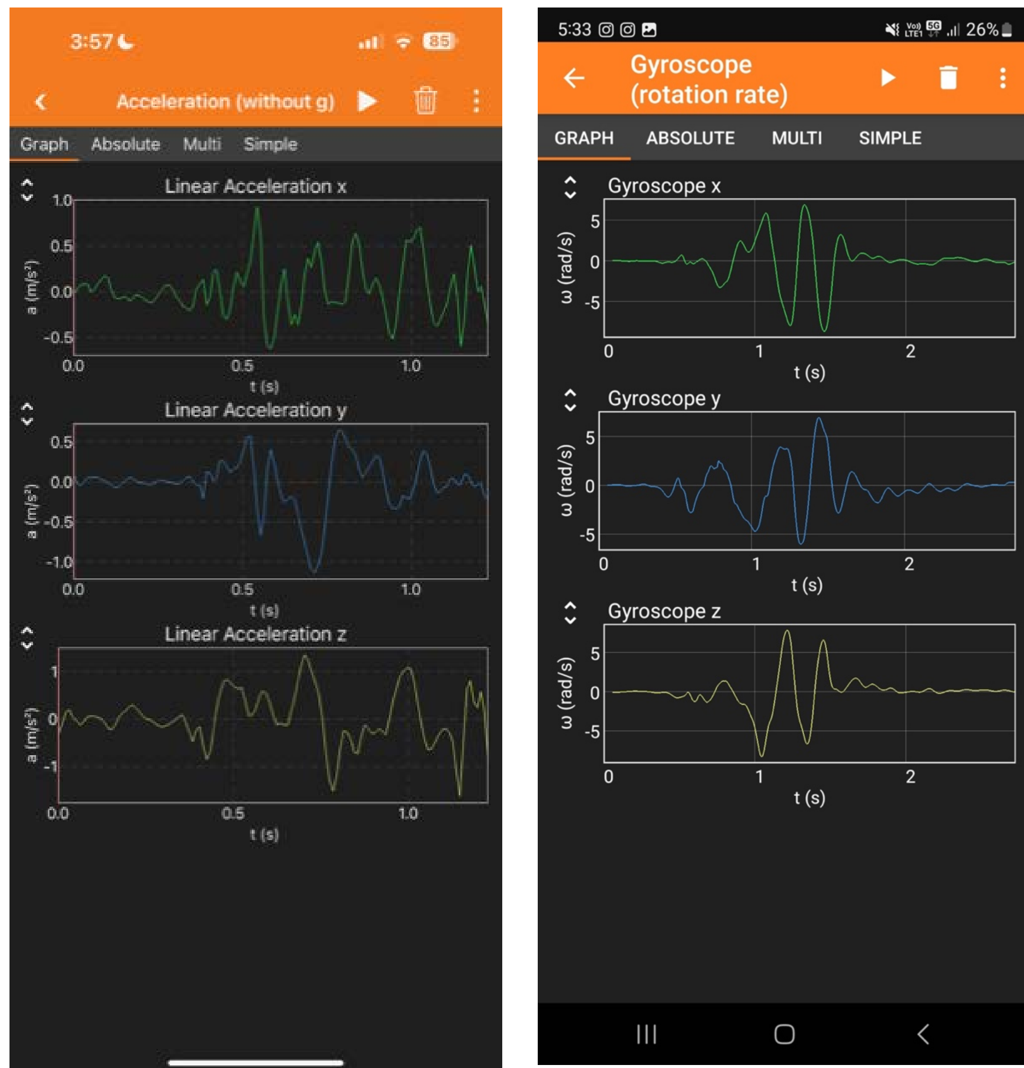
The technology used by students in this activity was the microelectromechanical system gyroscope sensor in the Phyphox app on their mobile phones to conduct rotational dynamics measurements. In the first part of the activity, students

measured their phones’ dimensions and weights and then calculated the moments of inertia of three principal rotation axes. They connected the Phyphox app on their phones to their laptops or classroom desktops by entering the URL link generated from the app on the web browser. This setup allowed students to control the app on their laptops, using the play and pause icons to start and stop recording their phone experiments. In the second part, students tossed their phones in the air and used the Phyphox app to measure the angular velocity of their rotating phones. After collecting data, they exported it from the app to Microsoft Excel to calculate the conservation of angular momentum and kinetic energy. The final part of the activity required students to determine the moment of inertia for a rotating phone as it fell off a table. They then collaborated with their group members to answer practical questions in an online shared document.

During one of the focus groups, a student demonstrated how he used his phone to measure acceleration and gyroscope physics experiments using the Phyphox app (see screenshots in Figure 3.15).

Figure 3.15

Case 3b Student Artefacts



3.6.4 Case Four

This case examined a 1st-year statistics hybrid lecture activity within the Faculty of Science at University B. With approval from the Faculty Dean and subject coordinator, the researcher was granted observer access to the course's learning management system, which included learning modules and lecture recordings. The data for this case study includes one-on-one interviews with a teacher (Case 4_Teacher), a learning designer (Case 4_Learning designer) and a student focus group with one student (Case 4_Student 1). Of the 50 students present during the observed lecture, 25 completed the survey, offering insights into their learning experiences. However, only one student participated in a focus group, meaning that findings from qualitative data should be interpreted with caution, as they may not fully represent the broader student cohort.

Activity Background. According to the subject outline, this subject aimed to equip students with a foundational knowledge of quantitative data analysis and statistical interpretation skills, preparing them to apply these techniques to real-world business problems. The curriculum covered key topics such as distributions, hypothesis testing, and simple linear regression. By the end of the 13-week course, students were expected to be able to organise quantitative data graphically and numerically, apply appropriate statistical techniques for data analysis and interpret statistical findings effectively. The weekly learning activities include a 2-hour hybrid lecture, a 1-hour tutorial and a 1-hour practical class. Students could attend the lectures synchronously in person or online, or asynchronously by viewing the recording.

During the semester, two different lecturers facilitated the sessions. The first teacher (Case 4_Learning designer), who participated in the study as the learning designer, utilised Kahoot quizzes for revision and used PowerPoint slides to present key concepts in her sessions. The researcher observed a lecture activity in Week 9 of the semester conducted by the second teacher (Case 4_Teacher). This teacher conducted the observed lecture in Week 9 and only used PowerPoint slides, without incorporating Kahoot.

The teacher began the lecture activity by reviewing the former week's concepts and questions using PowerPoint slides before moving on to the new topics for the week. During the activity, the teacher remained at the front of the class to present the content and occasionally interacted with students. She used an iPad and Apple Pencil to annotate and draw diagrams that were displayed on the projector screen for students to see. The researcher noted that the majority of students in the classroom used their laptops, iPads or notebooks to take notes.

3.6.5 Case Five

Case five focused on a 3rd-year chemistry hybrid workshop at University C. Data sources for this case included one-on-one interviews with two teachers (Case 5_Teacher 1 and Case 5_Teacher 2), a learning designer (Case 5_Learning designer) and two student focus groups. The first focus group consisted of two students while the second group had three; all attended the face-to-face workshop. Twenty-eight students were presented in the observed face-to-face activity and 19 completed the student survey.

Activity Background. According to the subject outline, this chemistry subject focused on the structures, functions and applications of metals. It aimed to equip

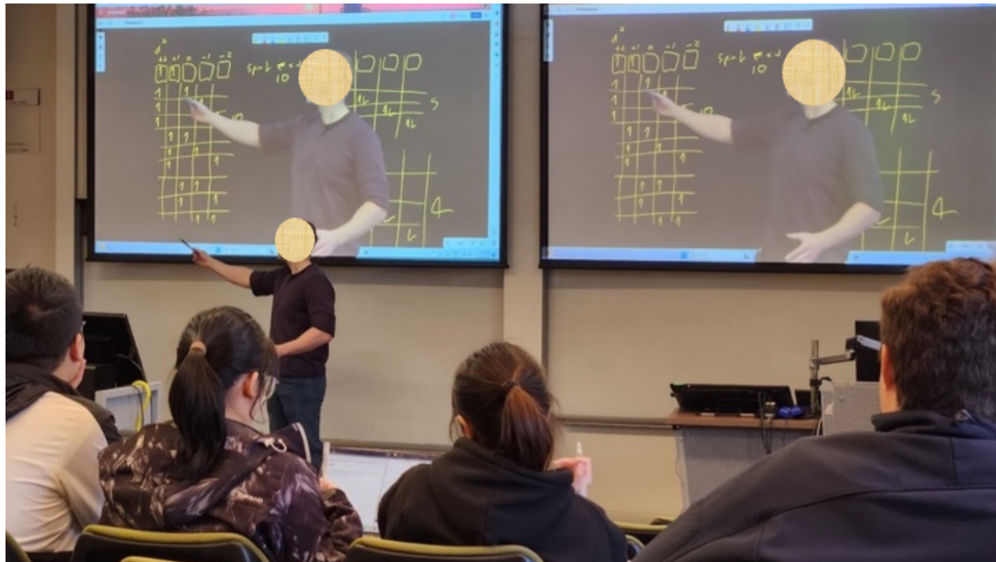
students with the ability to analyse and identify compounds and understand solid chemistry and its application to modern technologies. The subject's learning activities included synchronous hybrid workshops and hands-on laboratory classes. Before attending the weekly workshops, students were required to watch the recorded lectures and complete relevant exercises. These workshops aimed to reinforce students' understanding and provide opportunities to discuss questions. Students could choose to attend the workshop synchronously in-person or online, or asynchronously through the recorded videos.

The technology used in this workshop by the teacher was the embodied communication (or weatherman) green screen technology, implemented in the classroom by the science education technology team. Similar to the television weather broadcast effect, this technology allowed PowerPoint slides or digital whiteboard content to be projected onto the lecture screen, with the teacher superimposed on top when stepping into the stage area (see Figure 3.16). A green screen setup and a camera were positioned at the front of the classroom (see Figure 3.17), enabling students to observe the teacher's gestures and movements.

According to the learning designer, the green screen technology was implemented in response to concerns raised by one of the teachers (Case 5_Teacher 1) regarding technological challenges in his teaching. This teacher frequently moved around the classroom and found that the Echo360 camera could not track his movements effectively, resulting in poor hybrid learning experiences for both in-person and online students.

Figure 3.16

Green Screen Hybrid Workshop Activity



Note. *The teacher was projected on the screen while explaining the lesson content. The projected annotations on the screen were from the digital whiteboard tablet placed on the table (used with permission)*

Figure 3.17

Green Screen Hybrid Workshop Room Setting from the Back Views

(used with permission)

The learning designer also mentioned that the implementation of green screen technology aimed to reduce students' cognitive load, enhance engagement and foster stronger teacher-student connections. It also sought to improve naturalistic communication with face-to-face and online students, making hybrid teaching more intuitive for teachers. Additionally, the learning designer highlighted that capturing the teacher's body language alongside the projected content could improve the quality of the recorded lecture. Ultimately, this digital technology implementation aimed to improve students' connection with the teacher and facilitate a deeper understanding of the materials. Most students used their laptops, iPads or notebooks for notetaking.

The role of the teacher in this activity was to facilitate discussions on problem-solving questions related to the pre-recorded lecture. At the start of the lesson, the teacher distributed a quiz paper for in-class discussion. These questions were also accessible on the subject learning management site. Throughout the workshop, the teacher guided the discussion with occasional input from students. He frequently stepped into the green screen stage area to point at the chemistry formulas and concepts. Furthermore, he annotated the slides on the digital whiteboard while interacting with students at the same time.

3.6.6 Case Six

This case focused on teaching a 3rd-year microbiology laboratory activity at University D. With approval from the subject coordinator, the researcher was enrolled in the Canvas subject learning management system as an observer to gain insights into the subject and access learning content. This case study included interviews with a teacher (Case 6_Teacher), a learning designer (Case 6_Learning designer) and three focus groups with one student each. The subject coordinator nominated herself to be interviewed as a "learning designer" and nominated one of her teachers to be interviewed as a "teacher". Out of the 66 students present in the observed activity, 37 completed the student survey.

According to the subject outline, this subject provides students with foundational laboratory skills and techniques in microbiology diagnostics. The subject included fortnightly 1-hour online workshops, 2-hour on-campus workshops based on allocated practical groups and 3-hour on-campus practical classes. Through interactive workshops and hands-on laboratory sessions, students learnt to analyse and interpret real-world infectious disease cases. Before attending on-campus activities, students were required to complete the asynchronous learning

modules on Canvas. Although the observed practical activity was part of the subject assessment, the knowledge and skills acquired during these sessions were assessed through online quizzes and a final practical exam.

Activity Background. The observed activity took place in the Physical Containment Level 2 (PC2) standard super lab, which can accommodate up to 270 students and allows seven classes to run concurrently. The lab space was divided into five colour pods (red, orange, green, yellow and blue), each containing six chairs (see Figure 3.18). The technology used by students in this activity was the OneNote app on a Surface Pro, a two-in-one device that allows users to switch between tablet and laptop modes. Due to minimise the risk of contamination, hardcopy materials and personal devices were not permitted in the lab. Instead, each student was provided with a Surface Pro tablet to access the practical information and complete the activities. Students could access OneNote outside of the class by logging into their OneNote account from personal devices. Within the OneNote app, the subject coordinator set up a content library for students to access the practical manual, a private section for students to record their experiment results and a collaborative space where students could share experiment results with peers.

Figure 3.18

Superlab Setting

The observed class comprised 11 pods with 66 students, guided by one lead lab tutor and four lab demonstrators. The practical activity focused on standard operating procedures for diagnosing urinary tract infections (UTIs), simulating real-world clinical laboratory scenarios. This practical activity spanned over three consecutive days: preparation day (day zero), the actual experiment (day 1) and

result analysis (day 2). The researcher observed day 1, during which students conducted experiments using their digital notebooks.

The session began with a brief introduction from the lead tutor. Every two pods functioned as a diagnostic lab to process samples from six patients. Within each lab, twelve students were divided into pairs, with each pair assigned to diagnose a patient. They performed relevant tests to identify unknown microorganisms and recorded their results in their digital notebooks. The observed activity was highly dynamic and interactive, with students moving between pods and diagnostic test benches under the supervision and support from teachers. Some students also used the tablet's built-in camera to document their experiments. Toward the end of the session, the lead tutor provided a summary of lab results to the class.

3.7 Data Analysis

In this study, both quantitative and qualitative data analyses were performed to gain a comprehensive understanding of how mobile practices are employed in undergraduate science education. The analysis was grounded by the iPAC theoretical framework (Kearney et al., 2012) and innovative digital pedagogical criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005). Microsoft Excel was the primary software tool used to analyse most data in this study, while SPSS 28.0 was used for more advanced quantitative analysis. The following subsections describe the procedures used for analysing these data.

3.7.1 Analysis of Quantitative Data

Demographic and background information from the surveys were analysed using total counts and percentages in Microsoft Excel. These data were used to categorise participants into groups such as undergraduate levels, science disciplines, and years of teaching. Descriptive statistical analyses were conducted to summarise the characteristics of the data set, providing insights into the sample and its measurements. It included calculating the mean (M) of iPAC sub-constructs and innovation items for both phases. Using the 5-point scale (1= Strongly Disagree to 5= Strongly Agree), mean scores below 3 were classified as "low", scores above 3 as "high" and scores exceeding 4 as "very high". Quantitative analysis was undertaken more extensively for the Phase One survey data, whereas the Phase Two surveys served primarily as triangulation and stimuli for interview and focus group discussions and were subjected to limited statistical analysis due to the small sample sizes.

Standard deviation (SD) and standard error (SE) were calculated for the core iPAC sub-constructs, innovation and overall learning items in the Phase One survey. The reliability of these items were then examined using factor loadings (λ) with a benchmark of 0.7 (Hair et al., 2009). Convergent validity was evaluated through the average variance extracted (AVE), with recommended threshold of 0.5 (Fornell & Larcker, 1981). Reliability was further evaluated using Cronbach's alpha (α) for the iPAC subconstructs and Composite reliability (CR) for all items, with the recommended thresholds of 0.7 (Fornell & Larcker, 1981). Composite reliability was estimated from the standardised factor loading and error variances using Colwell's (2016) calculator. Cronbach's alpha is a widely accepted measure for assessing the reliability of items within each construct (Cronbach, 1951).

To examine the statistical differences between the subconstruct means of two groups – years of teaching and experience in digital teaching – inferential statistics were conducted using one-way analysis of variance (ANOVA). A *p-value* greater than 0.05 indicated no statistical difference, whereas a *p-value* less than 0.05 signified a statistically significant difference between groups. The analysis procedures were reviewed by an experienced quantitative researcher to ensure methodological rigour and the reliability of the statistical results.

3.7.2 Analysis of Qualitative Data

A richer and more nuanced interpretation of the research questions was made possible by using a holistic data analysis approach (Constas, 1992). This section outlines the procedures to analyse the qualitative data in this study.

Miles and Huberman (1994) proposed a systematic approach to data collection, storage and retrieval stages for effective data analysis, which includes three steps: data reduction, data display, and drawing conclusions. In this study, the data reduction process occurred when the open-ended responses in Phase One survey and Phase Two case studies (survey, interview, and focus group transcripts) were condensed, grouped and connected. Subsequently, these data were then used to facilitate in-depth analysis, leading to interpretation and the drawing of conclusions.

The open-ended responses from the Phase One teacher survey were analysed alongside Phase Two qualitative data to identify preliminary themes. The insights from Phase One responses informed the development of the codes, categories and themes. As Phase Two data provided significantly more detailed and

triangulated evidence, the examples presented in the final thematic maps were primarily drawn from Phase Two.

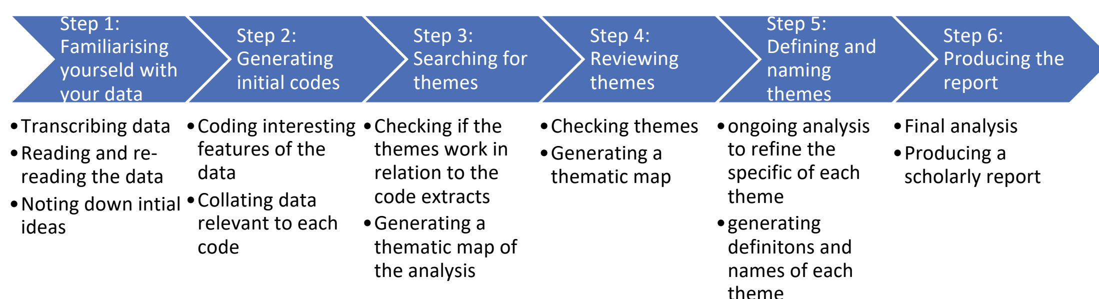
Interpretive analysis (Denzin and Lincoln (2003) was employed to analyse the qualitative data. This method aligned with the chosen theoretical lenses and aimed to generate new knowledge by interpreting multiple participants' perspectives. The following six phases of Denzin and Lincoln's (2003) interpretive procedure were demonstrated throughout this study:

1. Frame the research question → defined research objectives;
2. Deconstruct and critically analyse prior phenomenon conceptions → conducted a literature review and applied the sociocultural theory as analytical lens;
3. Capture the phenomenon in the natural world → engaged in Phases One and Two data collection;
4. Uncover the phenomenon of essential structures by reducing their element and categories → conducted data reduction and categorisation procedures;
5. Construct the phenomena by putting the essential parts back together → data displayed and analysis to draw relevant interpretations and conclusions;
6. Contextualise the phenomena or relocate it back in its natural world → identified the phenomenon's position in its context.

The development of appropriate categories and themes in step 4 was achieved by adopting Braun and Clarke's (2006) thematic analysis method. This approach was informed by the iPAC mobile pedagogical framework and innovative digital pedagogical criteria, facilitating a deeper understanding of the perspectives of undergraduate science teachers, students, and learning designers regarding their digital learning tasks. Figure 3.19 provides a summary of Braun and Clarke's (2006) thematic analysis process and how it was applied in this study.

Figure 3.19

Thematic Analysis Based on Braun and Clarke's Approach



Note. adapted from Braun & Clarke (2006, p. 87)

Step 1. Familiarising yourself with your data, and Step 2. Generating initial codes: The primary sources of qualitative data in this study included open-ended responses in the surveys, interviews, and focus group transcripts. These data were instrumental in exploring digital practices from multiple perspectives. Additionally, secondary data sources, such as observation notes and artefacts (e.g., lesson materials, subject outlines, lesson recordings and student-related materials) were exploited to gain further insights into the observed activities and participants' interactions with the digital resources. The researcher read through the focus group and interview transcripts thoroughly to familiarise herself with the data, and relevant responses of interest were highlighted to generate initial codes (see samples of transcripts in Appendix T).

Step 3. Searching for themes, and Step 4. Review of themes:
The coding process aimed to systematically identify participants' perspectives on mobile practices within their learning activities. To enhance accuracy and clarity, the researcher reviewed, merged or renamed the codes before grouping into themes based on their content. The iPAC framework (Kearney et al., 2012) and innovative digital pedagogical criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005) provided the theoretical lenses guiding this grouping process. Additional themes were added if the data could not be grouped into existing themes. These themes were examined in detail to ensure they precise alignment with the research questions and accurate reflection of the data content. During this process, some themes were combined or renamed to improve clarity and coherence. The open-ended responses from Phase One were initially condensed

and categorised according to the iPAC subconstructs using an interpretive approach, and these initial categories were subsequently refined to ensure consistency and alignment with Phase Two themes in steps 5 and 6 (see Appendix U for a summary of thematic analysis process).

Step 5. Defining and naming themes:

To convey each theme's meaning more precisely, specific names and definitions were created. Similar themes were grouped, when possible, to represent the broader categories of mobile practices. Direct quotes from participants were slightly edited, as necessary, to maintain readability and still preserve the core of the participants' statements. Tables 3.8 and 3.9 are thematic maps of the findings of this study.

Step 6. Producing the report:

Chapters 4 and 5 present the results of the data analysis of Phases One and Two. These findings will be discussed in the discussion chapter in the context of the chosen frameworks. The discussion chapter aims to unpack how mobile technologies have been used in undergraduate science education to support student learning and to what extent these activities were perceived as pedagogically innovative by participants.

Table 3.8

Thematic Map – Undergraduate Science Mobile Practices

Themes	Sub-Themes	Definitions	Examples
Conversations around and through the devices	Face-to-face conversations around devices	student dialogues occurring in person, where mobile devices served as a shared visual or reference point.	Because we were next to each other, and we discussed our topics. But there is a lot of collaboration … you can hear when the Menti thing goes off, everyone is talking to their friends. … So, it's very … networked. (Case 3a_Student 1)
	Conversations through devices (Teacher/student-initiated)	online conversations that were facilitated by use of mobile devices, including teacher- and student-initiated discussions via online platforms.	[Used Teams/Twitter/PowerPoint] to view and interact with the content - e.g. the ability to use the chat function on Teams allowed more real-time questions during a lecture or tutorial with peers being able to join it and answer. (Teacher #36) We do have discussion forums in the learning management system, which enables us to hear students' voices. (Case 4_Learning designer) They use WhatsApp to communicate with each other. (Case 2_Teacher 1)
Sharing of data and co-production of digital products	Exchange data	the use of mobile devices enabled students to collect and share data in support of knowledge building	It's built-in … [and] common to the whole cohort, but they can create spaces within the collaborative space that is ... where they share all the information. (Case 6_Learning designer)
Learner choice and control	Choice of slip-tasking (Student-initiated)	students personalised their learning by choosing what apps to use, beyond those prescribed by their teachers.	Canvas, Microsoft office (word, PowerPoint, notebook), YouTube, email, Facebook messenger [to] gather basic learning information, complete tasks and do additional research. (Case 6_Student #16)

Themes	Sub-Themes	Definitions	Examples
	Choice of mode of learning	the use of mobile devices enabled choices of synchronous (in-person or online) and asynchronous learning modes	It's a mixture since we have the traditional lecture where students can come to the face-to-face and also we have the online student cohort. So students can free to choose the mode of learning. (Case 4_Teacher)
	Choice of how to learn	students decided how to approach the learning tasks	EPviewer is an app used to capture images from Olympus microscopes. Students can choose to capture images of stained cells that they have generated during the class. (Teacher #9) There's a certain structure that we provide and what they need to complete, but how they complete that is up to their decision. So, if they would prefer to write down their observations, they can write it down … They prefer to upload a photo or a video, then they can do it that way. (Case 2_Learning designer)
	Control over pace and spaces	students controlled the time and spaces of their learning mediated by mobile devices	We were given ostensibly at least, a certain amount of freedom to set the pace … the way that we move through the area … the way that it's presented in terms of technology really facilitates a more agentic approach. (Case 1a_Student 2)
Use of realistic apps		the extent to which mobile learning activities mirror real-world scientific practices	Getting access to species identification lists, and information about the nature reserve (via a QR code linked to a purpose-built website). Conducting bird surveys via remote cameras linked by a purpose-built website. (Teacher #94) So it's real-world activities. If they do research, they will use the same equipment. (Case 2_Teacher 2).

Themes	Sub-Themes	Definitions	Examples
Use of real-world contexts		mobile learning experiences situated in realistic settings	It is the biggest storage deposit in the world, … the context is pretty relevant. It's in these kinds of places that all of Australia's valuable mineral resources are. (Case 1a_Student 2)
Learning across multiple spaces		the use of mobile devices enabled students to learn across multiple physical and virtual settings	When you're actually at home doing questions yourself, that's when the device is most helpful because ... that's how you communicate with people. (Case 5_Student 2)
Tailored app settings and workflow		students used mobile devices to personalise app settings and workflow based on individual needs	There are fundamentally different ways that you can work with this app … For example, … when you do the rock ID in the field identification … you can make a list of the rocks that you will encounter and then start adding from that list, … make the list as you go, or … not to make the list … There are different levels at which you can go and describe your data. You can stay at the surface or … go very deep. (Case 1a_Learning designer)

Table 3.9

Thematic Map – Perceptions of Mobile Pedagogical Innovation

Themes	Sub-Themes	Definitions	Examples
Features of mobile pedagogical innovation	Self-directed learning through structured autonomy	the use of mobile tools presented new ways of learning by promoting more student autonomy in their decision-making processes within the boundaries of the activities.	It gives me more freedom because it enables us to take measurements a lot easier. It enables us to take photos and do sketches ... We choose what we are learning while we are in the field. (Case 1a_Student 13) We do not have the right to choose what we want … but we definitely have the flexibility in how we choose to learn something. (Case 5_Student 1)
	Authentic learning tasks	the use of mobile tools introduced students to new scientific practices, fostering learning experiences that are more closely aligned with professional scientists.	This app is almost game-changing … With StraboSpot, we were able to move in the field so easily. I would assume that … future geologists would still have training in using a normal compass. But having used the app, it makes everything so much easier ... I could go out to the field really [with] just a compass to back up the data or recheck the data on the iPad. (Case 1a_Student 14)
	Incremental innovation	while mobile practices added something new to the existing activity, such as increased convenience and improved data access, they did not substantially alter the underlying pedagogical approaches	It does modify the learning, but at the end of the day, we still have to go out and look at the rocks. … StraboSpot has got the iPads to add something new, but I don't think it fundamentally changes the … paradigm of what we would've done without the iPads. (Case 1a_Student 6) The use of technology is more of a convenience than a really adaptive and disrupt or disruptive innovation to the subject itself. It just allows for the subjects to be more streamlined. (Case 6_Teacher)

Themes	Sub-Themes	Definitions	Examples
Perceived barriers to mobile pedagogical innovation	Persistence of traditional settings	the mobile activities were in formal settings	It's still pretty traditional because you have to be in that room to get that microscope. (Case 1b_Student 8) The technology helps again for online but like in terms of it hasn't really changed a whole lot in terms of the context of the learning. (Case 5_Student 1)
	Continuity of traditional teachers' roles and limited external facilitators	while mobile technologies were implemented in university science learning episodes, the teachers' roles were largely unchanged	The nature of the lecture is that there is a lecturer up here talking to us about the content. (Case 3a_Student 1)

Overall, the adopted data analysis approaches enabled a deep exploration of mobile practices and pedagogical innovation in undergraduate science education from multiple perspectives.

3.8 Study Rigour

This section evaluates the rigour of the adopted research design in the present study. Validity refers to the extent to which a study accurately measures what it intended to measure, while reliability is the accuracy of the measurement methods in which the results accurately reflect the population being studied (Golafshani, 2003). In mixed methods research, validity and reliability are assessed differently in the quantitative and qualitative strands. The quantitative data in this study were assessed using four criteria, namely, internal validity, external validity, reliability and objectivity (Creswell & Plano Clark, 2007), whereas the trustworthiness of qualitative data was assessed using their qualitative equivalents: credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985). Table 3.10 outlines the corresponding measures used to assess validity.

Table 3.10

Validity Measures for Quantitative and Qualitative Research

Quantitative Terms	Qualitative Equivalents
Internal validity	Credibility
External validity	Transferability
Reliability	Dependability
Objectivity	Confirmability

3.8.1 Qualitative Data

Credibility: Credibility refers to the confidence researchers have that their study is a faithful representation of participants' experiences. This can be enhanced by collecting data from multiple sources to triangulate findings (Lincoln & Guba, 1985; Patton, 1990). Triangulation not only strengthens the evidence but can also reveal discrepancies between data sources and offer further insights into the phenomenon under investigation (Patton, 1999).

In Phase Two of this study, data were collected through the researcher's observations, the teachers' and students' surveys, the teachers' and learning designers' semi-structured interviews, and the student focus groups. These approaches enabled the researcher to cross-check data sources and enhance the trustworthiness of the

findings. Although artefact data were not formally analysed, they still contributed to triangulation in interviews and focus groups (Patton, 2002). Additionally, differences in participants' perspectives further strengthened the credibility of the findings. To minimise researcher bias, regular meetings were held with her academic supervisors to evaluate interpretations and guide the development of ideas. Furthermore, aspects of the findings of the study's findings were also shared via staged doctoral assessments and conference presentations, providing opportunities for further feedback.

Transferability: Transferability is the extent to which the research findings can be generalised in other (similar) contexts or broader populations. It is acknowledged that qualitative research often involves a limited number of settings and participants; hence, it may not be possible to generalise the results to other contexts or groups (Shenton, 2004). Although this study focused on perceptions of teachers, learning designers, and students of distinctive and innovative mobile practices in undergraduate science education from four Australian universities, its findings may still be transferable to similar settings, such as other higher education levels or STEM education. This thesis provides detailed contextual information about the participants and the case backgrounds (see Section 3.6) to enable readers to assess the transferability of the findings to other similar contexts (Firestone, 1993; Lincoln & Guba, 1985).

Dependability: Dependability emphasises the consistent operations of a study so that its results can be repeated using the same research methods. In this study, the methodologies and analyses of each stage were fully documented and reviewed to ensure transparency of the research process. To ensure a clear chain of evidence, the data collection and analyses were detailed and executed strategically to develop a case study database. The dependability of this study was further promoted through the use of "overlapping methods", which included both semi-structured interviews and focus groups (Shenton, 2004). These discussions were audio-recorded to accurately identify speakers for data analysis, and the researcher also took notes during these sessions to capture additional observations. Phase Two participants were invited to review their transcripts to confirm their excerpts. No questions or comments were raised from participants who reviewed their transcripts.

Confirmability: Confirmability refers to the extent to which the findings represent the participants' views rather than the researcher's perspectives, and whether the findings can be confirmed by other sources. In this study, confirmability was achieved through the systematic rigour in the data collection and analysis processes using Microsoft Excel and Word software to create an audit trail. Triangulation from multiple data

sources further strengthened results by minimising potential researcher bias. Additionally, all transcripts were de-identified using the naming system described in Section 3.6.

3.8.2 Quantitative Data

Internal validity. Internal validity refers to the level of confidence that the effects observed in the data are causal. The question items in the surveys were based on the validated iPAC teacher survey (Kearney et al., 2019) and student survey (Burke et al., 2022). Inter-researcher validation was achieved through regular consultation with two of the iPAC framework designers (Kearney et al., 2012). This process was crucial for making necessary minor adjustments to ensure that the survey language aligned with the theoretical framework and context of university science education, particularly for Phase One participants in English- and Chinese-speaking countries. Validity was assessed using the Average Variance Extracted (AVE), with all average ratings for iPAC sub-constructs and innovation items exceeding the threshold of 0.5, thereby confirming the convergent validity (Fornell & Larcker, 1981).

External validity. The iPAC mobile framework has been used in number of studies across educational settings (see Chapter 2), further supporting the validity of its use in the current study. The validated teacher survey was previously used with school teachers (Kearney et al., 2015) and mathematics and science teachers (Kearney et al., 2020), while the student survey was used and validated in Burke et al.'s (2022) study. It is acknowledged that the external validity of this study is limited because the sample was drawn from only 14 countries in Phase One and four Australian universities in Phase Two. These samples are unlikely to represent the broader population of global university science teachers (Phase One) and university science teachers and students in Australia (Phase Two). Nevertheless, these results may still apply to contexts that share similar characteristics with those included in this study.

Reliability. Reliability refers to the repeatability and consistency of research results. In this study, the reliability of Phase One survey was assessed using rigorous statistical techniques. Factor loadings indicated the majority of the iPAC sub-constructs and innovation items were close to or exceeding the recommended threshold of 0.7 (Hair et al., 2009). Furthermore, reliability was confirmed as the Cronbach's alpha (α) and Composite Reliability (CR) values for the majority of measurement items were above the 0.7 benchmark (Fornell & Larcker, 1981; Raykov, 1997). The quantitative analysis procedures were conducted with guidance from a quantitative research expert to ensure their rigour and reliability.

Objectivity. Objectivity is the confidence that the results are unbiased and represent the truth. The data analysis was structured and transparent to reduce the researcher's bias. Although the same researcher conducted all data collection, the triangulation of multiple data sources provided cross-validation of responses.

Overall, the strategies outlined above were implemented to enhance the validity and reliability of both the qualitative and quantitative components of this study. Discrepancies that emerged between data sources were also assessed and addressed in the findings and discussion chapters to provide a comprehensive interpretation of the findings.

3.9 Ethics Considerations

This study strictly adhered to the ethics guidelines of the University of Technology Sydney (UTS) and received approval (see Appendix V) from the UTS Human Research Ethics Committee (Approval number ETH22-7239). Prior to submitting the ethics application, the researcher completed the two mandatory research integrity modules required by the UTS Graduate School for all Higher Degree Research (HDR) students. A research data management plan was also developed.

Informed Consent

All potential participants in this study received a participant information sheet and consent form (see list of Appendices). The researcher explained to them the purpose of the study, the research procedures, and the use of the sociocultural iPAC mobile pedagogical framework and innovative digital criteria as theoretical lenses. Participation was completely voluntary, and participants could withdraw anytime without having to provide a reason. Meetings and communications before, during and after the data collection process reinforced transparency and built trust between the researcher and participants. Participants were encouraged to ask any questions at any stage, and opportunities were provided to review the data and findings. In the activity observation, the researcher re-introduced the study at the start of each session and made it clear that no video-recording would be made; only observational notes would be taken and only consenting students would be included in the observation data. Permission was obtained from participants for the use of their photos.

Confidentiality and Privacy

Confidentiality and participant privacy were maintained throughout the research process. The study employed anonymous surveys, and all identifiable information from interviews and focus groups was not disclosed during data processing, reporting and

dissemination. A name list to identify Phase Two participants is saved in a secured file available only to the researcher. To further ensure confidentiality, all interviews and focus groups were conducted in private meeting rooms. No signs of discomfort or distress were observed during these sessions. All digital data are stored securely on a password-protected UTS secure cloud storage system. Hard-copy documents, including signed consent forms and field notes, are stored in a locked cabinet accessible only to the researcher.

3.10 Chapter Summary

This chapter has outlined the research methodologies adopted in this study. Guided by sociocultural theory, a mixed methods approach was deemed appropriate to investigate how distinctive mobile practices have been used in undergraduate science education, as well as how these m-learning activities have been perceived as pedagogically innovative by teachers, learning designers, and students. The findings from Phases One and Two of this study will be presented in Chapters 4 and 5, respectively.

Chapter 4
Phase One Findings

This chapter presents the findings from the analysis of Phase One data. The iPAC mobile pedagogical framework (Kearney et al., 2012) and innovative digital pedagogical criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005) were employed as theoretical lenses guiding this study. The survey asked participants to reflect on one science learning activity that they recently implemented where their students used mobile devices to support their learning (see Section 3.4 for research methods). These findings address the main research question used to guide this study:

> How are mobile technologies being used in undergraduate science education to support teaching and learning?

Phase One also explored two subsidiary research questions:

- How are university science teachers using distinctive mobile pedagogies?
- To what extent are educators' mobile learning activities perceived as pedagogically innovative?

These questions were designed to establish a broad understanding of current mobile practices in undergraduate science education globally, thereby laying the foundation for more detailed case studies conducted in Phase Two (see Section 3.2 for research design).

This chapter is organised into six main parts. Following the overview, the first part provides background information on the learning activities nominated by 132 university science teachers worldwide. The second part presents concurrently the descriptive statistical analysis and qualitative responses from the survey, organised according to the distinctive mobile practices adopted by teachers. This is followed by an analysis of teachers' perceptions of innovative mobile practices and overall learning, along with an examination of statistical relationships between teacher characteristics. The chapter concludes with a summary of the key findings from Phase One of the study.

4.1 Background of Teachers' Chosen Digital Learning Activities

The Phase One findings reflect the responses of university science teachers (N = 132). The background information about the participants and the survey completion rate is presented in the methodology chapter (Section 3.5.2). The following sub-sections

describe the science disciplines, undergraduate levels, types of mobile devices, and application(s) students used in their teachers' nominated learning activities.

4.1.1 Science Discipline Areas

The science discipline areas in the survey were compiled based on the analysis of undergraduate science courses offered by science faculties at universities worldwide. Participants could choose from 17 science discipline areas, with an additional “other” option to specify their discipline if it was not available on the list provided. Table 4.1 presents the distribution of science disciplines from the nominated learning activities.

The discipline areas were grouped according to their respective fields of research, based on the Australian and New Zealand Standard Research Classification (Australian Bureau Statistics, 2008). The data shows physical science and medical and health sciences each represented 20% of responses, followed by biological sciences (18%), chemical sciences (17%), and mathematical sciences (8%). The “other” category specified by participants included responses such as biotechnology, data science, food science, science practice and communication, and interdisciplinary science.

Table 4.1

Number and Percentages of Participants' Responses to, "What is the Science Discipline Area of your Chosen Digital Learning Activity?" (N=132)

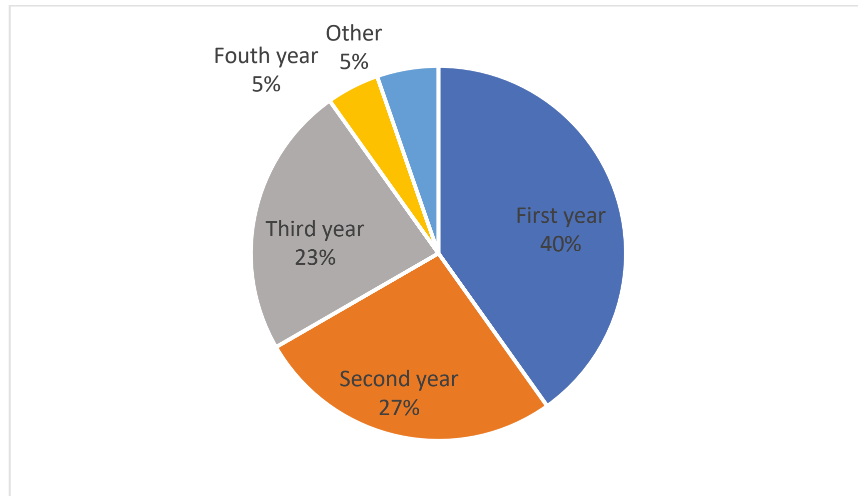
Field of research	Science discipline areas	Frequency	Total	%
Mathematical sciences	mathematics	11	11	8
Physical sciences	physics	25	26	20
	astronomy	1		
Chemical sciences	chemistry	22	22	17
Earth sciences	earth science	6	8	6
	geology	2		
Environmental sciences	environmental sciences	5	5	4
Biological sciences	biochemistry	4	24	18
	biology	19		
	ecology	1		
Medical and health sciences	biomedical science	16	27	20
	medical science	5		
	forensic science	1		
	anatomy	5		
	animal science	1		
Other, specified by participants		8	9	7
Total		132	132	100

4.1.2 Undergraduate Levels and Types of Devices

Figure 4.1 illustrates the distribution of the undergraduate levels at which the surveyed teachers implemented their science learning activities. Most of the learning activities were implemented in the early stages of the undergraduate science degrees: the first year (40%) and the second year (27%).

Figure 4.1

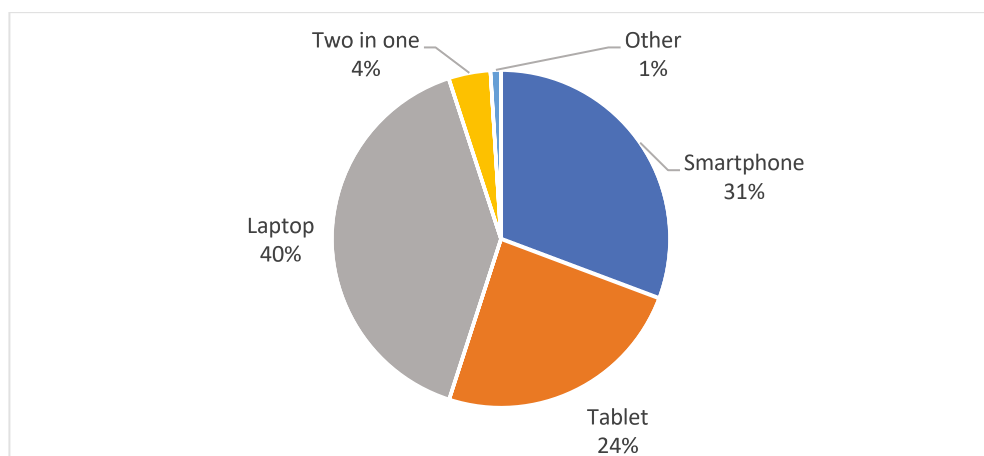
Phase One: Distribution of Undergraduate Levels (N=132)



Regarding device types, participants responded to: "*What type(s) of portable digital device did your students use in this activity? Choose all that applied.*" Figure 4.2 presents the distribution of portable digital devices used by students. Laptops were the predominant device (40%), followed by smartphones (31%) and tablets (24%). An example of the "other" category was Virtual Reality (VR) headsets.

Figure 4.2

Phase One: Distribution of Devices Used By Students (N=132)



Regarding the number of devices used in the nominated learning activities, the data indicates that 51% of activities utilised one device, while 49% incorporated two or more devices.

4.1.3 Main Applications Used in Teachers' Nominated Learning Activities

Teachers' responses to the open-ended question about mobile applications revealed diverse usage patterns, with several instances of teachers stating more than one mobile application. Table 4.2 shows a breakdown of app types across three main categories: science-specific, discipline-agnostic, and generic apps.

Table 4.2

Examples of Apps Used by Students in the Teachers' Nominated Learning Activities

App types		Examples
Science-specific apps	Fieldwork and data collection	Field Friend, plant identification app American Meteorological Society (AMS) Realtime Weather Data National Weather Service (NWS) ClimateWatch, iNaturalist GPS data collection using a smartphone-based app
	Subject-specific	Complete anatomy, Visible Body Human Anatomy Atlas, Aktiv chemistry, SPARKvue, Pymol Chirality-2 game, MILAGE LEarn+ App, Oasis Montaj QGIS, Phyphox
	Simulations	CircuitJS Molecular modelling software NEOS
Educational apps	Create digital product	Padlet, Kaltura, Moviemaker, Microsoft PowerPoint
	Data analysis and reporting	SPSS, Microsoft Excel Internal software program, Lab Archives
	Game-based learning/ Interactive polling	Kahoot, Mentimeter, Learning Catalytics, Pollev, Wooclap, In-house polling app
	Learning management system	Canvas, Blackboard, Campuswire, Google Classroom, GoSoapbox, NearPod, OpenEdX 智慧树 (Wise tree), 雨课堂(Rain class)
	Peer review	Feedback fruit, Peer Wise
Generic apps	Communication	Email, Outlook, WhatApps
	Collaboration	Google Suite, OneNotes
	Video conferencing	Zoom, Ring Central, Teams
	Search engine	Google, Baidu
	Social media	Facebook, QQ, YouTube, Twitter

Overall, these applications demonstrated a wide range of ways in which undergraduate students used mobile devices to support their learning in the teachers' nominated learning activities.

4.2 University Teachers' Adoption of Distinctive Mobile Practices

This section presents the key findings on university teachers' adoption of digital pedagogies, based on a survey of 132 participants. The teachers could select all applicable locations where their students engaged in the nominated digital learning activity. As can be seen in Table 4.3, university science teachers reported mainly formal settings (60%) (e.g., tutorials, on campus, laboratories, lectures) and at home (22%).

Table 4.3

Locations of the Teachers' Nominated Learning Activities (N=132)

Locations	%
At home	22
Tutorial	16
Out of classroom, but on campus	14
Laboratory	12
Lecture	12
In other places	10
In educational settings outside campus	6
Computer lab	5
Other	2
Total	100

Data also shows that 72% of teachers chose more than one location where their activities occurred, and the median number of activity locations chosen per teacher was three. Several teachers described how the use of mobile devices enabled students to engage in learning tasks before, during and after class:

> Every task in my courses is designed to be completed on the iPad. Students use Notability to annotate skeletal lecture notes and complete lab reports. Students use Aktiv Chemistry to complete online homework, in-class assignments, and practice exams. In lab students use their camera to document their lab learning ... (Teacher #107)

This illustrates how mobile device was deeply embedded in students' formal and informal learning routines. Similarly, other teachers described their students' blended use of mobile technologies both in and outside of class schedule:

> My students use Canvas to complete online quizzes, watch pre-class videos and complete their lab quizzes during the practical classes. (Teacher #57)
>
> … answering quiz, read during their museum tour, discuss in online meetings. (Teacher #55)
>
> Students first explored resources on hydrostatic pressure. Then they were invited into the online environment to explore the effects of different variables on pressure ... In class, we looked at the results and related it to theory. (Teacher #22)
>
> Students would be provided with various content on Canvas e.g. YouTube videos, recordings of past classes, tutorial/lecture notes which they can engage with during class or in their spare time. (Teacher #19)

Overall, these insights highlight how the use of mobile devices support continuous engagement with learning across diverse settings, enabling students to bridge synchronous and asynchronous learning experiences. The data suggests that teachers were not only referring to the synchronous activity they nominated to answer the questions in the survey, but also related tasks that students need to complete outside of class time.

4.2.1 Measures and Evaluation of Reliability and Validity

The participants used a 5-point Likert scale (1= Strongly Disagree to 5= Strongly Agree) to respond to survey items measuring students' behaviours when using portable devices to learn. The core items in the survey were structured around the sociocultural iPAC framework and innovative mobile pedagogies. Table 4.4 presents descriptive statistics for the iPAC sub-constructs, including mean scores (M), standard deviation (SD) and standard error (SE), as well as factor loadings (λ) and reliability measures.

Overall, university science teachers in Phase One perceived their m-learning tasks as fostering high levels of student agency and co-creation. However, lower ratings were observed for task authenticity and networked conversations. There was also limited evidence of tailored and contextualised learning experiences in university science education.

Table 4.4

Mean Ratings for Personalisation, Authenticity and Collaboration Sub-Constructs (N=132)

Constructs and measurement items	M	S.D.	λ	SE
Personalisation: Agency (α = 0.655; AVE = 0.596; CR = 0.815)	3.37	1.01		
P1. Choose the place to do the activity	3.58	1.37	0.796	0.12
P2. Determined the pace at which they did the activity	3.70	1.19	0.801	0.10
P3. Decided what they wanted to learn	2.83	1.39	0.716	0.12
Personalisation: Customisation (α = 0.810; AVE = 0.641; CR = 0.877)	2.65	1.12		
P4. Were guided by the app(s) based on their past use	2.40	1.39	0.811	0.12
P5. Tailored app(s) settings to their preferences	2.76	1.42	0.814	0.12
P6. Received individualised information through the app(s) about themselves	2.98	1.45	0.698	0.13
P7. Customised feeds and links for their learning needs	2.45	1.38	0.871	0.12
Authenticity: Context (α = 0.781; AVE = 0.698; CR = 0.874)	2.44	1.24		
A1. Learned in a place suggested by the topic	2.65	1.51	0.852	0.13
A2. Learned in a realistic/ virtual space	2.30	1.48	0.746	0.13
A3. Learned at a time suggested by the topic	2.38	1.46	0.902	0.13
Authenticity: Task (α = 0.768; AVE = 0.593; CR = 0.853)	2.87	1.04		
A4. Worked like an expert	3.15	1.37	0.651	0.12
A5. Participated in real-world activities that benefit society	2.69	1.40	0.840	0.12
A6. Learned serendipitously in an unplanned way	2.70	1.28	0.776	0.11
A7. Engaged in activities related to everyday life	2.93	1.36	0.802	0.12
Collaboration: Conversation (α = 0.785; AVE = 0.699; CR = 0.874)	2.71	1.16		
C1. Discussed the work online with their friends/peers	3.20	1.45	0.850	0.13
C2. Discussed the work online with people they don't know	2.07	1.21	0.756	0.10
C3. Communicated with others using texts, image or video	2.86	1.48	0.897	0.13
Collaboration: Co-creation (α = 0.767; AVE = 0.684; CR = 0.867)	3.22	1.25		
C4. Worked together to create a digital product	3.31	1.59	0.846	0.14
C5. Shared digital content	3.46	1.46	0.881	0.13
C6. Contributed to existing digital content	2.88	1.48	0.751	0.13

Note. M = Mean; SD = Standard Deviation; λ = factor loadings; S = Standard Error; α = Cronbach's alpha; AVE = Average Variance Extracted; CR = Composite Reliability

Each of the iPAC sub-constructs and innovation items achieved an AVE higher than the recommended threshold of 0.5 to establish convergent validity (Fornell & Larcker, 1981). Composite reliability (CR) and Cronbach's alpha (α) values for most measured items were also close to or surpassed the 0.7 thresholds, confirming reliability (Fornell & Larcker, 1981). Similarly, the standard errors results and the majority of items had factor loadings (λ) exceeding or approaching the benchmark of 0.7 (Hair et al., 2009), confirming the reliability and stability of the constructs measured. The standard deviations indicate the variation of responses, providing insight into the degree of agreement among participants. Samples of the SPSS statistical outputs are provided in Appendix S (numbers 1 to 8).

4.2.2 Mobile Pedagogical Features Emphasised by Teachers

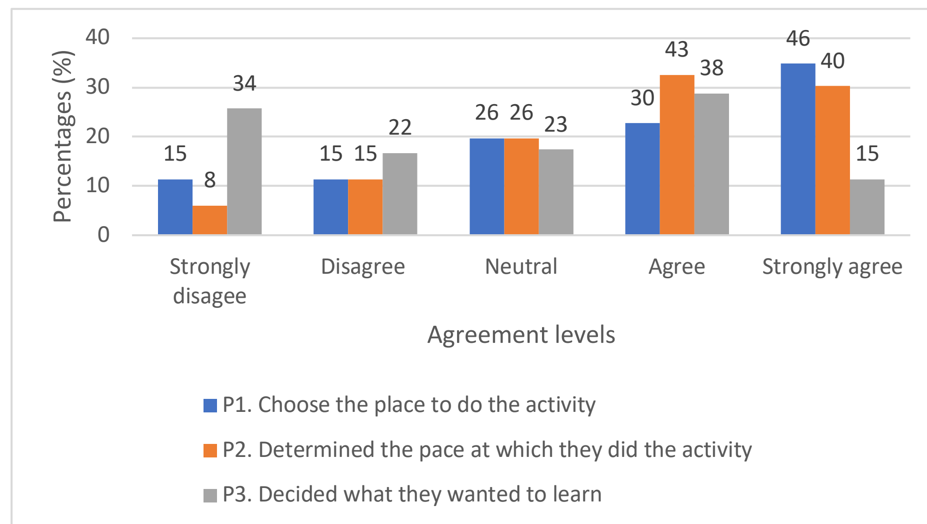
Phase One's findings indicate that university science teachers in this study prioritised student agency and co-creation, signifying a top priority for student control and co-production in university science digital practices. The following sub-sections provide the relevant quantitative survey data, presented concurrently with the qualitative data to create the trendlines on distinctive mobile learning aspects. The quotes in these sub-sections were chosen from items with a mean score of equal or greater than 3. Other than asking participants which of the main app(s) their students used in the nominated activities and how they used it, there were no open-ended questions for the core iPAC and innovation items. This limitation is addressed in Section 6.7.

4.2.2.1 Learner Choice and Control

As may be seen in Table 4.4, most of the university science teachers in this study rated student agency more highly when considering the distinctive mobile practices underpinning their nominated learning activity (M = 3.37; SD = 1.01). These teachers agreed that the use of mobile devices enabled students to control the pace (M = 3.70; SD = 1.19) and choose the location (M = 3.58; SD = 1.38) of their learning tasks. Nevertheless, students had limited opportunities to decide on "what they wanted to learn" (M = 2.83; SD = 1.39), suggesting that university science teachers still largely control the learning content. Figure 4.3 provides detailed percentages of student agency ratings. The number above each bar indicates the number of responses it represents.

Figure 4.3

Distribution of Results for Personalisation: Student Agency Items (N=132)



More than half of the teachers supported the idea that digital tools enhanced students' choice of learning location and pacing. Teachers who implemented activities promoting self-paced learning shared the following examples of how mobile apps supported this process:

> [Used Nearpod] to compartmentalise difficult subjects by having individual components broken down and worked through at a student-led pace. (Teacher #3)

> EPviewer is an app used to capture images from Olympus microscopes. Students can choose to capture images of stained cells that they have generated during the class. (Teacher #9)

> [Used PeerWise] writing, peer-reviewing and answering multiple choice questions anonymously in their own time and responding to, and discussing, MCQs presented in lectures using an audience response system. (Teacher #79)

Several teachers also highlighted the role of flipped learning in fostering student agency, as students engaged with asynchronous pre- and post-class activities at convenient times and spaces prior to the scheduled synchronous class:

> They saw the new content outside of class for the first time, allowing them to learn at their own rate, so in class we could more deeply engage with the material. (Teacher #64)

> Students would be provided with various content on Canvas, e.g., YouTube videos, recordings of past classes, tutorial/lecture notes which they can engage with during class or in their spare time. (Teacher #19)

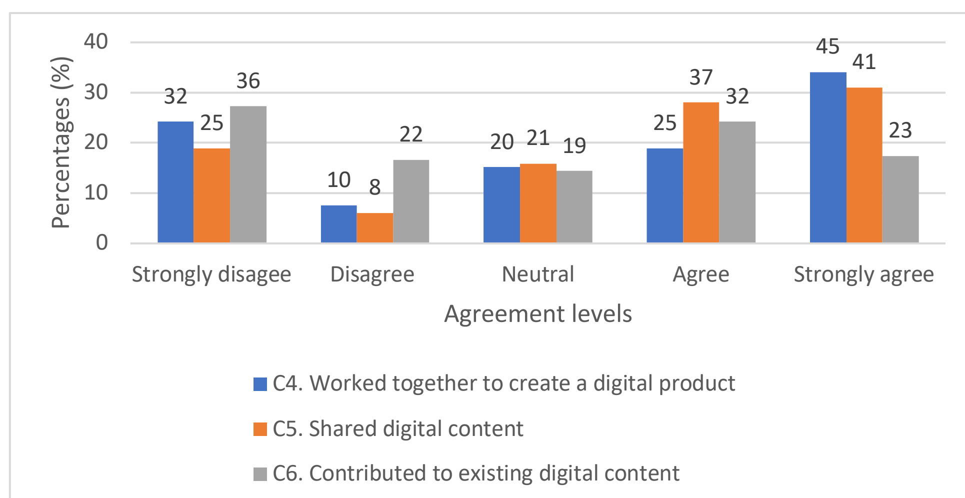
These findings suggest that the interrogation of digital practices offered students flexibility over time, pace and location, predominantly supporting asynchronous learning but offering limited autonomy in the learning content. This could potentially explain the high number of teachers in Table 4.3 choosing "home" as a location where students learn.

4.2.2.2 Sharing of Data and Co-Production of Digital Products

As shown in Table 4.4, co-creation emerged as the second-most favourably ranked subconstruct by teachers (M = 3.22; SD = 1.25), highlighting the perceived potential of mobile learning to support collaborative learning among students. According to Figure 4.4, when students used mobile devices to learn, more than half of the teachers agreed that their students "shared digital content" (M = 3.46; SD = 1.46) and "worked together to create a digital product" (M = 3.31; SD = 1.59). However, there was slightly less evidence that students contributed to existing content (M =2.88; SD = 1.48).

Figure 4.4

Distribution of Results for Collaboration: Co-creation Items (N=132)



Teacher #87 rated their students very high for co-creation items (M =5.0), providing examples of how their students in a science practice and communication activity used multiple Google suite programs such as Google Docs, Google Slides, Google Sheets and Google Forms to collaborate in real-time, exchange data and ideas with peers and thus achieve mutual learning goals. Below are more teachers' descriptions of how students used their mobile devices to work together to co-create and share digital products such as videos and slides in the teachers' nominated learning activities:

> They had to make a video about a scientific subject and post on YouTube, group activity four students working together. (Teacher #111)

> Teams collaborated to create short slide packs over some weeks, that were shared with each other on Padlet for information/comment. (Teacher #32)

> The students were required to create a forensic digital media artefact in groups. (Teacher #76)

> They mostly talked with each other via the app, occasionally sharing files when necessary. (Teacher #16)

Students also worked together to review each other's work, as shared by Teacher #87:

> Students also gave feedback to peers in class on assessment tasks via Feedback Fruits (GME and Peer review tools). Students also used Feedback Fruits (GME tool) to evaluate their own contribution to the teamwork and their team members contributions to teamwork. (Teacher #87)

Overall, students utilised a variety of applications to collaborate on group projects. Using their mobile devices in this way, they contributed to the learning content and shared data, which fostered a sense of collaborative teamwork and enhanced their science learning experiences. The overlap between co-creation and conversation subconstructs is discussed in Chapter 6.

4.2.3 Mobile Pedagogical Features Less Emphasised by Teachers

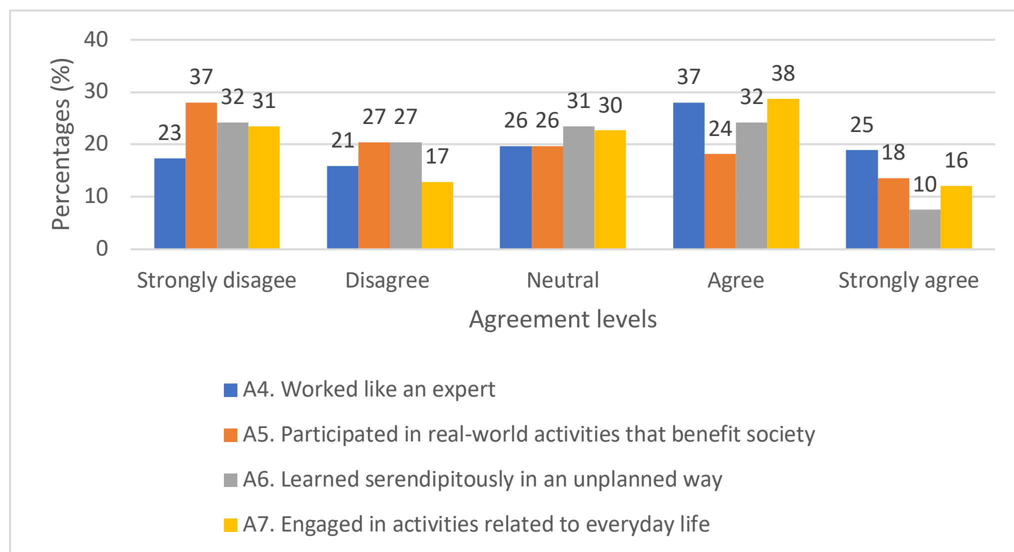
Analysis of the data revealed four mobile pedagogical approaches that were less emphasised by the teachers in this study: task (authenticity construct), conversation (collaboration construct), customisation (personalisation construct), and context (authenticity construct). The following sub-sections explore these subconstructs, supported by survey data and commentaries from participating teachers.

4.2.3.1 Use of Realistic Apps

Teachers in this study rated task authenticity (M = 2.87; SD = 1.04) slightly more favourable than context authenticity (M = 2.44; SD = 1.24), although these ratings were still below average of a 5-point Likert scale. According to Figure 4.5, while some teachers incorporated mobile tools to promote professional practices where their students "worked like experts" (M = 3.15; SD = 1.37) and engaged in activities related to daily life" (M = 2.93; SD = 1.36), there were fewer instances of learning tasks where students "participated in real-world activities that benefit the society" (M = 2.69; SD = 1.40).

Figure 4.5

Distribution of Results for Authenticity: Tasks Items (N=132)



In their responses, the teachers provided examples of technology-enhanced authentic task design in field-based activities, such as using a realistic app to learn field-based skills in an earth science activity:

> The customised Field Friend app brought students on learning trails at selected nature reserves to observe landforms, soils [and] plants. At each stop, scaffolding questions and instructions were provided to help students make field observations and measurements and also support analysis of the landscape to integrate understanding of geology, soils, ecology and hydrology. (Teacher #44)

Their students used subject-specific online resources on their mobile devices to identify bird or plant species in outdoor nature settings:

> Getting access to species identification lists, and information about the nature reserve (via a QR code linked to a purpose-built website). Conducting bird surveys via remote cameras linked by a purpose-built website. (Teacher #94)

> To record the location of specific plants or fauna within their local area to determine their geographical distribution. (Teacher #74)

> Students collected tree location and attributes using a smartphone app and their phone's built-in GPS. (Teacher #99)

> Collect and process geological field data. Make reports using the devices and the corresponding apps. (Teacher #131)

Students also recorded experiment results in a digital logbook in physics and chemistry lab activities:

> They used OneNote to keep lab book records in a way that is realistic to professional practice. (Teacher #60)

> The students documented their laboratory results (images, tables etc) and answered pre-set questions (set by the teachers) on Lab Archives on a laptop. (Teacher #14)

> In lab, they used the Spectrometer and SPARKvue apps (from PASCO Scientific) to collect and analyse data. (Teacher #107)

Some teachers also described how their students used simulation or virtual reality to simulate realistic learning in classroom settings:

> Used the simulations to learn how to use various measuring instruments in Physics. (Teacher #33)

> They used CircuitJS to simulate the electronic circuits they were constructing." (Teacher #31)

> I uploaded the Virtual Lab apps on our Learning Media System, so they can download and run it on their devices. They were divided into groups and did lab work simulation using that VR apps. (Teacher #125)

[Used Molecular modelling software] To help visualise the orientation and constitution of molecules. (Teacher #128)

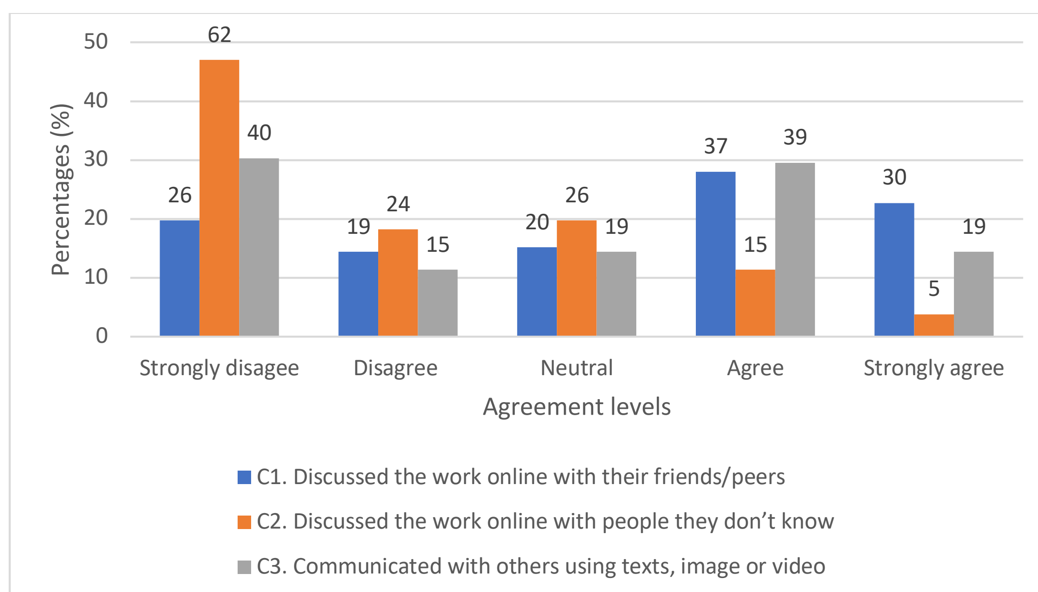
Overall, these responses indicate that the teachers in this survey recognised the value of authentic learning tasks mainly in field-based and lab-based learning activities, but these were not implemented across all university learning activities and science disciplines. This will be discussed further Chapter 6.

4.2.3.2 Conversations Through the Devices

The conversational aspect of the nominated learning activities was rated relatively low by teachers (M = 2.71; SD = 1.16). Although some teachers perceived high students' engagement in online discussion among peers (M = 3.20; SD = 1.45), the patterns of ratings were inconsistent with other conversation items: "communicated with others using texts, image or video" (M = 2.86; SD = 1.48) and opportunities for connecting with people outside of the university network (M = 2.07; SD = 1.22). Figure 4.6 presents the teachers' agreement levels about the extent to which students collaborated online to exchange ideas and thoughts.

Figure 4.6

Distribution of Results for Collaboration: Conversation (Online) Items (N=132)



In addition to the subject-specific apps prescribed by the teachers for students to interact with each other, students also independently utilised other platforms such as generic or social media apps to facilitate collaborative discussions with peers. For example, Teacher #16 reported that his 3rd-year chemistry students used an instant

messaging Chinese app called QQ to chat with each other or exchange files. Other exemplars showcase evidence of students connected with peers through online conversations to discuss their learning with the use of multimedia such as texts, images and videos:

> [Student used Padlet] to ask and answer questions during a lecture. It enabled students who were in the classroom and students who were joining virtually to interact with each other and me. (Teacher #82)

> Students used multiple communication means, e.g., Facebook groups, email, texts to chat to one another about tasks. (Teacher #87)

> the ability to use the chat function on Teams allowed more real-time questions during a lecture or tutorial with peers being able to join it and answer. (Teacher #36)

> WhatsApp, PowerPoint, Telegram, Zoom, Facebook – Students [used] these apps for discussion, presentations, assignments. (Teacher #90)

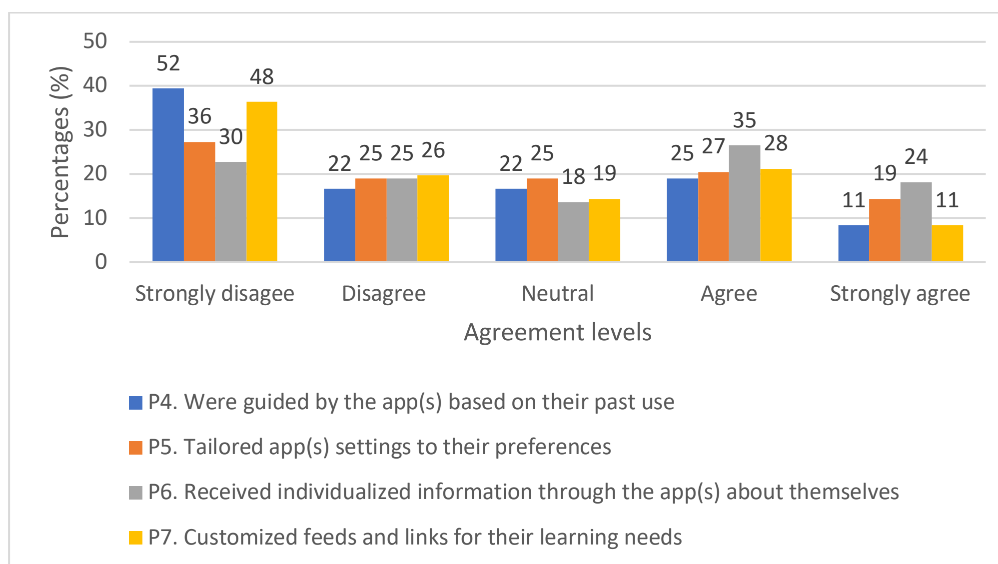
Overall, although teachers did not highlight networked conversations as a strong theme, there was some evidence of such interactions in synchronous online or hybrid activities, as well as students' use of social media.

4.2.3.3 Tailored App Settings and Workflow

Analysis revealed that customisation was the second-lowest rated subconstruct (M = 2.65; SD = 1.12) within the iPAC subconstructs. This suggests that the participating university science teachers held less favourable views toward tailored learning experiences mediated by mobile devices. Specifically, despite some evidence that students "received individualised information through the app(s) about themselves" (M = 2.98; SD = 1.45), many teachers did not agree that their students "were guided by the app(s) based on their past use" (M = 2.40; SD = 1.38) or could "tailor app(s) settings to their preferences" (M = 2.76; SD = 1.43). Figure 4.7 provides a breakdown of responses to the items in this sub-construct.

Figure 4.7

Distribution of Results for Personalisation: Customisation Items (N=132)



Below are examples of comments from teachers about the value of customisation mobile practices where students received feedback from the app based on their performances in biology and animal science learning activities:

> The app provided feedback so they could correct errors. The app guided them to the next process in solving a problem and communicating their findings. (Teacher #119)

> They [students] receive automated feedback at points throughout the activity. Upon submission, students automatically receive a response report as a record of their participation directly to the email address provided. (Teacher #9)

Given the benefits of digital pedagogies for personalised learning (Pachler et al., 2010), it was somewhat surprising that there was less emphasis on mobile practices supporting customisation.

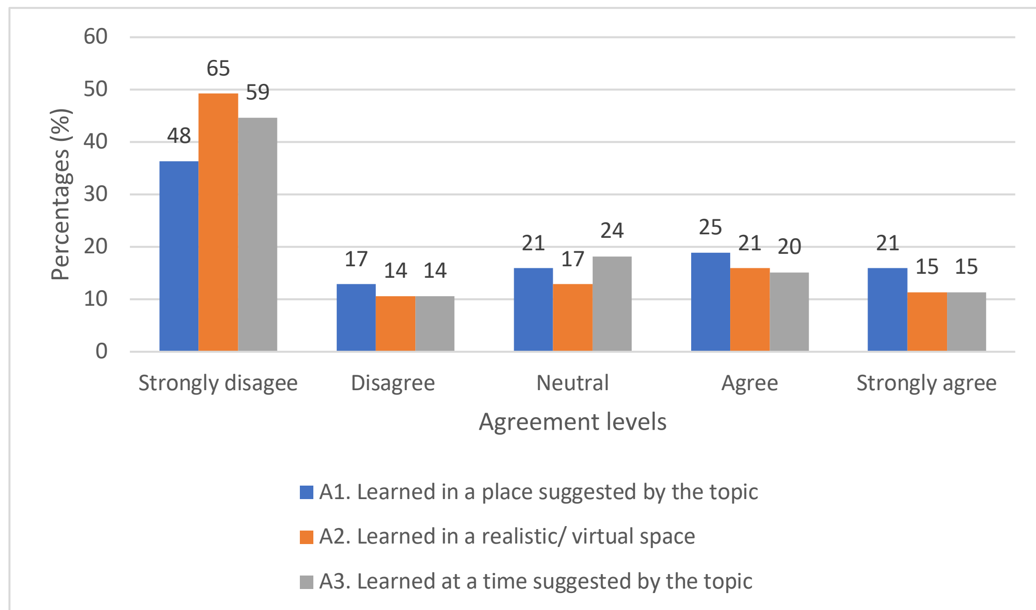
4.2.3.4 Use of Real-world Contexts

The context subconstruct was rated the lowest by teachers in Phase One (M = 2.44; SD = 1.24). In the survey responses, only a quarter of the teachers agreed that their students used digital devices to “learn in a *place* suggested by the topic” (M = 2.65; SD = 1.51). Particularly concerning was the limited use of realistic spaces (M = 2.30; SD = 1.48) where students “learned at a *time* suggested by the topic” (M = 2.38; SD = 1.46). As shown earlier in Table 4.3, university classrooms were the most common settings

for the learning activities in Phase One. Figure 4.8 is the breakdown of the items in percentages for this subconstruct.

Figure 4.8

Distribution of Results for Authenticity: Context Items (N=132)



Overall, the lower rankings of the task authenticity, online conversation, customisation and context subconstructs suggest that the university science teachers had not fully exploited the distinctive pedagogical features of mobile devices to enhance mobile practices supporting customised, contextualised, networked and authentic learning experiences. These findings will be discussed further in Chapter 6.

4.3 Teachers' Perceptions of Pedagogical Innovation

As mentioned in Chapter 3, the current study also explored teachers' perceptions of their practices in comparison to approaches that do not use mobile devices. The findings presented in Table 4.5 and Figure 4.9 reveal a high overall rating for pedagogical innovation (M = 3.31; SD = 0.95), suggesting that many teachers perceived their practices as innovative. The innovation items were used to assess the extent to which the teacher's nominated learning task differed from conventional, non-digital science learning tasks.

Table 4.5

Mean Ratings for Innovation Items (N=132)

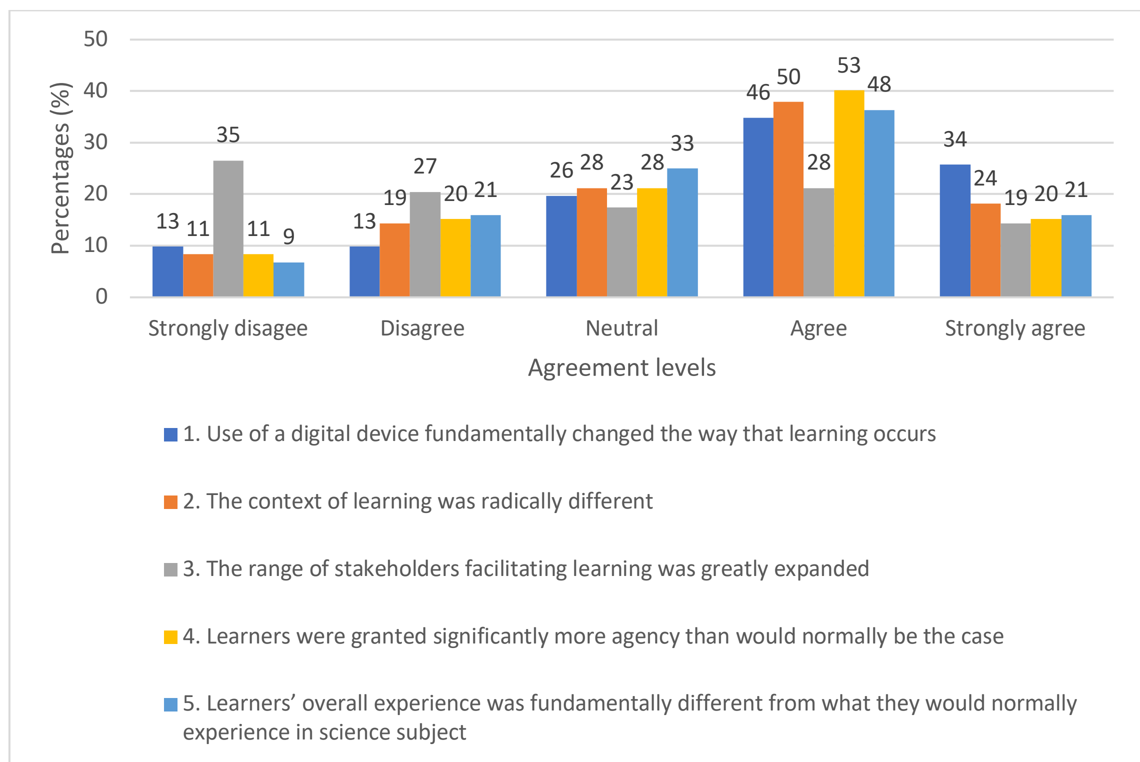
Measurement items	M	S.D.	λ	SE
Innovation (AVE = 0.596; CR = 0.881)	3.31	0.95		
1. Use of a digital device fundamentally changed the way that learning occurs	3.57	1.25	0.787	0.11
2. The context of learning was radically different	3.43	1.20	0.806	0.10
3. The range of stakeholders facilitating learning was greatly expanded	2.77	1.42	0.702	0.12
4. Learners were granted significantly more agency than would normally be the case	3.39	1.16	0.753	0.10
5. Learners' overall experience was fundamentally different from what they would normally experience in science subject	3.39	1.14	0.810	0.10

Among the five measurement items, the teachers emphasised the transformative role of mobile devices in the learning processes (M = 3.57; SD = 1.25), providing radically different learning context (M = 3.43; SD = 1.20) and enhanced learner agency (M = 3.39; SD = 1.17). Moreover, these teachers perceived their students' overall learning experiences using mobile devices as fundamentally different from traditional science activities (M = 3.39; SD = 1.16). However, the variability in responses, indicated by relatively high standard deviations, suggests considerable diversity in the teachers' experiences and familiarity with mobile practices. The teachers generally perceived their mobile practices as moderately innovative, indicating the benefits of leveraging mobile devices for new and effective science learning episodes.

A limitation of this study's survey was the lack of open-ended questions for the innovation section, which could have provided further insights into details of the perceived innovative mobile practices. The range of stakeholders such as experts, scientists, family or community members involved in these activities was also limited.

Figure 4.9

Distribution of Results for Innovation Items (N=132)



4.4 Teachers' Perceptions of Overall Learning

Similar to the favourable ratings in the innovation items, the data in Table 4.6 indicate that the majority of Phase One teachers agreed that the use of mobile devices in their nominated activities could improve their students' learning (M = 4.02; SD = 0.93) and that their students "enjoyed using digital devices to learn about science" (M = 4.05; SD = 0.86). Many teachers emphasised that the use of mobile devices helped students understand science concepts (M = 3.90; SD = 0.96) and practise science skills (M = 3.68; SD = 1.05). These results suggest positive students' experiences with mobile learning activities.

Table 4.6

Mean Ratings for Overall Learning Experience Items (N=132)

Measurement items	M	S.D.	λ	SE
Overall Learning Experience (AVE = 0.665; CR = 0.888)	3.68	0.77		
E1. Using digital devices improved my students' science learning	4.02	0.92	0.841	0.08
E2. My students enjoyed using digital devices to learn about science	4.05	0.86	0.789	0.07
E3. ^My students found it difficult learning science using digital devices (R)	2.75	1.02	-	0.09
E4. Using digital devices helped my students to understand concepts in science	3.90	0.96	0.861	0.08
E5. Using digital devices helped my students to practise science skills	3.68	1.05	0.77	0.09

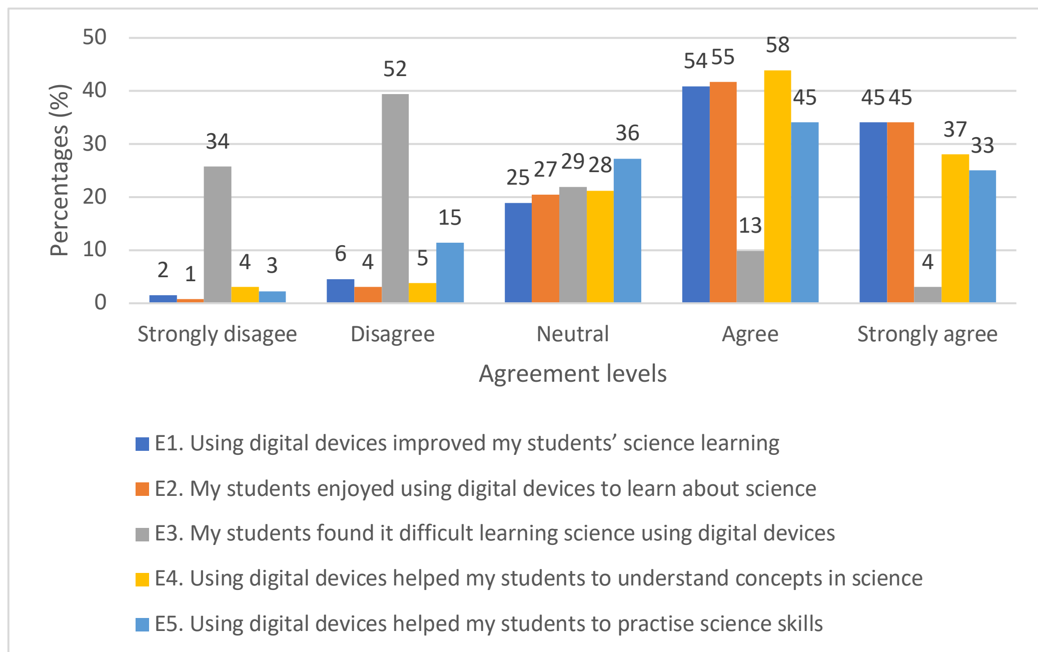
Note. ^ Item not used in factor analysis; R = reverse code

As shown in Figure 4.10, the Phase One university science teachers assigned notably high scores for their students' overall learning experiences in their nominated digital activities (Items E1, E2, E4, E5: M = 3.91 out of 5). Item E3 was a reverse question and, based on the inadequate factor loading, it was removed as a measure for overall learning to mitigate potential misinterpretation.

In summary, based on the positive responses in the overall learning experience items, the recently implemented mobile-mediated learning activities examined by the teachers in this survey were evidently supported undergraduate students to learn science knowledge and skills.

Figure 4.10

Distribution of Results for Overall Learning Experience Items (N=132)



4.5 Comparisons Across Teachers' Characteristics

One-way analyses of variance (ANOVA) were conducted to examine differences across the iPAC subconstructs and innovation items in relation to teachers' years of teaching experience and their experience with digital teaching (see Table 4.7). See Appendix S (numbers 9 to 10) for SPSS statistical output samples.

Student agency (p = 0.03), customisation (p = 0.01), authentic context (p = 0.03) and innovation (p = 0.007) were reported to be statistically significantly higher among teachers who were experienced or very experienced with science mobile pedagogies. In other words, university science teachers with more experience in mobile practices perceived themselves as implementing more mobile approaches that support student agency, customised, contextualised and innovative learning. On the other hand, there were no statistical differences in the iPAC dimensions and innovation based on teachers' number of teaching years. The implications of these results are addressed in Section 6.5.

Table 4.7

Summary Statistics For Teachers' Characteristics

	P_a	P_c	A_c	A_t	C_{con}	C_c	Innovation	n
Aggregate mean	3.37	2.65	2.44	2.87	2.71	3.22	3.31	132
Years of teaching								
<10 years	3.40	2.72	2.55	2.83	2.78	3.40	3.50	63
10-20 years	3.34	2.61	2.47	2.98	2.75	3.15	3.08	32
20+ years	3.34	2.56	2.24	2.83	2.54	2.97	3.17	37
p value	0.94	*0.76*	*0.50*	*0.77*	*0.61*	*0.24*	*0.07*	
Experience in digital teaching								
Inexperienced/occasional user	3.07	2.26	2.08	2.64	2.49	3.00	2.96	37
Experienced/very experienced	3.49	2.80	2.58	2.96	2.80	3.30	3.44	95
p value	*0.03**	*0.01**	*0.03**	0.18	0.16	0.21	0.007*	

Notes: P_a = Personalisation_Agency; P_c = Personalisation_Customisation; A_c = Authenticity_Context; A_t = Authenticity_Task; C_{con} = Collaboration_Conversation; C_c = Collaboration_Co-creation

** denotes mean significant difference from mean for iPAC and Innovation dimensions at 0.05 level.*

4.6 Chapter Summary

This study was guided by the sociocultural iPAC mobile pedagogical framework (Kearney et al., 2012) and criteria of innovative mobile pedagogies (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005). Phase One of this study investigated the adoption of mobile science pedagogies across science learning tasks implemented by 132 university science teachers worldwide, highlighting key insights into the use of mobile practices in undergraduate science education.

The findings reveal that these university science teachers predominantly focused on fostering student agency and co-creation. These aspects were central to the m-learning experiences implemented by the teachers, allowing their students to have more control over their learning and co-create with peers. However, other mobile pedagogical features such as task authenticity, online conversation, customisation and context were less strongly featured. This suggests opportunities for university science teachers to further exploit these areas, as they could benefit from integrating more authentic tasks and networked m-learning activities. Furthermore, there is potential to further customise and contextualise m-learning activities to align them more with students' individual learning needs in relevant professional settings.

The Phase One teachers perceived that the use of mobile devices fundamentally changed their nominated m-learning activities, creating a radically different context and increasing learner agency. They also perceived their students' overall learning experience differed significantly from their usual science activities. However, there was limited involvement from a range of external stakeholders in these activities.

These insights, along with findings from Phase Two (see Chapter 5), will be explored in greater depth in the discussion chapter to illuminate how undergraduate science students from various global and Australian universities utilise distinctive and innovative mobile pedagogies. Overall, this chapter has established a foundational understanding of current mobile practices in undergraduate science education, setting the stage for further analysis of case studies presented in the next chapter.

Chapter 5
Phase Two Findings

This chapter presents the findings of Phase Two of this study. It focuses on six case studies comprising eight learning activities from four universities. Background information on each case can be found in Section 3.6 of the research methodology chapter. Building on the findings from the Phase One teacher survey, Phase Two expands the investigation by collecting quantitative and qualitative data from teachers, learning designers, and students to triangulate the findings and provide deeper insights into the use of mobile technologies in undergraduate science education and the extent of pedagogical innovation as perceived by participants.

The findings emerging from these data sets address the following four subsidiary research questions:

1. How are university science teachers using distinctive mobile pedagogies?
2. How do learning designers view these mobile pedagogies?
3. How do students experience these mobile pedagogies?
4. To what extent are educators' mobile learning activities perceived as pedagogically innovative?

The chapter begins with an overview and then explores the science mobile pedagogical approaches and the participants' perceptions of pedagogical innovation identified across all cases. Table 5.1 provides an overview of the collected data across six case studies, including case numbers, universities, subjects, activity types, durations and participant numbers.

The cases spanned four universities, four activity types, and five undergraduate science subjects. University A had three cases with two activities in Cases 1 and 3. The cases represent a diverse range of learning activities (field trips, labs, lectures, and workshops), as selected by the teacher participants, across different undergraduate science subjects.

Table 5.1

Overview of Phase Two Case Studies

Case No	Universities	Subjects	Activity types	Duration	Teachers	Students			Learning designers
						Observation	Survey	Focus group	
1a	A	Geology	Field trip	7 days	1	15	14	4	1*
1b			Workshop	2 hrs	1	16	13	6	1*
2		Chemistry	Lab	3 hrs	2	26	12	1	1
3a		Physics	Lecture	1 hr	1	12	7	2	1*
3b			Lab	3 hrs	1	20	2	2	1
4	B	Statistics	Lecture	2 hrs	1	14	25	1	1*
5	C	Chemistry	Workshop	2 hrs	2	18	19	2	1
6	D	Microbiology	Lab	3 hrs	1	19	37	3	1*

Note. * *Subject coordinator self-nominated to be interviewed as learning designer*

Case 2 involved a chemistry laboratory activity co-taught by two teachers, both of whom were interviewed at the request of the science lab director (who nominated himself as learning designer). In Case 5, two teachers led separate workshops for the same course in weeks 4 and 9 of the semester. Both sessions were observed and both teachers were interviewed based on the request of the subject coordinator. Student participation is reported in three categories: observation, survey and focus group. It is noted that some focus groups only included one participant (cases 1b, 2, 3a, 3b, 4 and 6).

These case studies offer valuable insights into the implementation of mobile practices in undergraduate science learning episodes by drawing on multiple stakeholders' perspectives through surveys, semi-structured interviews, focus groups and researcher observations. Thematic analysis was employed to identify prominent themes that emerged from each case.

5.1 Science Mobile Pedagogical Approaches

This section presents the science mobile practices identified across the Phase Two cases and addresses the subsidiary research questions 1, 2 and 3. As outlined in Section 3.4, the iPAC and innovation sliders was used during interviews and focus groups to prompt discussions. Table 5.2 summarises the themes and subthemes across cases, as mapped against the iPAC constructs and sub-constructs. Themes and subthemes are grouped according to the iPAC constructs and subconstructs and presented in order of strength. A strong thematic presence is indicated if it is supported by three or more data sources (e.g., teacher/student surveys; teacher/learning designer interviews; student focus groups or researcher observations) in each case. A moderate thematic presence is indicated if it is supported by at least two data sources or it emerged in four or more cases. The analysis revealed that among the 12 identified mobile practices, four related to collaboration, four supported student agency, two enabled authentic learning, and one each supported learning across multiple spaces and customisation. Differences in participants' perspectives on mobile practices are also noted, and they are discussed further in Chapter 6.

Table 5.2

Science Mobile Pedagogical Approaches Identified in the Phase Two Cases

Themes	Sub-themes	Strong presence	Moderate presence	iPAC Construct/Subconstructs
1. Conversations around and through the devices	1.1 Face-to-face conversations around devices	1a, 1b, 3a, 3b	6	Collaboration /Conversations
	1.2 Conversations through devices (Teacher/student-initiated)		2, 3a, 3b, 5	
2. Sharing of data and co-production of digital products	2.1 Exchange data	1b, 2, 6		Collaboration/ Co-creation
	2.2 Co-produce digital product	3b		
3. Learner choice and control	3.1 Choice of slip-tasking (Student-initiated)		1a, 1b, 2, 3a, 3b, 4, 5, 6	Personalisation/ Student Agency
	3.2 Choice of mode of learning	3a, 4, 5		
	3.3 Choice of how to learn	1a	2, 6	
	3.4 Control over pace and spaces	1a, 1b		
4. Use of realistic apps		1a	1b, 2	Authenticity/Task
5. Use of Real-world contexts		1a	1b, 6	Authenticity/ Settings
6. Learning across multiple spaces		1a	4, 5	
7. Tailored app settings and workflow		1a		Personalisation/ Customisation

Note. Themes are grouped by iPAC pedagogical constructs and subconstructs. Strong presence of the theme supported by three or more data sources in each case. Moderate presence of the theme supported by at least two data sources in each case, or presence in four or more cases.

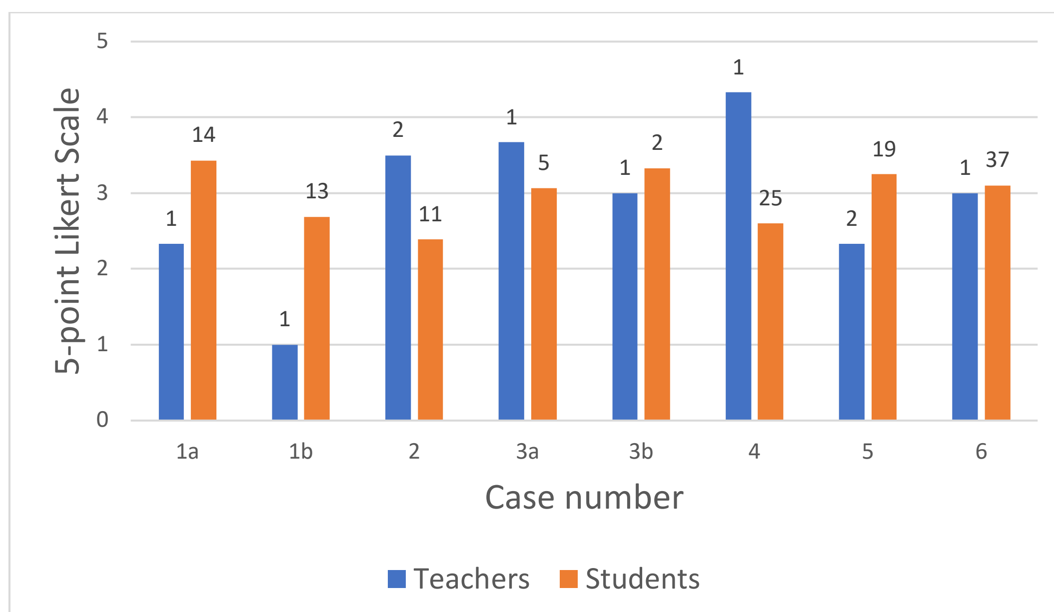
The following section discusses each theme and how the various mobile practices were utilised in undergraduate science learning episodes in this study. Each theme begins with a definition, followed by supporting evidence from educators (teachers and learning designers), students and the researchers.

5.1.1 Conversations Around and Through the Devices

This theme reveals how the use of mobile technologies supported students in engaging in meaning-making conversations that fostered rich connections with peers and learning resources. Data indicated that face-to-face conversations around devices (Theme 1.1) were more prominent than digital conversations through devices (Theme 1.2). Each sub-theme highlights distinct ways in which students communicated their ideas and thoughts mediated by mobile devices. Figure 5.1 illustrates a range of teachers' and students' perceptions regarding online conversations across cases. Participants rated their agreement level using a five-point Likert scale (1= Strongly Disagree to 5= Strongly Agree).

Figure 5.1

Case Teachers' and Student Cohorts' Mean Ratings of the Conversation Sub-Construct in Each Case



Note. The columns represent the mean scores from teachers' (in blue) and students' ratings (in orange) for the subconstruct items in the survey in each case. The number above each column indicates the number of participants.

Theme 1.1: Face-to-Face Conversations Around the Devices. This sub-theme refers to student dialogues occurring in person, where mobile devices served as a shared visual or reference point. Face-to-face dialogues, whether in field, laboratory or lecture settings, supported students' explanations and negotiations in five out of eight cases.

This pattern was consistently observed in the interviews, focus groups and the researcher's observations in four cases. In Case 1a, students used iPads to capture and annotate geological features, supporting clarification of complex topics among peers:

> We were looking at an outcrop and … the fold … goes a certain way … if we're just showing it, it's very hard to actually see it, but when we take a picture of it with the iPad and then annotate it and show the other person, it's a lot easier to have a conversation and a visualisation of the outcrop with the annotations rather than just looking at the outcrop and pointing at it and making a drawing. Because that's two different things, but when you overlap them, it's really powerful to have a discussion about it. (Case 1a_Student 3)

This demonstrates how the use of digital annotation supported students to express their ideas. Another student echoed this view, noting how annotated images could bridge interpretation gaps:

> You can show someone an image, they might not see what you see, but … annotating on the image might help them to see it better. (Case 1a_Student 14)

Mobile practices also supported the comparison of measurements, enabling peer review and knowledge building:

> When you're taking measurements. You can … compare with each other, … it's really easy to show … this is what I got and you can compare notions. (Case 1a_Student 10)

According to the learning designer, the StraboSpot app's data-sharing feature was intentionally disabled to ensure students learnt the data collection processes independently and to minimise unforeseen technical issues in the field. Despite not being able to collaborate online, students still engaged in extensive face-to-

face discussions by comparing data on their iPads and exchanging insights throughout the field activities:

> The way we do this cannot collaborate while using the app because the [mobile devices] do not communicate, but … [students] collaborate all day because they are in the field, and they exchange views. They … look at the app … different screens and they compare the data and … measurements. (Case 1a_Learning designer)

In Case 3a the use of digital polls enabled students to actively contribute to the learning process by voting and exchanging ideas with each other, transforming traditional lectures into participatory discussions. The use of Mentimeter polls prompted bursts of conversations between peers and between students and the teacher in a physics lecture hall. The teacher explained:

> The idea of those concept tests [via Mentimeter] is that they can discuss with the person next to them. (Case 3a_Teacher)

The learning designer confirmed the aim of her mobile practices in this activity:

> The networking is quite high … we do encourage students to discuss, for instance, the problems that we're showing to them. (Case 3a_Learning designer)

In a focus group, a student described aside from the conversations with her friend who sat next to her; there were also other conversations in the lecture hall:

> Because we were next to each other, and we discussed our topics. But there is a lot of collaboration … you can hear when the Menti thing goes off, everyone is talking to their friends. … So, it's very … networked. (Case 3a_Student 1)

The learning designer mentioned the use of real-time polling tools to foster collaborative learning through in-class discussions:

> In our lectures, we tend to use things like Mentimeter or Socrative to give students to do instant polling. … You ask a student a concept question and then have them discuss it with each other and then vote on an

> answer. And then you can … use the class time to discuss the responses to that. (Case 3a_Learning designer)

In Case 3b, the use of mobile devices served as both a practical tool for data entry and in-person knowledge exchanges. This highlights an overlap between conversation and co-creation mobile practices.

In the Phyphox physics lab, the researcher observed students working on a shared online report while simultaneously engaged in verbal discussions with peers. These face-to-face conversations happened concurrently where the online report served as a central point of reference during their discussion, as mentioned by the educators:

> They are busy working, but the whole point is group work and collaboration. (Case 3b_Learning designer)

> In this [lab] setting, they will have more conversation. (Case 3b_Teacher)

Students echoed these educators' insights, describing how conversations around devices guided their understanding and collaboration. One student described the constant interactions around the digital devices during the lab session:

> There are lots of communications. We're always bouncing ideas off each other. (Case 3b_Student 1).

This highlights the role of mobile devices in supporting knowledge negotiation. Another student reinforced this point, noting the social value of discussing data while working together on the group report:

> There's definitely a lot of time just to collaborate. You … can ask questions with each other. …There definitely is a lot of conversation occurring. (Case 3b_Student 3).

In another lab case (Case 1b) the researcher observed that the use of Labscope apps on iPad enabled microscope images to be projected onto the screen in front of the class to stimulate small-group and whole-class conversations. The educator described how this prompted students to compare their samples and reflect on their mineral identification:

> One student will describe something and then the other student would observe the same thing on their samples, so they're sharing views and knowledge. (Case 1b_Teacher/Learning designer)

Students also reported that being able to project their microscopic views and annotate images on the iPads facilitated more inclusive dialogue:

> I would definitely say it would help … for conversations to go more easily [and] for ... other people to understand your point of view …, we … were able to project the image of the microscope into a monitor and annotate it a lot easier. (Case 1b_Student 13)

Another student explained how this moved one-on-one conversations with the teacher to a more collaborative class discussion:

> The whole class can be involved in a discussion ... instead of just you and the professor having a one-on-one engagement ... So more co-creation. (Case 1b_Student 8)

In Case 6, students used mobile devices in microbiology labs to support exchanging their experiment results with peers. One student explained:

> I wouldn't say we did that through the device, though. We kind of just spoke" (Case 6_Student 1).

This was also confirmed by another student:

> I don't think we communicate that much in the actual class via mobile devices as we could. (Case 6_Student 3)

Her group members were unfamiliar with how to collaborate through the collaborative spaces on OneNote app and chose to communicate their results with each other verbally around their devices:

> My group generally doesn't like doing that [conversations through Surface Pro]. They don't really know how to, so they don't do it. I would have liked it ... But I know a lot of other groups do, and they find it helpful. (Case 6_Student 3)

The researcher also observed how the use of mobile devices for conversations varied between groups, reflecting students' choices in how to interact with their lab partners, either communicating around the devices or through them.

Theme 1.2: Conversations Through the Devices. This sub-theme focuses on online conversations that were facilitated by use of mobile devices, including teacher- and student-initiated discussions via online platforms. Although this was a moderately strong theme, it was supported by data sources from four cases. In Case 4, the learning designer highlighted the use of weekly discussion forums to extend conversations beyond class schedules:

> We do have discussion forums in the learning management system, which enables us to hear students' voices. (Case 4_Learning designer)

In Case 3a, the forum served as a space for students to raise subject-related queries and engage in asynchronous communications with peers and teachers. The teacher noted minimal students' use of the institutional discussion forum (named Ed):

> We've also got Ed …. They're not using a huge amount .... Probably means they're using something else. (Case 3a_Teacher)

This was echoed by a student in Case 6, who said:

> I never really post on there, I just read to see if anyone else has asked it. (Case 6_Student 1)

While institutional forums were available, students may have preferred alternative communication platforms. Student-initiated use of social media apps to message each other during the lab activities was noted by two teachers.

> They use WhatsApp to communicate with each other. (Case 2_Teacher 1)

> I've seen people discussing things with other via WeChat and stuff like that. (Case 3b_Teacher)

Student-initiated use of social media apps to facilitate their learning was further confirmed when they showed their phones to the researcher as a prompt for discussion in the focus groups.

In Case 5, although there were limited conversations in the chemistry hybrid workshop, survey responses from the student cohort indicated high levels of online conversations (M = 3.25 out of 5, n = 19). The following data illustrate that the use of mobile devices supported conversations more in online learning environments rather in on-campus activity. These students mentioned their informal use of apps such as Messenger, Instagram, Discord, and email to communicate with peers in the survey. A focus group student noted how the mode of learning influences communications in his face-to-face workshop:

> I feel like that question would be a lot different if it was like an online class…, but it was some people online, some people in person ... because we're all sitting together. There's like not much [conversation mediated by digital devices]. (Case 5_Student 2)

Another student supported this view and emphasised the value of mobile devices for remote data sharing and conversations:

> If it was online, … obviously it's just really handy to … screenshot something, send a photo to a friend and be like, help me with this or if you're helping them. (Case 5_Student 1).

Furthermore, the learning designer in this case also reported that the use of EchoPoll facilitated discussions during some workshops that were not observed directly by the researcher. He stated:

> As soon as … [the teacher] pulled [the EchoPoll, students] sent through lots of questions. Because the way he designed it was like it was a guessing game … and then they had to ask questions to get clues from him to come to the answer … that was … actually really good for conversation. (Case 5_Learning designer).

This approach enabled more opportunities for conversations in hybrid learning environments. It is important to note that in Case 5, the researcher's observations, and the interview and focus group sessions with the teachers and students occurred prior to the implementation of EchoPoll. Having access to

lecture recordings of activities that were not observed in person enabled the researcher to have a more comprehensive view of how mobile practices were implemented across different sessions during the semester.

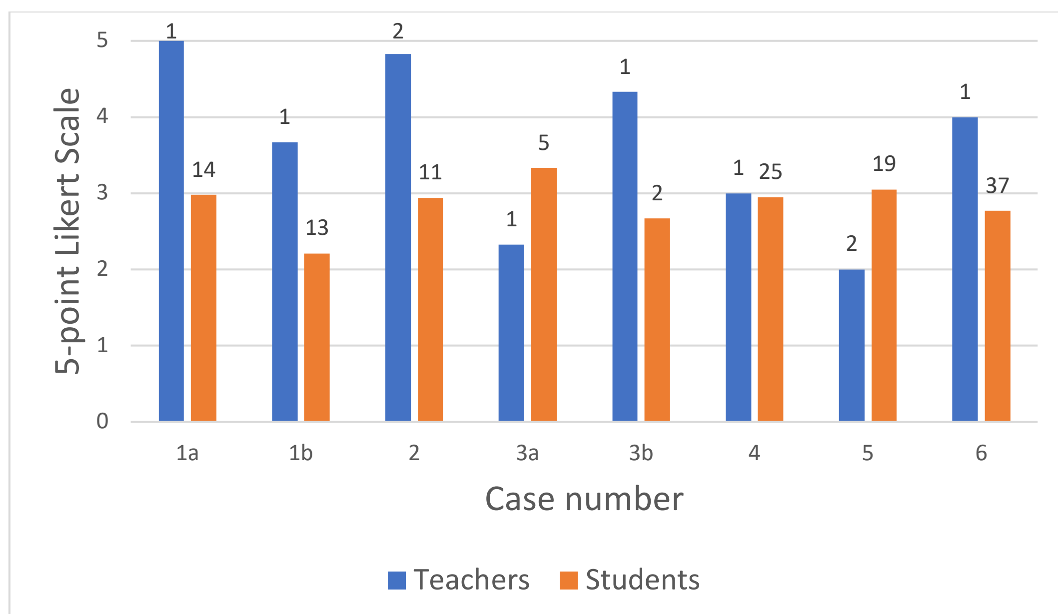
Overall, the data show that face-to-face conversations “around” the device were more prominent for in-class activities. While the institutional discussion forums were underused, students tended to use informal social platforms for communication instead.

5.1.2 Sharing of Data and Co-Production of Digital Products

The use of mobile devices facilitated co-creation practices by enabling students to share data and work together to produce digital products. Supported by strong data triangulation, this theme was evident in four out of eight cases. In the undergraduate science laboratory activities, students often worked in groups to conduct different parts of experiments and share the data to obtain all results. Mobile devices were used to capture photos or videos and record data during learning. Two subthemes were identified: exchange data (Theme 2.1) and collaborative co-production (Theme 2.2). Figure 5.2 shows how teachers and students rated the extent of co-creation in their respective cases.

Figure 5.2

Case Teachers’ and Student Cohorts’ Mean Ratings of the Co-creation Sub-Constructs in Each Case



Theme 2.1: Exchange Data. This theme refers to how the use of mobile devices enabled students to collect and share data in support of knowledge building. This was a strong theme, and it was highlighted by many participants in three out of eight cases. In Case 2, students performed parts of the experiments and shared their results with lab partners to compile the full dataset required to complete the questions in the LabArchives notebook. Both teachers rated the co-creation subconstruct highly (M = 4.83 out of 5), reinforcing the importance of sharing data in their practices. In their interview, one teacher described how students divided tasks and later compared findings:

> I have encouraged them to [exchange the results] … more because … they collect different parts of the experiments … and then they need to … compare what each of them got. (Case 2_Teacher 1)

The researcher observed that students shared data in pairs and later with other groups via their portable devices to obtain all experiment results. One teacher described this process:

> They just record their observations. Upload their data to [LabArchives] and they can share those links amongst each other easily. (Case 2_Teacher 2)

Based on the participants' responses, the students had also initiated their own communication channels such as WhatsApp, Instagram, and Facebook Messenger to share the lab results among peers. A teacher noted how this student-driven sharing promoted scientific data sharing and discussion:

> They use technology as a tool to help write down their data and to help share data … with each other and talk about answers and … giving each other ideas on how to explain things. (Case 2_Teacher 1)

The use of mobile technologies not only facilitated data sharing but also stimulated idea generation. The overlap between data exchange and conversational collaboration will be addressed in the discussion chapter.

The learning designer emphasised that LabArchives was integrated with the learning management system, which simplified submission and feedback processes. He also highlighted the use of multimedia to document experiment results in different forms:

> They can record their results information through photos and videos and sometimes that can be quicker because there are times when things are moving too fast and you might just have to take a photo or a recording rather than writing some information. (Case 2_Learning designer)

In light of the cohort's high rating for the co-creation sub-construct (M = 3 out of 5, n = 11), the focus group student noted that she shared her group results with a large group (15 to 20 students) and also relied on student-initiated group chats to collect all experiment results:

> I tried to [take a photo of the nanobeam light result] but when there's such a large group of people it really didn't turn out that well. I'm sure someone got a good photo of it but that's the type of stuff where it's good to share over like messaging apps like we have an Instagram group chat or something. And I would like if someone got a good photo, then everyone can share that around. (Case 2_Student 1)

This highlights how students leveraged social media to extend the teacher-assigned mobile tools, blending formal and peer-networked learning.

In Case 6, the researcher observed that students first worked in pairs to perform the experiments before exchanging results with their group through Surface Pro. The learning designer highlighted that students could create their own tabs or sections in the OneNote collaborative space and choose their collaborators:

> They can create … [and] choose who they talk to and who they share their information with. (Case 6_Learning designer).

This learning designer further explained that students from different lab benches or practical sessions could also access the OneNote collaborative learning spaces, as it was common to the entire student cohort:

> It's built-in … [and] common to the whole cohort, but they can create spaces within the collaborative space that is ... where they share all the information. (Case 6_Learning designer)

This structure supported greater student agency, enabling students to make decisions about with whom and how they collaborated. Similarly, the teacher in Case 6 rated co-creation highly in the survey (M = 4 out of 5) and explained in

the interview that each pair of students was assigned one out of six diagnostic samples and they needed to share their results to complete a full dataset:

> Students need to be very proactive in sharing the information … this is why we promote them to share their information as much as possible through OneNote and [the learning designer] has set up collaborative spaces to promote that as well. (Case 6_Teacher)

A student noted that some students preferred to share data online, while others chose to share verbally using the information on their devices as a stimulus:

> Different groups do things differently. Some groups in the collaboration space on OneNote, they like to just make a new section, a new tab saying their … time of the practical and then their team name … patient number … what tests they did, what results they got, and some notes on how to describe the organism culture on the plate … that's how some people do it. Other people, what they do is they just talk about it. They just explain, oh, this is what I got. What did you get? (Case 6_Student 3)

Students exchanged data in ways that reflected the practices and preferences of their groups, with some choosing the structured documentation on OneNote, while others used verbal sharing, using prompts from Surface Pro for discussion. These practices highlight student ownership in learning with mobile devices. Consistent with the researcher's observation, students often blended verbal interactions with the use of mobile devices to exchange data during the lab session. The following data show how collaboration can occur through mobile platforms in on-campus lab activities.

One student highlighted the use of the collaborative space to access shared data:

> The ability to … share your results with everyone in that class, which you wouldn't previously be able to do without the Surface Pro. (Case 6_Student 1)

According to her, those students who did not communicate directly with her during the practical session could still access the data in the OneNote collaborative space:

> There were members of the classroom that I never spoke to, but they would be able to access what I've done because I've put it in the collaboration space. (Case 6_Student 1)

Another student mentioned that she primarily used her Surface Pro to access the lab manual, and she viewed her peers' comments to initiate collaboration:

> If somebody else in my group made some notes they could share those notes with me on the Surface Pro, so that it helps with like collaboration. (Case 6_Student 2).

Nevertheless, the teacher also reported that some students primarily "consumed" data rather than contributing to the content and "producing" data in the collaborative space:

> There's definitely a lot more consumption of materials from the OneNote as opposed to production sharing, quite often what they share is just the bare minimum sort of thing. (Case 6_Teacher)

He acknowledged that group collaboration depends on students' willingness:

> That's very much up to the students. As I said, some students love to share. They love to … give as much information to each other as possible. Some students are very much like, no, I don't want to work with anybody else. I'm just doing my subject. This is what I do. ... that's not to say … technology isn't useful for collaboration. It's just the students sometimes don't want to (Laugh) … collaborate in any way. (Case 6_Teacher)

This again highlights the interplay between data sharing and student agency where students' involvement in the learning activity is dependent on the group culture and individual preference.

In Case 1b, the researcher observed students sharing the Labscope images with their peers and teacher, either via the class projector or their personal devices. This workflow enhanced whole-class discussions, as it would be challenging for all students to view each microscope one by one, as explained by the teacher:

> They did share photos that they collected from the microscope, and they first shared the photos from the microscope to the iPad, and then from the iPad to whatever personal device that they had. (Case 1b_Teacher/Learning designer)

The ability to view images from multiple microscopes broadened these students' observational scope, enabling them to examine more mineral slides from other students. In focus groups, the students also reported how this real-time sharing supported collaboration:

> The biggest part is being able to … share what you're seeing on the screen and that's probably like the best one. (Case 1b_Student 5)

> I could … see every single microscope that was working in the room. (Case 1b_Student 7)

> You can also just save the image and then send it to your friend. (Case 1b_Student 12)

These insights illustrate how mobile practices amplified data visualisation and sharing capacity in science labs.

In summary, the use of mobile devices enabled students to keep records and organise the results of their experiment, thus facilitating more effective means of collaboration in undergraduate science learning activities. The overlap between data sharing and student agency will be explored further in the discussion chapter.

Theme 2.2: Co-produce digital products. This sub-theme shows how students worked together to produce digital products. Case 3b students worked in small groups of three to four to collect data using the Phyphox app on their mobile phones and collaborated on an online group report on their laptops. Their teacher stated:

> We are doing not that many measurements, but a lot of it is collecting, analysing huge quantities of data using Excel and using it to calculate the angular momentum and kinetic energy of a phone thrown into the air. (Case 3b_Teacher)

The teacher highlighted how multiple students contributed to the same document simultaneously, allowing more efficiency and multitasking among group members:

> [They] shared what you called documents, where … they can each have a look at it … on three different computers … it helps them work in parallel in a more efficient manner. (Case 3b_Teacher)

The learning designer reinforced that co-production was a core mobile practice in her case. Students were expected to read lab procedures beforehand, perform experiments, and produce a group report during the lab session:

> When they come to the lab … they work on the shared logbook. So, it's no longer paper-based logbook, it's a shared document. They can use Google Docs or Office 365. (Case 3b_Learning designer)

In the focus group, one student described how her group members distributed workload on a shared document:

> We use the group work function on Word so we can both edit it at the same time and that works well for us. (Case 3b_Student 1).

Another student reflected on how his team worked efficiently and supported one another throughout the lab session:

> We all split the load pretty evenly …, we do get through it all quite efficiently … I'd say we get through it all and we're all sharing … answers and we're all rebounding off each other. (Case 3b_Student 3)

Mobile practices thus facilitated co-production of group reports in real time. Despite the lower mean rating from the student cohort (M = 2.67 out of 5, n = 2), this sub-theme was evident in educators' and students' responses, the researcher's observations, and the teacher's high rating for co-creation items in the survey (M = 4.33 out of 5).

In summary, the use of mobile devices strongly supported students in data sharing and co-production of digital products. Collaboration was also shaped by student agency, highlighting the interplay between collaboration and student choice. While mobile practices encouraged collaboration, the extent to which

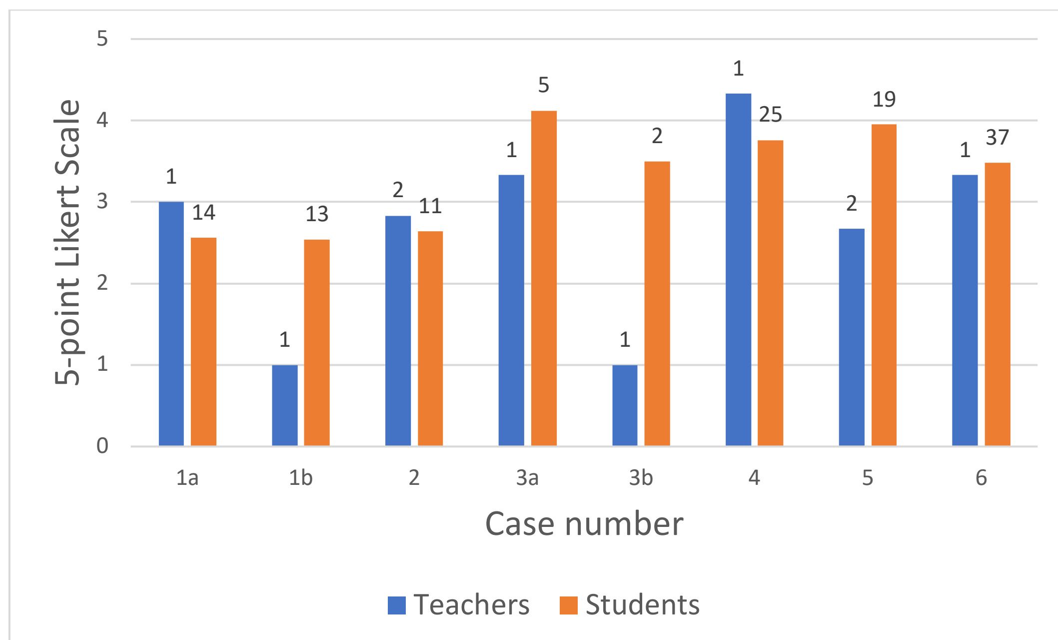
students were involved in the activities could vary across group dynamics and students' willingness to collaborate with peers. These dynamics will be explored further in the discussion chapter.

5.1.3 Learner Choice and Control

This theme reveals the extent to which students exercised their choices and control over their learning with mobile devices. This theme comprises four sub-themes, each shedding light on aspects of student agency in technology-enhanced learning environments: Theme 3.1 – choice of slip-tasking initiated by students; Theme 3.2 – choice of modes of learning; Theme 3.3 – choice of how to learn; and Theme 3.4 – control over pace and spaces. Figure 5.3 summarises teacher and student ratings on the agency subconstruct across cases.

Figure 5.3

Case Teachers' and Student Cohorts' Mean Ratings of the Agency Sub-Construct in Each Case



Theme 3.1: Choice of slip-tasking. This subtheme highlights how students personalised their learning by choosing what apps to use, beyond those prescribed by their teachers. In the survey responses, students across all cases reported a wide range of tools they had used, including apps for notetaking, data collection, collaboration, research, and communication.

In Case 1a, alongside StraboSpot, students mentioned using the iPhone camera, iPad notes and Stereonet app:

> To take notes and pictures and also measurements (Case 1a_Student #2)

In Case 1b, students used OneNote to check notes and Google for searching for information. In Case 2, students navigated between LabArchives, the learning management system for accessing course content, Google Drive, and Microsoft Word for report writing.

Case 3a students reported using various applications, such as Canvas for accessing materials and submitting assignments; Mentimeter for answering quiz question; and YouTube for research:

> Goodnotes for noting and scrap working out for problems, OneNote for note taking in lectures and Canvas for assignment submissions, accessing lectures” (Case 3a_Student #4)

In Case 3b, students listed Phyphox for data collection; Microsoft Excel for data analysis; Microsoft Word and Goodnotes for documentation; and Google Chrome for web access.

In Case 4, students used Microsoft Excel for statistical analysis and graphing; PowerPoint and Word or Google Docs for notetaking and presentations; and PDF Viewer and Goodnotes for annotating slides. They also accessed online resources via Google Chrome and Google Scholar and used Echo 360 for live streams and lecture recordings.

Case 5 students reported their self-driven use of various mobile applications during the hybrid workshop such as Moodle learning management system for accessing learning materials; Google Chrome for information searching; Endnotes for research; One Drive for file storage; and Microsoft Words, Noteshelf, Goodnotes, and OneNote for notetaking. They used Microsoft Excel to create graphs; Adobe PDF scanner; and computational chemistry software to conduct molecular modelling. Another student added:

> YouTube, internet browsers, Excel, email, messenger, Instagram [to] talk to others, seek more information to clarify. (Case 5_Student #16)

Case 6 students described using OneNote, Canvas, Google Chrome, and YouTube for searching information; and email and Facebook messenger for data sharing.

> Good notes, Excel [for] collating ideas, making mind maps, group work. (Case 6_Student #35)

Overall, these responses demonstrated how students frequently used multiple science-specific and generic educational apps in combination to support their learning.

Theme 3.2: Choice of Mode of Learning. This sub-theme focuses on how the use of mobile devices enabled choices of synchronous (in-person or online) and asynchronous learning modes in three hybrid learning cases. In Case 4, the statistics teacher explained students had control over their learning modes:

> It's a mixture since we have the traditional lecture where students can come to the face-to-face and also we have the online student cohort. So students can free to choose the mode of learning. (Case 4_Teacher)

The learning designer acknowledged this flexibility and noted that students who chose to watch the recorded lectures would miss opportunities to interact with their teacher and peers:

> Our lectures are streamed so if they choose, they can log in during the lecture from anywhere. And it's also recorded so if they don't have time during the lecture time, they can access the recordings. However, that stops interaction, if they decide to go with the recorded messages. So, from the agency perspective, they have all the authority to decide when they want to learn. (Case 4_Learning designer)

The focus group student attended the face-to-face lecture and appreciated the flexibility of hybrid learning. She noted her autonomy in the learning activity with her devices:

> When I study in a lecture, I can … control … what I want to read … to watch on my iPad and … to take notes. (Case 4_Student 1)

She also mentioned that she revisited the recordings if she did not fully understand the content during class.

With the hybrid learning mode, Case 3a students could participate in the synchronous hybrid learning activity either on-campus or online. The teacher rated the agency subconstruct highly (M = 3.33 out of 5) in the survey and explained in the interview that the real-time voting tool aimed to enhance participation by allowing anonymous responses, thus reducing students' fears of making mistakes:

> Mentimeter is definitely better, and it gives the students … [anonymity]. So, they can have a go without feeling that they're making a fool of themselves. So, I think it's valuable in that way ... And if they show their hands, you don't get that. (Case 3a_Teacher)

In this way, his mobile practices enabled students to choose whether to participate in the voting process or not. When asked about online attendees, the teacher mentioned that remote students could also participate in the poll if they were taking part in the activity synchronously. However, he suspected that few students would attend the live lecture remotely:

> It's live-streamed ..., they could do it at home ... If they do, and they have access to the Mentimeter ... So, in principle, they can participate in the polls from home. (Case 3a_Teacher)

In the interview, the learning designer noted that students who attended the lecture synchronously could participate in the Mentimeter poll, but those who learnt asynchronously by watching the recordings afterwards could not engage in the poll. Among the focus group students, two attended the lecture in person, whereas the third student attended the livestream lecture while commuting to campus for the afternoon lab activity; he also described how the recorded lectures support personalised learning by highlighting the flexibility they offer:

> Sometimes you can watch them at double speed … you can slow down or pause, so I guess if it's online … you have a lot of agencies. Because you can always pause, you can rewind your speed up, slow down, but if it's in person you don't. (Case 3a_Student 3)

These insights highlight the importance of choices of learning modes, with students able to participate either synchronously or asynchronously based on their schedules. This flexibility potentially promotes inclusive learning, particularly

for students with additional learning needs. For instance, a student with dyslexia shared how technology-enhanced learning supported her to gain a deeper understanding of complex physics content:

> If you are just reading from a textbook, it can be quite hard to memorise or like deeply understand the content because, especially with me, I'm a bit dyslexic so sometimes I skip lines and the words don't go in my brain properly and that can be a problem when I'm reading big sections from a textbook, but when I have like digital learning and Menti, it applies… in a way that is helpful, especially for the way my brain works, cause it's not too many words and I get time to think about the answer. (Case 3a_Student 1)

This highlights some benefits of using mobile devices, especially for students with additional learning support.

In Case 5, a teacher described how students could engage with asynchronous materials at their convenience throughout the week:

> They can access that anytime. It's released weekly, but at any time in that week, they can access it anywhere for the content. (Case 5_Teacher)

However, this flexibility did not extend to the synchronous session. Students who wanted fully interactive experiences were required to attend the workshop in person, as shared by one teacher:

> For the workshop, … if they want an active experience, they have to be in the class because there's no provision for online communication. They can access it remotely, just watch it passively as a video ... if they want the full experience, there's very little choice. They have to turn up and they have to be there… it's not completely flexible and it's not completely inflexible, … there is some online capacity, but it's less than the in-person. (Case 5_Teacher 2)

Despite the high ratings for student agency from the cohort (M = 3.95 out of 5, n = 19), focus group students attended the in-person workshop and indicated limited control over their learning:

> I don't think students have control over this. (Case 5_Student 3)

Figure 5.3 reflects these insights, where agency sub-construct was rated higher by majority of participants in hybrid learning cases, as students could choose how, where and when to engage in their learning.

Theme 3.3: Choice of How to Learn. This sub-theme describes how students decided how to approach the learning tasks in three out of eight cases. In Case 1a, while the field location and schedule were predefined, students could choose how to collect and organise data. The teacher explained:

> We tell them where the field area is and … what the aims are … We do give them some bounds, but then they have to make a plan … That's … where the agency comes into play. (Case 1a_Teacher)

This highlights how students exercised their agency, particularly through the use of mobile devices to support their decision-making and planning within the scope of the activity. The learning designer further reinforced this view:

> Although the area is specified in the field ... within the eight hours that we are in the field ... they can organise their day however they want. (Case 1a_Learning designer)

This approach enabled students to exercise control over how they structured their time and learning processes within the defined boundaries of the technology-mediated activity in the field.

Students reported diverse ways of using the StraboSpot app in the survey – for recording geological notes and measurements; viewing geological data; capturing and annotating photos and diagrams; navigating and orienting themselves on maps; uploading sketches; and organising data. This highlights the app's versatility in supporting students' fieldwork learning experience and reflects a sense of ownership and autonomy over their learning. In one of the focus groups, a student reflected on how the use of apps enabled greater choices in collecting and organising his data:

> The StraboSpot app allows you to take the observations you want. So, it does have a lot of features you can choose from ... I found that really helpful … it makes it organised to take the observations you want, which gives the agency of what you're recording. (Case 1a_Student 13)

In Case 2, while the chemistry lab activity was structured with limited control over the time and location (Teachers: M = 2.83 out of 5, n = 2; Students: M = 2.64 out of 5, n = 11), students had some control in how they documented their experiment results. The learning designer explained:

> There's a certain structure that we provide and what they need to complete, but how they complete that is up to their decision. So, if they would prefer to write down their observations, they can write it down … They prefer to upload a photo or a video, then they can do it that way. (Case 2_Learning designer)

A student described how she chose to capture her experimental results with her phone:

> [I took photos] of the nanoparticles … as they're forming up … I have a little video of it bubbling away. And then this week when it was changing colour, we took a video of that. (Case 2_Student 1)

Students, therefore, had some choices in documenting their experiment results either via photos or videos. Similarly, educators in Case 6 pointed out that students could choose alternative apps to complete the practical activities:

> It's not Montessori so I wouldn't say that they have complete freedom [laugh] … we give them the information in the class notebook, but if they don't want to use the class notebook, for instance, during the practical lab, they can write that on the Word file and then figure it out after for the other activities ... So, it's up to them to make the most of whatever tools we give them, but then they more than welcome to use something else if they want to. (Case 6_Learning designer)

> Students have quite high agency. They're able to control most of the practicals themselves with the exception of the patient that they've been assigned, they control … which tests they do, they control how quickly they go through things, and every other aspect. (Case 6_Teacher)

While educators reported the range of options available to students, students perceived their agency was limited to

> that specific lab, at that specific time and the pace. (Case 6_Student 3).

Nevertheless, this student also highlighted students' choices on how to collaborate with peers, either verbally around the devices or through the devices (see sub-themes 1.1 and 2.1).

In summary, the use of mobile devices supported students in personalising some aspects of their learning processes, although their choices remained bounded by the activity schedules.

Theme 3.4: Control Over Pace and Spaces. This sub-theme explores how students controlled the time and spaces of their learning mediated by mobile devices in two cases. In Case 1a, students reported that the technology-mediated activities offered greater flexibility in their field-based learning compared to conventional non-mobile approaches. The following students' reflections also align with the teachers' sharing and the researchers' observations, reinforcing how mobile practices supported students' spatial and temporal autonomy in field-based learning.

> We were given ostensibly at least, a certain amount of freedom to set the pace … the way that we move through the area … the way that it's presented in terms of technology really facilitates a more agentic approach. (Case 1a_Student 2)

Another student highlighted the benefit of the StraboSpot app to enable him to make independent decisions on the locations and pace of the learning activity:

> With the app … you do have the ability to … control … where you go to take your measurements … [the] place and also your pace of action. (Case 1a_Student 12)

The use of iPads also improved productivity and workflow by allowing students to collect more data in the field, as explained by a student:

> I can do more in the time because taking measurement does not take as long. … So, I think it is a lot faster. It means I can cover more areas. (Case 1a_Student 6)

In Case 1b, the educator rated student agency subconstruct very low (M = 1.0 out of 5) and justified it as being due to the regimented nature of the university lab activity:

> They don't have any control over the place, pace, or time. (Case 1b_Teacher/Learning designer)

Nevertheless, his students reported that they had more control over their learning, for example:

> We did have … a lot of influence all over our own time and when we wanted to do it, especially with the app, … we could have really just gone into the microscope … thin section, images, screenshotted them and then analysed them when we're home. It … allowed a lot of freedom for us to kind of control the pace and time of where we wanted to do the assignment and the activity. (Case 1b_Student 13)

In addition, another student reported that being able to capture the microscope photos and take them home gave him greater autonomy in analysing and interpreting his data:

> The fact that I can go home and have my own agency over what I do with those interpretations with those pictures, and then how I interpret them at home is I got a lot of agencies from my perspective. (Case 1b_Student 3)

A student appreciated the ability to refer to his classmates' microscope photos, allowing him to crosscheck his microscope views at his own pace:

> Because they had it on the board, I could then go back into mine and find my own example … I had pretty good control over my pace. (Case 1b_Student 8)

Likewise, another student emphasised that the use of mobile tools allowed her to visualise and understand others' work, guiding her on what to do next:

> It really allowed us to … have some control over what we're doing … we're able to kind of understand and see what other people are doing … that also helps us … take control of the time, and then … pace ourselves so we know what else we should do, and it gives us direction, and also just having it on our laptop or personal device is really helpful. (Case 1b_Student 14)

These findings contrast with the educator's perspectives of limited student agency and show the reality of how students exercised their agency despite the highly regimented on-campus laboratory session.

Overall, student agency was evident in the nominated science learning activities in Phase Two of this study, varying depending on their choices of slip-tasking, mode of learning, and method of learning, and their control over the pace and spaces of learning. However, the students had limited choices on what to learn. Their choices about what to learn were also often absent in the participants' responses, seemingly constrained by predetermined content and tasks within the university science curriculum.

In Case 2, the learning designer for a 1st-year chemistry subject acknowledged that early lab tasks, while incorporating mobile devices, remained quite structured:

> The first semester can usually be very … recipe-driven, very teacher-driven. (Case 2_Learning designer)

Although digital lab notebooks were used to support their learning, students had limited control over the learning process and what to learn. However, this learning designer noted that students would have more choice in the subsequent semesters, where they would use mobile devices to support more self-directed experiments. This view was reinforced by a teacher in another case:

> Later on, when they do projects where they actually design their own projects and their own investigations. But for semester-1 labs it's all pretty much just follow the manual. (Case 3b_Teacher)

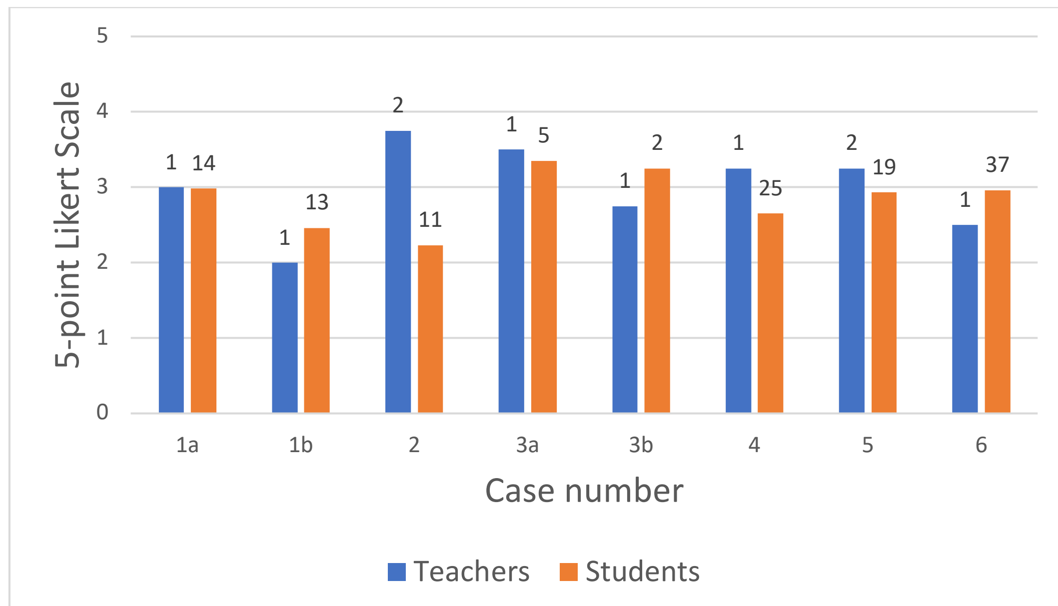
Students can have meaningful decisions about their learning processes in the later stage of their science degrees mediated by mobile tools. This will be explored further in the discussion chapter.

5.1.4 Use of Realistic Apps

This theme explores the extent to which mobile learning activities mirror real-world scientific practices. Figure 5.4 shows that teachers' and students' ratings for task authenticity were generally aligned across cases, although qualitative data were primarily drawn from Cases 1a, 1b, and 2.

Figure 5.4

Case Teachers' and Student Cohorts' Mean Ratings of the Task Sub-Construct in Each Case



In Case 1a, the following responses, triangulated with the teacher and student ratings (both M = 3 out of 5), illustrate how the use of digital tools enhanced the authenticity of field-based tasks. During the interview, the teacher emphasised that her practices closely mirrored industry practices and the learning designer was confident that his mobile practices were integral to contemporary geology:

> It is 100 percent realistic and when they're going to work as professional geologists, most likely they will be using an app to collect data, … it's a way to introduce them to the profession … practice of geology. (Case 1a_Learning designer)

Over the 7-day observation period, students used iPads to collect data in the field, which was later analysed to produce a geological map and report. During a focus group discussion, a student expressed his interest in exploration geology and perceived the activity was relevant:

> If I was ever an exploration geologist … I like the bush, and I like being outside … and I'm thinking about this app, and it would be pretty … useful. (Case 1a_Student 1)

Another student indicated that StraboSpot comprises a variety of applications, making it a versatile tool for geologists:

> The use of StraboSpot … can … apply to any sort of geologists because … it just encompasses all … the applications that geologists do on the field. (Case 1a_Student 9)

Reinforcing the inherent value of the Broken Hill field location, one student described the task as

> very relevant to the place and space. (Case 1a_Student 4)

Another student reflected that the field trips earlier in her degree involved the manual use of a compass and satellite printout images for mapping exercises. The mobile practices in the current field trip streamlined the data collection process. All data were organised in one place, enabling her to conduct field measurements more efficiently. She said:

> We’re still looking at the rocks … and studying the same geology, but it’s been really different to have it all organised in one app. And it makes taking measurements a lot faster, and you just hold your iPad and it takes a measurement rather than having to … get down in the rock. It’s a lot more efficient. (Case 1a_Student 6)

In Case 1b, there were mixed responses from the teacher and students on the relevance of the Labscope app to real-world geological practices. While the teacher acknowledged that some specific geologists use similar technologies, he rated the task subconstruct low (M =1.0) due to the limited applicability across geological careers:

> Specific type of geologists, yes, would need to … be on the microscope and describe samples … it does not correspond to a big portion of the geologists out there, but some small portion. (Case 1b_Teacher/Learning designer)

He also provided some examples of geologists whose work involves studying the mineralogy of rocks and would use the Labscope app and microscope daily. Further, he reported using the same app in his research, considering it an “in-situ” practice:

> In my research, I will use the same app … students used a technique that professionals or experts use. (Case 1b_Teacher/Learning designer)

Students, however, identified some alignment between the workshop activities and real-world practices. Despite this recognition, the student cohort rated the task sub-construct relatively low in the survey (M = 2.46 out of 5, n = 13). One student indicated that his technology-enhanced learning activities were the foundation steps of professional geologists:

> That's basically the first step for a lot of what we have to do, especially in most jobs as well, whether that be research, education, or even mining. (Case 1b_Student 13).

The use of the app to project the microscope images directly onto the iPad and class projector's screens offered learners more genuine learning experiences, as shared by one student:

> The whole app is very real-world specific because it is just a projection of what you see in the microscope to your screen ... It is like real projection … [and] very real-world related instead of just animation. (Case 1b_Student 11)

Similar to Case 1b, the student cohort's ratings of task authenticity in Case 2 were also lower than those of teachers (M = 2.23 out of 5, n = 11), showing a less consistent perception of professional relevance of the mobile app.

In Case 2, participants provided insights into how students engaged in realistic work practices by using a professional app. The task sub-construct was rated highly (M = 3.75 out of 5, n =2) by teachers, reflecting the authenticity of the LabArchives app. One teacher noted:

> So it's real-world activities. If they do research, they will use the same equipment. (Case 2_Teacher 2).

The learning designer echoed this, explaining that the digital lab notebooks aligned with contemporary research practices, helping prepare students for future research careers:

> It is kind of training them up in preparation for research and real-life applications, so electronic notebooks are used currently by our researchers and so it's a chance to get them … job ready as part of their lab program. (Case 2_Learning designer)

For students interested in chemistry research, this digital approach provided exposure to professional laboratory practices. One student interviewee, who had no prior work experience in a laboratory, expressed some uncertainty about how closely her technology-enhanced lab learning experience aligned with real-world practices:

> It definitely feels we're getting closer to that real researcher type stuff than in high school. I couldn't say exactly, like I've never been in that real proper work environment with chemistry, but I think so. … the lab supervisors make a big effort to ensure that we're doing everything to protocol and that we're developing the right practices for when we actually have to go into that workplace, so I would think it's pretty authentic. (Case 2_Student 1)

In Case 6, authenticity was viewed as limited by the teacher due to the pathology lab's focus on specialised diagnostic equipment instead of mobile devices:

> From what I've seen when I worked in pathology, but that was five years ago, things like mobiles and that's like mobile phones. That's not used all that much. ... The only computers that are in these labs are to record patient information and patient details. In terms of technology, what's mostly in pathology labs is … equipment for diagnostics. So robotics, sorting samples or like automatic staining and plate streaking. (Case 6_Teacher)

This comment highlights the discipline-specific nature of authenticity in science education where mobile devices may align more with some but not all science disciplines.

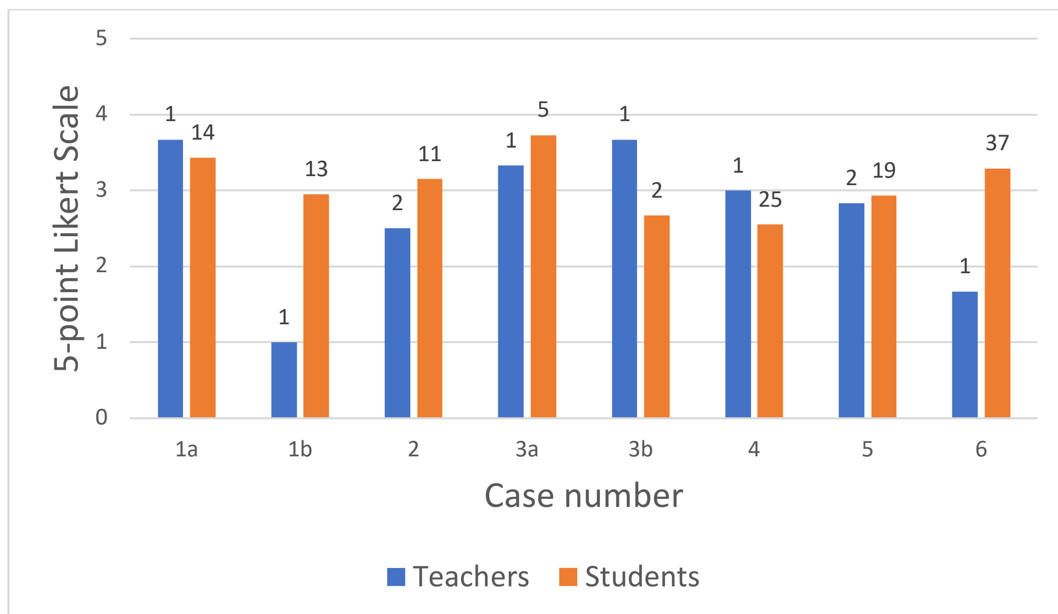
Overall, while teachers generally viewed the use of mobile tools in lab cases as reflective of professional scientific practices, students were more tentative in their perceptions. Task authenticity was most evident in field-based context, with lower alignment in lab-based settings.

5.1.5 Use of Real-World Contexts

This theme focuses on mobile learning experiences situated in realistic settings. Figure 5.5 presents teachers' and students' ratings of the context subconstruct across all cases. Notably, only Case 1a provided consistent quantitative and qualitative data to show that learning occurred in authentic environments. There were limited qualitative data from students to support the realistic settings in lab activities, and no qualitative evidence for mobile practices supporting authentic contexts in lectures or workshops.

Figure 5.5

Case Teachers' and Student Cohorts' Mean Ratings of the Context Sub-Construct in Each Case



In Case 1a, participants consistently described their learning in the Broken Hill field trip as deeply connected to real-world geological practices. The field location was seen as an inherently authentic environment that professional geologists have used for exploration and research for many years. According to the learning designer, Broken Hill has long held exceptional geological value and significance for the geological community:

> We are in a place where it's the largest lead ore deposit in the world … where geologists have been working here for decades … [and] a century … it's approximated the reward conditions. (Case 1a_Learning designer)

Many students also considered the use of mobile devices to learn field geology in real-world settings mirrored professional practices. One student highlighted the connection between the settings and broader industry practices:

> It is the biggest storage deposit in the world, … the context is pretty relevant. It's in these kinds of places that all of Australia's valuable mineral resources are. (Case 1a_Student 2).

Another student emphasised how being in the field connects theoretical knowledge and practical applications with the use of mobile devices,

> because we're out in the field … the context is exactly realistic. I do not think it can be any more realistic. (Case 1a_Student 6)

Consistent with the researcher's observations, the strength of this theme was supported by the learning designer's responses, students' and teachers' ratings for the context subconstruct ($M = 3.67$ and $M = 3.43$ out of 5 ($n = 14$), respectively). In contrast, students in lab-based activities expressed greater uncertainty about the authenticity of their learning environments:

> I promise we don't really know what professional geology looks like. (Case 1b_Student 5)

> I imagine as long as you have like a microscope in front of you, it should be kind of the same environment, but I don't know if it would be more like rundown … [in] a rural mining. (Case 1b_Student 4)

> I have not been to a real lab, so I don't know how. (Case 6_Student 1)

Another student pointed out the relevance of lab versus fieldwork contexts:

> I feel like the context of fieldwork is more relevant to professional geologists than the context of lab work. (Case 1b_Student 8)

One of the students in Case 6 provided a more nuanced comparison between university science and diagnostic labs:

> If you want to compare our lab to an actual diagnostic lab, from what they've taught us, they showed us what an actual diagnostic lab looks like. It's a bit different. Our natural diagnostic lab, the whole lab is literally

> made so the specimens are processed from one area to another systematically. So it kind of goes around so it's easier for everything to flow. In our lab, if you've seen us, we go everywhere (Laugh). It's kind of because it's not like the university is going to make a special diagnostic lab for us. (Case 6_Student 3)

The educators, however, often viewed their lab settings as an approximation to professional environments:

> They would be in a lab with microscopes. So it wouldn't be much different. It wouldn't be at the university, … it would be a similar environment. (Case 1b_Teacher/Learning designer)

> We've tried to organise it as much as possible, looking like it would look like in a real lab where it's not everything on your bench, but you have different areas that are dedicated to different tasks. (Case 6_Learning designer)

The teacher in Case 6 reflected on how the lab mimics aspects of a real diagnostic setting:

> I think it's pretty relevant, … the environment of the hive lab is … artificial by nature because it is a subject rather than real-world diagnostics. So there's going to be a lot more control over it and what's happening, but the chaos of it, … dealing with other people … or working out where's what and so on ... That's very much like real-world pathology. (Case 6_Teacher)

Overall, the context of field-based learning was perceived as a highly authentic and closely aligned with professional practices. However, lab activities were perceived as less clearly connected to real-world settings, particularly by undergraduate students who had limited exposure to real-world science work environments.

5.1.6 Learning Across Multiple Spaces

This theme highlights how the use of mobile devices enabled students to learn across multiple physical and virtual settings in three case studies (1a, 4, and 5). In Case 1a, the ubiquity of mobile devices supported students in accessing tools and resources across semi-formal and informal settings. With internet access at

the accommodation site, students downloaded satellite images and geological maps onto their StraboSpot app for offline use in the field, enabling real-time location tracking and map referencing during fieldwork. Throughout the field trip, the researcher observed students using their devices continuously in the field and while travelling between sites and when returning to the accommodation areas. The learning designer explained that with mobile devices, students could choose where to work during and after the field trip:

> Students can go wherever they want … in the predefined area … when we're back in the cabins, the students can work either in the gallery or in the cabins or wherever they want … and still use … the app. (Case 1a_Learning designer)

The use of mobile tools reinforced student autonomy, allowing learners to control where and when they wanted to learn. The learning designer explained that since the app connects to a database and a server, students could transfer their field data from iPads to laptops by logging into their StraboSpot accounts. This implementation streamlined the reporting process and enabled seamless workflow:

> The link between the iPad and the computer is offered through the use of these apps. It's really helpful for the students … to start writing the reports immediately ... it makes the process really easy. (Case 1a_Learning designer)

In this way, students could immediately process their data and work on their reports upon returning to the accommodation area. The connection between devices created an efficient workflow, bridging data collection and analysis in real time. This highlights the multifunctional nature of mobile devices to streamline learning tasks. Students echoed this in the focus groups, one student described the convenience of having all necessary geological tools consolidated into one portable device:

> It is one device that's easier to access. So that is … easy to use … it is very versatile, wherever you are. (Case 1a_Student 8).

Repeatedly, students noted how mobile practices enhanced their learning experiences during and after the field trips, thus serving as a bridge across

multiple settings, promoting science learning on the go. A student noted how the portability of iPads enabled him to extend study hours in more informal settings:

> Because of the iPad, I can do more in non-traditional settings like my cabin and like here [gallery] at night. (Case 1a_Student 6).

This student also noticed how his annotated field images improved his report writing processes by helping him to recall observations in the field:

> When I come back to the cabin at night, having an annotated drawing that I did in the field makes it a lot easier to reflect and prompt myself for … what was happening, like that I understood in that moment ... StraboSpot allows me to connect better to my headset in the field when I'm writing my report later on. (Case 1a_Student 6)

In Case 4, while there were limited conversations in the lecture, the educators noted that students would often engage in discussion outside formal schedules:

> … not during the lecture. After the lecture, they would communicate. (Case 4_Teacher)

> These [conversations] happen more … after lecture activities, like during our tutorials and practical ... In the lectures, conversation is low, co-creation is low. (Case 4_Learning designer)

The researcher observed the focus group student using her iPad to discuss questions with peers and teacher after class, exemplifying how the use of mobile technologies facilitated learning beyond class time. This reflects peer learning in less formal environments mediated by mobile tools. As this student stated in the interview:

> It's really hard for me to understand all things really well on my own … I need to discuss with my friends. (Case 4_Student 1)

In Case 5, students described how mobile practices supported learning primarily after class, particularly for peer communication and task completion:

> When you're actually at home doing questions yourself, that's when the device is most helpful because ... that's how you communicate with people. (Case 5_Student 2)

Similarly, another student said:

> Both conversation and co-creation happen outside of the class ... That's when the device is most useful. (Case 5_Student 2)

Furthermore, the teacher highlighted asynchronous learning tasks that allowed students to learn in their preferred times and spaces:

> The flipped content they can do whenever they want, wherever they want. (Case 5_Teacher 1)

However, he also pointed out that synchronous learning remained tied to university schedules:

> The workshop content has to be done when we're doing the workshop, … it's sort of the online allows them to do whatever they want, whenever they want, but the in-class engagement is very limited to strict times. (Case 5_Teacher 1)

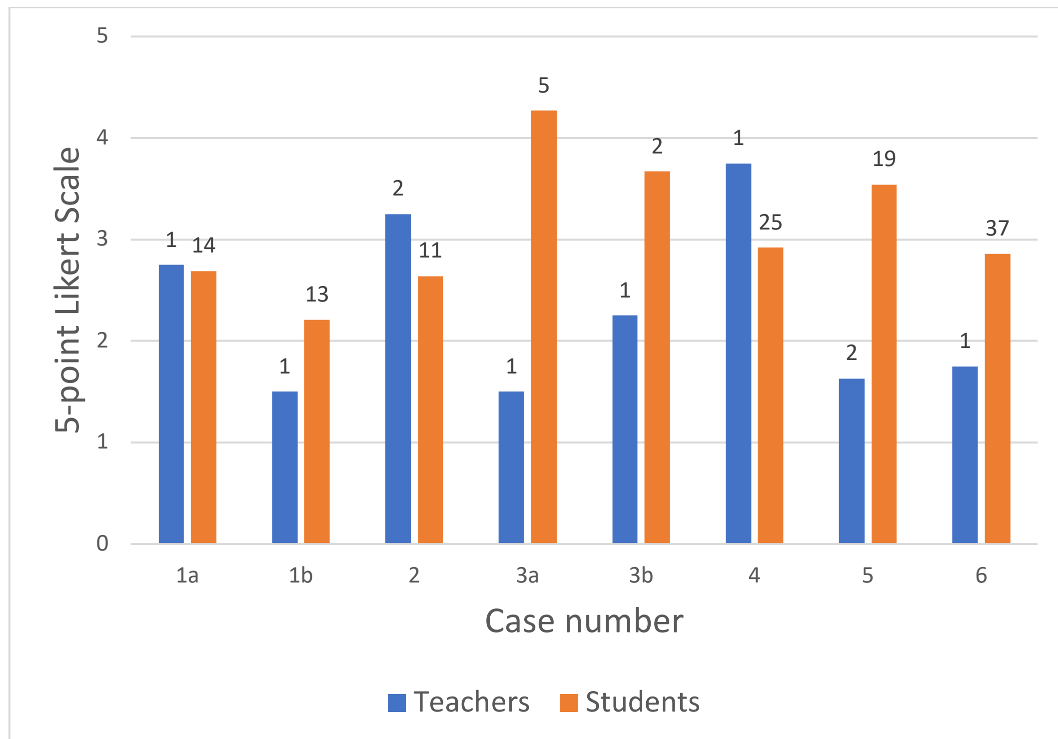
Overall, while synchronous learning remained highly structured, the use of mobile devices extended learning beyond formal schedules, particularly for asynchronous activities, promoting student autonomy in learning time and locations.

5.1.7 Tailored App Settings and Workflow

This theme explores how students used mobile devices to personalise app settings and workflow based on individual needs. Figure 5.6 shows teachers' and students' ratings for customisation subconstruct across all cases. However, only Case 1a provided strong qualitative evidence to support this theme.

Figure 5.6

Case Teachers' and Student Cohorts' Mean Ratings of the Customisation Sub-Construct in Each Case



In this case, the use of the StraboSpot app enabled students to personalise their data collection methods at both the tool (app settings and features) and the activity levels (how tasks were carried out in the field), as stated by the teacher:

> Definitely, they can customise a lot of items in the app. (Case 1a_Teacher)

Similarly, the learning designer highlighted how mobile practices accommodated different fieldwork approaches:

> There are fundamentally different ways that you can work with this app … For example, … when you do the rock ID in the field identification … you can make a list of the rocks that you will encounter and then start adding from that list, … make the list as you go, or … not to make the list … There are different levels at which you can go and describe your data. You can stay at the surface or … go very deep. (Case 1a_Learning designer)

Using the StraboSpot app, learners could decide what and how detailed they wanted to record their science data. Two students mentioned a wide range of features in the app, such as options for recording rock types, foliation and lineation, that enabled them to tailor their data collection and workflows:

> There are a lot of options there for us to choose from, and through tailoring learning it allows us to be able to … think about … what … features that there are on the app … which allows us to … have that customisation on … our data. (Case 1a_Student 9)

> There is a high level of customisation allowed by the activity and by the app … you can create very different workflows that suit you. (Case 1a_Student 2)

A further example came from a student who described how the app integrated multiple platforms, supporting his learning needs:

> It meets my requirements very well … It can upload, … backup, … output to the Stereonet, … Excel, …Google map, … PDF, … photos, anything you can think … I have more options to deal with my data ... no other app can mix everything together to meet all your needs. (Case 1a_Student 5)

This emphasises how the use of the StraboSpot app empowered students to extend their work across multiple digital platforms for further data processing based on their needs. As another student also said:

> It's also real customisable that … not only does it give you … a bunch of options, but you can also just recover and choose your own if it's not there. (Case 1a_Student 12).

Beyond default settings, students could also choose their own options, further supporting their device ownership. Customisation also supported visual and reflection, as one student described how being able to annotate directly on images helped bridge field data and later interpretation:

> One of the features in the app is … taking a picture and annotating it on the image, which … I used a lot, and it helped me … make sense of what it means. Because sometimes it's a bit harder to just take a picture and

> then come back to it without remembering what it was. (Case 1a_Student 14)

During their interview, the learning designer highlighted one of the app's features that allowed users to rate their confidence in the data they collected, which helped them later to select more reliable results for modelling:

> There is an option for the students … to rate the measurement from 1 to 5 based on how confident they are about the measurement. These propagate into their data and therefore later on when they … use their data in order to make a model, they know which data to trust more compared to others. (Case 1a_Learning designer)

The researcher followed different groups on different field days and observed many students utilise these tailored app settings. Despite the low survey ratings (Teacher: M = 2.75; Students: M = 2.66 out of 5, n = 14), extensive qualitative data indicated strong customisation in Case 1a. The discrepancies between the quantitative and qualitative data are further explored in the discussion chapter.

5.2 Science Mobile Pedagogical Innovation

This section addresses subsidiary research question 4: To what extent are educators' mobile learning activities perceived as pedagogically innovative?

Drawing on surveys, interviews, focus groups and observational data, this section explores perceptions of pedagogical innovation from university science teachers, learning designers, and students across all cases. Although this section does not explicitly reference the iPAC framework, participants in interviews and focus groups frequently described their experiences using iPAC terminology, such as authentic learning. As explained in Section 3.4, the innovation slider was used as stimulus for interview and focus group discussions.

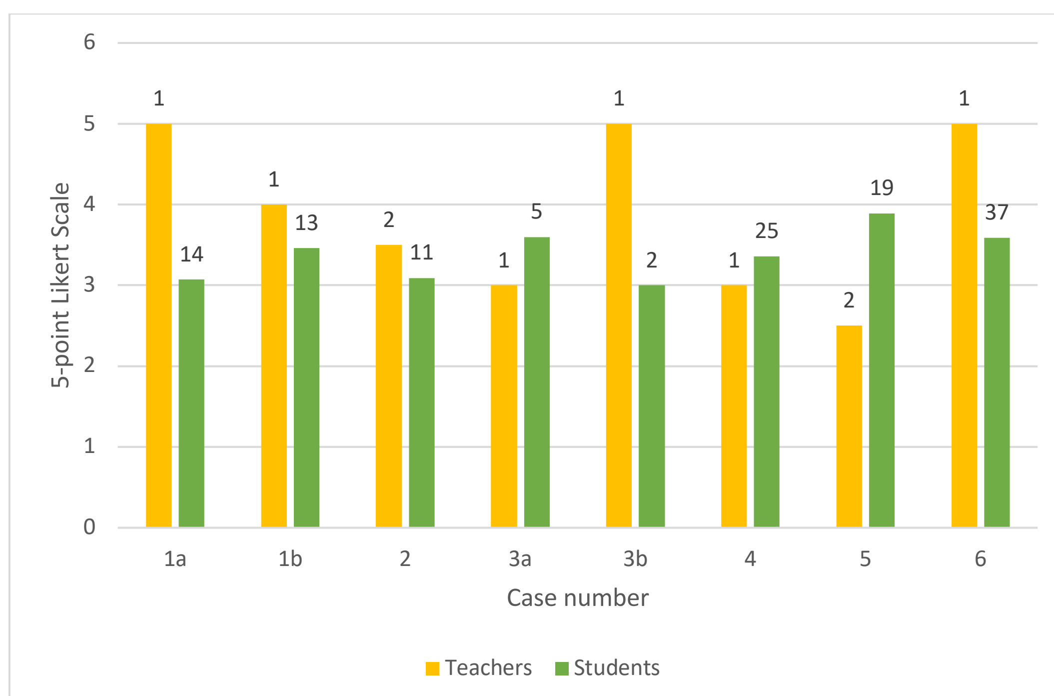
As mentioned in the literature review chapter, in this study the term *innovative mobile practices* refer to approaches that differ fundamentally from typical approach without mobile devices. These practices lie on a continuum ranging from sustaining innovations, which modify existing practices, to disruptive innovations, which create entirely new practices (Christensen et al., 2008; Cranmer & Lewin, 2017). This study adopted the digital pedagogical innovation criteria developed by Burden, Kearney, Schuck, & Hall's (2019), building on Law et al. (2005), as an analytical lens. These criteria focus on the purpose of

learning; the context of learning; the role of teachers and their relationship with students; and the role of learners. The validated teacher and student surveys (Appendices L and M) included five innovation items, the first four of which aligned with these criteria. The fifth item captured whether the participants' overall experience was fundamentally different from their typical science learning experience without mobile devices.

Before exploring the features and barriers of pedagogical innovation, it is helpful to first present participants' responses to innovation item 1 and 5 (see Figures 5.7 and 5.8, respectively). These items provide a holistic view of how the participants perceived whether the use of digital devices fundamentally changed how learning occurred (item 1) and the overall experiences compared to normal learning without mobile devices (item 5). Participants rated their agreement level using a five-point Likert scale (1= Strongly Disagree to 5= Strongly Agree), with the number above each column indicates the number of respondents.

Figure 5.7

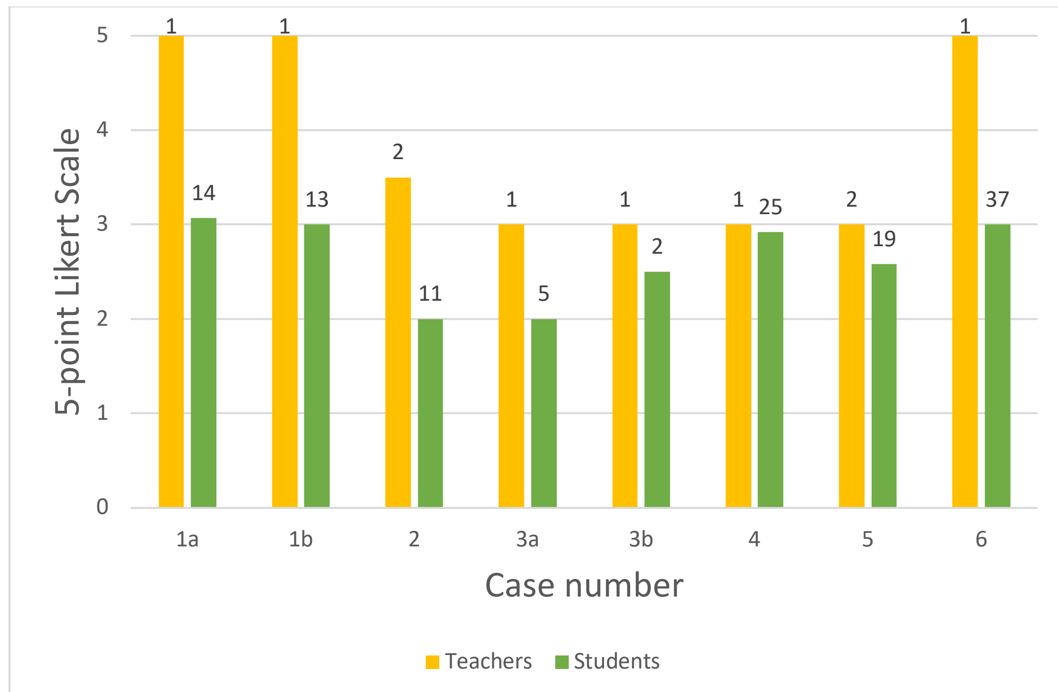
Case Teachers' and Student Cohorts' Mean Ratings of the Innovation Item "Use of a Digital Device Fundamentally Changed the Way That Learning Occurs" in Each Case



Note. The columns represent the rating scores from teachers (in yellow) and students (in green) for innovation item 1 in the survey in each case.

Figure 5.8

Case Teachers' and Student Cohorts' Mean Ratings of the Innovation Item "Learners' Overall Experience Was Fundamentally Different from What They Would Normally Experience in Science Subject" in Each Case



Note. The columns represent the rating scores from teachers (in yellow) and students (in green) for innovation item 5 in the survey in each case.

Figure 5.7 presents teachers' and students' responses to innovation item 1. Overall, university science teachers rated this item higher than did the students (M = 3.88 versus M = 3.38 out of 5). Similarly, as shown in Figure 5.8, teachers consistently rated item 5 more favourably than did students across all cases (Teachers: M = 3.81; Students: M = 2.63 out of 5). This highlights a consistent difference in how the two groups perceived the extent of pedagogical innovation relative to their normal science learning experiences.

The following sub-sections are structured into two parts: features of mobile pedagogical innovation and perceived barriers to mobile pedagogical innovation to examine the underlying reasons of these results, accompanied by the quantitative results from innovation items 2 to 4.

5.2.1 Features of Mobile Pedagogical Innovation

This sub-section presents innovative mobile practice features, as perceived by teachers, learning designers and students. Many of the examples here were derived from Case 1a, the only off-campus case, and involved one full week of researcher observations. This case was of extended duration and provided a unique learning experience where students used a realistic app in real-world settings, unlike all other more time-constrained campus-based cases in this study. Participants in this case appeared to be more open about sharing their experiences in depth with the researcher. It therefore provided a more comprehensive illustration of mobile learning in undergraduate science and offered valuable insights into pedagogical innovation in field-based learning.

a) Self-Directed Learning Through Structured Autonomy

This theme refers to how the use of mobile tools presented new ways of learning by promoting more student autonomy in their decision-making processes within the boundaries of the activities. The use of StraboSpot apps enabled students to manage fieldwork more independently, replacing traditional compasses and paper notebooks. The following data illustrate how educators and students perceived new educational purposes where the use of mobile technologies supports more autonomy and reconfigures the way geology is taught in the field.

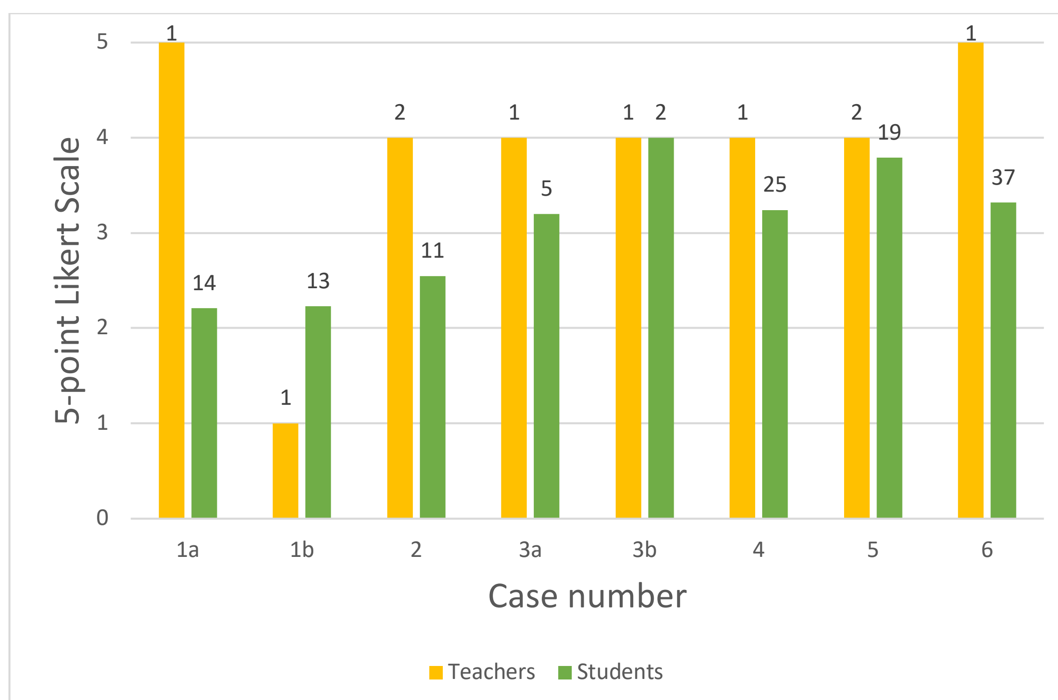
One of the key criteria for pedagogical innovation identified by Law et al. (2005) is the evolving role of learners, which refers to student capacity to exercise autonomy in their learning with the use of mobile tools. According to Figure 5.9, responses to the innovation item 4: “Learners were granted significantly more agency than would normally be the case” were relatively high across many cases (Teachers: M = 3.88; Students: M = 3.07 out of 5), despite some inconsistencies emerged in the qualitative data. The following perspectives highlight that while mobile practices enhanced the process and workflow, they did not fundamentally change the learning structure.

According to the Case 1a participants, the app guided students step-by-step on necessary observations and data collection:

> [The app] basically guides [students] on what observations they need to make and what data they need to collect in order to have a complete … set of observations from a specific outcrop, and this is definitely something new. (Case 1a_Learning designer)

Figure 5.9

Case Teachers' and Student Cohorts' Mean Ratings of the Innovation Item "Learners Were Granted Significantly More Agency Than Would Normally Be the Case" in Each Case



Note. The columns represent the rating scores from teachers (in yellow) and students (in green) for innovation item 4 in the survey in each case.

> It facilitates relatively rapid engagement with the tasks that we've been given … you can achieve an imaginative understanding of the landscape that you're studying much faster. (Case 1a_Student 2)

Another described how the use of mobile tools marked a pedagogical shift from long-standing geological practices:

> Geological mapping is kind of the same thing that it has been since the principles of it were first articulated, but in terms of actually meaningfully working with digital methods of collection … is quite paradigm shifting. (Case 1a_Student 8)

Several students reported a sense of agency in deciding how to conduct field tasks using the app. For example:

> It gives me more freedom because it enables us to take measurements a lot easier. It enables us to take photos and do sketches ... We choose what we are learning while we are in the field. (Case 1a_Student 13)

However, this autonomy was perceived to be within preset boundaries. Students emphasised that while mobile tools supported more flexible data collection, the objectives remained predetermined:

> It doesn't really fundamentally change the task itself. Like we would be here ... But it changes how we do the task. (Case 1a_Student 13)

> Maybe we do have a little bit of flexibility with how we want to use the app, but at the same time. We do have to use it and make the measurements and do everything that's expected of us as normal. (Case 1a_Student 11)

Other students also noted that while they could decide how to use the app and which locations to visit, the tasks, timing, and content remained structured and predetermined.

> We are … learning metamorphic and structural geology. So we don't have a lot of flexibility over that. … but we can go, we have got a big area. We can pick what places we want to look at. We have a lot of flexibility with that for a long time in the day, ... it is… structured to an extent. (Case 1a_Student 6)

> You have the freedom to … explore whichever spots you want to go to. But at the end of the day, you still have to … explore the spots in a certain timeframe. (Case 1a_Student 12)

Mobile practices supported students in navigating the field activities independently and facilitated efficient data retrieval during the report writing process.

In lab-based learning, some flexibility was enabled by the use of mobile apps, such as taking photos for review after class:

> We did it and then we took it home … I like the fact we just looked at one slide really intensely… then we could go home and then examine those slides in more detail once we've taken those pictures. (Case 1b_Student 3)

Hybrid activities offered slightly more flexibility in how students learnt, but not in choices over the content:

> We do not have the right to choose what we want … but we definitely have the flexibility in how we choose to learn something. (Case 5_Student 1)

> Absolutely not complete freedom, they have to learn what they have to learn [laugh]. But how they can learn and their own time is possible. (Case 4_Learning designer)

While mobile practices supported students with some choices in how they learn, they had no control over learning content or objectives, somewhat limiting the degree of pedagogical innovation in the role of learners.

b) Authentic Learning Tasks

The use of mobile tools introduced students to new scientific practices, fostering learning experiences that are more closely aligned with professional scientists. The use of tablets with location tracking enabled Case 1a students to navigate field locations more efficiently, compared to traditional approaches without the use of mobile devices. These findings align with favourable survey ratings for the overall pedagogical innovation item 1 from the teacher (M = 5 out of 5) and students (M = 3.07 out of 5, n = 14). The following examples suggest that participants recognised the alignment between the authenticity of their technology-enhanced learning activities and professional scientific practices.

One student described his use StraboSpot app to perform real-world task as "game-changing":

> This app is almost game-changing … With StraboSpot, we were able to move in the field so easily. I would assume that … future geologists would still have training in using a normal compass. But having used the app, it makes everything so much easier ... I could go out to the field really [with]

just a compass to back up the data or recheck the data on the iPad. (Case 1a_Student 14)

Another student highlighted the way digital tools supported more accurate navigation, data collection, and enhanced practical engagement in fieldwork:

> The use of … a physical map … is not going to be as accurate as … [the] digital device … [The app] definitely does change the way that we [find our location], ... using this app is much more exciting experience for us … [and] changes the way that students feel about going on the field. (Case 1a_Student 9)

Several students reported how the use of the StraboSpot app helped them avoid errors in field mapping activities. One student mentioned how his hand-drawn map was inaccurate due to mislocation, which was solved by the app's location service. Another student described the ability to trace previously visited locations helped her plan the field activities more strategically:

> It is easy to locate yourself … [and] trace things back … This also helps us to find which areas we covered [and] which … we have not. (Case 1a_Student 5)

A student's experience during the COVID-19 pandemic further highlighted the importance of integrating both fieldwork and technology:

> It is integral to have like a joint experience, ... having the field and the technology, it makes it a really … powerful learning experience. (Case 1a_Student 3)

Additionally, the self-rating feature in the StraboSpot app offered a novel way for students to evaluate data quality, as stated by the following participants:

> [Rating confidence level] is not something that we tend to do in field geology. So, this is something new and helps the students to assess … and engage with uncertainty. (Case 1a_Learning designer)

> You can use [the self-rating score] to then pick which ones you think are the best to use ... you could filter out that kind of uncertain data and just

> use the data that you've been comfortable with … that is a very good aspect of it. (Case 1a_Student 8)

In Case 3b, the implementation of the Phyphox app allowed students to conduct physics experiments that would have been infeasible without mobile devices. The teacher explained that the measurement of angular velocity without mobile devices would have become unachievable:

> If this was done … before smartphones, it would be undoable. We wouldn't have found such accurate devices for measuring the angular velocities on three different axes of an object. So, with a smartphone, we can not only do measurement but also export it to a computer and we can analyse it with Excel. (Case 3b_Teacher)

The learning designer noted that while the core physics concepts remained unchanged, using mobile phones to perform physics experiments was uncommon in universities:

> In terms of the concepts, the lab teaches… they are the same… It's the physics of rotation. So … we have not modernised that, revolutionised that but the use of the phones … makes it more like internalised the topic better for the students ... so in terms of using phones in the lab, I would say it's really high … because that's not common. (Case 3b_Learning designer)

These examples illustrate how mobile practice was perceived as supporting new educational experiences that would have been impossible without mobile devices. However, this innovation may be characterised as a novelty but not necessarily a pedagogical transformation, since the underlying physics concepts remained the same.

One student appreciated smartphones as accessible and cost-effective tools for new physics experiments:

> If you wanted to do any old technical device, you probably need like a lot of wires and stuff like that. So, you wouldn't be able to ... drop something and get a lifetime gyroscope graph of … its motion. So … it is quite innovative. (Case 3b_Student 3)

He also noted that using mobile phones as scientific experiment tools was relevant and aligned with the broader trend towards digital technologies in education, eliminating the need for expensive lab facilities:

> It’s not like you need to go and buy some super fancy device or very technical advice ... It’s becoming that you think everything from the phone. So, … it’s pretty relevant to … be using mobile phones and classrooms because I think that’ll be… a trend that will continue to occur increasingly. Yet you don’t have to buy books. It’s just on your phone. (Case 3b_Student 3)

c) Incremental Innovation

While mobile practices added something new to the existing activity, such as increased convenience and improved data access, they did not substantially alter the underlying pedagogical approaches. In multiple cases, participants also acknowledged that the use of mobile tools, such as StraboSpot in fieldwork, and Labscope and Surface Pro in lab activities streamlined learning processes by allowing more efficient data collection and analysis. The following data illustrate how mobile devices were layered onto existing practices to make them more efficient yet did not fundamentally change the underlying educational processes.

Some Case 1a students were of the opinion of these mobile practices did not fundamentally shift the existing paradigm:

> It does modify the learning, but at the end of the day, we still have to go out and look at the rocks. … StraboSpot has got the iPads to add something new, but I don’t think it fundamentally changes the … paradigm of what we would’ve done without the iPads. (Case 1a_Student 6)

> We already had field geology, this is a twist on it, but it’s not the game changer. It’s not a new paradigm …[and] it’s a new way to go about the same skill and we’re still looking at rocks … [and] interpreting structures. (Case 1a_Student 4)

> We still have to do the exact same amount of things, very structured … this is what you need to do. Throwing an iPad in our hands, I don’t think it necessarily changes that. Which is not a bad thing, again, … that’s how

we learn, … they give us the tasks that we need, right? But … I don’t think the technology necessarily alters that dynamic. (Case 1a_Student 5)

In Case 1b, the educator shared similar views:

> Paradigm is a ... big thing to say. (Case 1b_Teacher/Learning designer)

> At the end of the day, they can do whatever they want, but to be able to work, there’s only one way to do it, so, not much freedom. (Case 1b_Teacher/Learning designer)

Although a microscope was connected to an iPad, the underlying structure of the microscope activity remained largely conventional. His student also acknowledged that mobile practice improved the learning process, but the core learning task remained the same:

> I don’t think it was necessarily a game changer ... you could have run over to the microscope. I have to look through this, anyway ... That’s simplified the process that you could have already done without [mobile devices]. (Case 1b_Student 1)

Another student noted prior lab learning experiences and expressed familiarity rather than novelty:

> It’s not like ground-breaking. It's definitely better, but it’s not ... crazy different ... digital cameras are everywhere and basically ... it is... a digital camera and a microscope ... it’s a fairly obvious thing. (Case 1b_Student 5)

Other students also emphasised the value of consistency in familiar practices, noting that teaching approaches do not necessarily need to change every time:

> I imagine there’s not going to be so many game changes. I think it’s pretty consistent with my university so far. (Case 1b_Student 1)

> I’d say low [innovation] because that kind of activity is just like standard. To be honest, I don’t think that’s a bad thing, right? You don’t need to reinvent the wheel every time. (Case 1b_Student 2)

As the students in Cases 1a and 1b were of the same cohort, they were able to reflect on the differences between the Labscope and StraboSpot activities:

> When it compares to a Strabo app on an iPad, it's hugely different. And it makes your life like 10 times easier, but… I think this is just kind of taking what you see on a microscope, just putting it in digital form. (Case 1b_Student 4)

In Case 6, the teacher explained how the use of the Surface Pro modified previously manual microbiology identification processes:

> The use of tablets is a lot more innovative, having the ability to automatically look up your APIs rather than manually looking them through on a chart, so much better. Having automatic access to your EUCAST breakpoints to determine antibiotic sensitivity, a lot better than what we used to have to do, which was … a massive table at the end of our book, and we'd be sifting through it to see the correct organism…, it was a lot more hassle. Now, they have all the stuff there ready for them and easy to access, and the workflow is a lot more improved. (Case 6_Teacher)

However, he also clarified that mobile practices streamlined learning, rather than disrupted existing practices:

> The use of technology is more of a convenience than a really adaptive and disrupt or disruptive innovation to the subject itself. It just allows for the subjects to be more streamlined. (Case 6_Teacher)

A student highlighted the changes she perceived in her technology-enhanced lab learning experiences but did not mention whether it is a pedagogical innovation:

> It's done very differently ... If we didn't have … technology, we couldn't look at the lab stuff beforehand and do … the pre-lab activities ... And in the lab we … [can] not access … all the online, the lab manual … you can't bring paper and stuff because it's disinfecting. ... So I think it changes the whole activity. (Case 6_Student 2)

In Case 2, despite providing relatively high ratings for item 1 (higher than 3) in the survey, both teachers did not perceive the use of digital lab notebooks as

innovative. One teacher described it as merely converting the paper version of the practical manual to a digital version:

> It's just a worksheet that's online. (Case 2_Teacher 1).

The learning designer acknowledged that his practice, while incorporating multimedia, was somewhat new - albeit not entirely novel:

> It's not something completely novel, but a new way of doing things. …You're adding in some novel components … the ability to add in multimedia components allows you to change that around. (Case 2_Learning designer).

A student recognised the novelty in documenting experiment results digitally when comparing it with her experiences at high school:

> Take photos and videos as a form of observations to record that was ... something new. Normally we would just like write down…, I saw this colour and … being prompted to take photos and upload those as part of our results. I think it is a good thing because you can forget otherwise. (Case 2_Student 1)

Nevertheless, this student also acknowledged that such mobile practices did not significantly alter the standard scientific procedures:

> Compared to just following a very rigid outline and being directed every step of the way, like there was some more innovative, … freedom for the individual to figure out the problems on their own and do their own write ups … it was still rather a standard scientific procedure that we were following. So … nothing crazy. (Case 2_Student 1)

Overall, these examples show that while the use of mobile devices improved task efficiency and workflow, participants generally viewed them as incremental rather than pedagogical innovation, as it did not radically alter the existing paradigms.

5.2.2 Perceived Barriers to Mobile Pedagogical Innovation

Despite the implementation of mobile technologies, many case studies were perceived by participants as retaining conventional pedagogical characteristics. Mobile devices were often layered onto existing practices traditionally

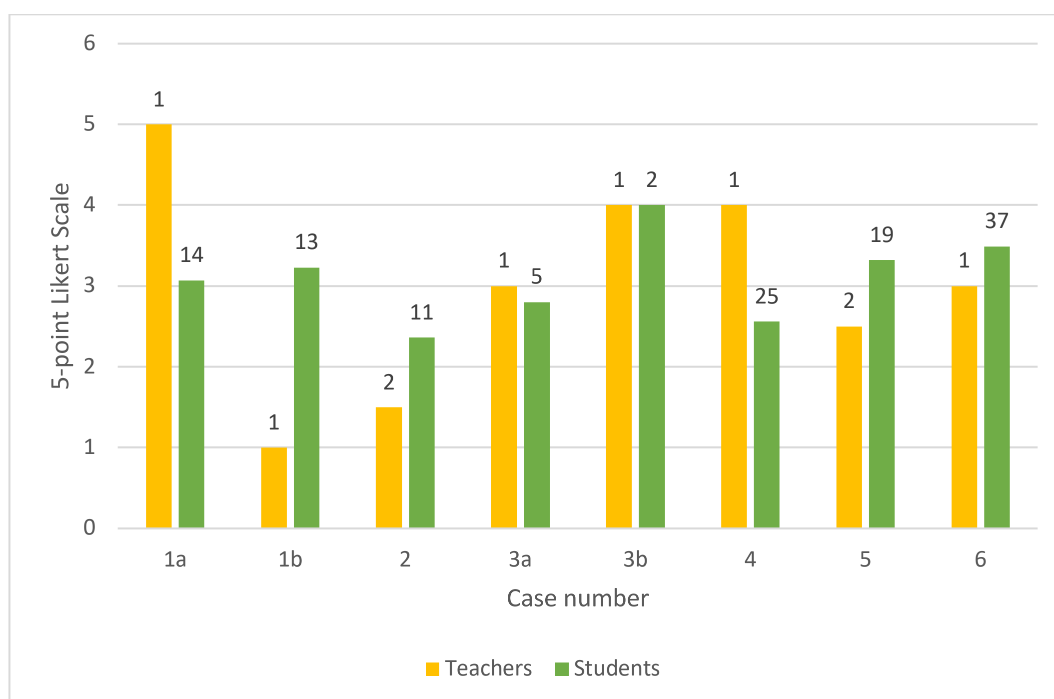
implemented without mobile devices, with limited shifts in the learning settings or roles of teachers and students. The following themes highlight areas where pedagogical innovation was constrained in undergraduate science education.

a) Persistence of Traditional Settings

Many synchronous activities in this study were still tied to formal settings such as university lecture halls, and to laboratory classrooms or semi-formal settings such as a field trip, regardless of the implementation of mobile tools. Exceptions were hybrid learning activities where students could learn either on campus or remotely from home. As can be seen in Figure 5.10, despite moderate high ratings for the innovation item 2 "The context of learning was radically different", it was not supported by qualitative evidence.

Figure 5.10

Case Teachers' and Student Cohorts' Mean Ratings of the Innovation Item "The Context of Learning Was Radically Different" in Each Case



Note. The columns represent the rating scores from teachers (in yellow) and students (in green) for innovation item 2 in the survey in each case.

In Case 1b, participants said that using iPads did not alter the lab location and students still required the physical lab spaces with microscopes; neither the time nor the location of the learning activities changed due to mobile practices; for example:

> It's still pretty traditional because you have to be in that room to get that microscope. (Case 1b_Student 8)

> We cannot do it anywhere else. It has to be in the lab space. (Case 1b_Teacher/Learning designer)

Even when the digital lab notebook was used, students were still expected to attend the chemistry lab session on campus:

> The context is all the same, the setting, the time. It's still just keeping an [online] lab notebook. (Case 2_Teacher 1)

In Case 3b, the teacher noted that although students performed the mobile phone rotation experiment at home during the COVID lockdown period, they had already returned to campus:

> Since COVID is over, well not a big deal now. They have to come into the labs. (Case 3b_Teacher)

Students echoed these views, often describing their activity settings as traditional:

> It's definitely somewhat of a formal environment. (Case 3b_Student 3)

These comments reflect how mobile practices were often introduced into existing structures without altering the activity locations. Even in hybrid learning case studies, the traditional context was unchanged for face-to-face students, while only remote students could benefit from flexible locations:

> It's a mixture since we have the traditional lecture where students can come to the face-to-face and also we have the online student cohort. So, students can be free to choose the mode of learning. (Case 4_Teacher)

> Given the options we provided for students, for the lectures, it is high because they could take it anywhere and everywhere, anytime. (Case 4_Learning designer)

> For those who show up, it's totally [traditional], but ... there is the full capability for somebody to engage with it to a slightly lesser degree

> because they don't get any immediate feedback remotely. So it's kind of mixed but it's not fully mixed. (Case 5_Teacher 2)

The Case 5 focus group students who attended the on-campus workshop shared similar views to the educators on conventional classroom settings:

> A lecture workshop in a lecture hall. I don't think there was anything like radically different … it's pretty traditional for how a workshop has always been run. (Case 5_Student 2)

> The technology helps again for online but like in terms of it hasn't really changed a whole lot in terms of the context of the learning. (Case 5_Student 1)

Despite the use of mobile practices, the requirement for students to be physically present in the field remained unchanged. Although students in Case 1a acknowledged a fluid dynamic where they could learn with the app beyond scheduled times, often in communal spaces or private cabins, they still needed to travel to the field locations, which took approximately 14 hours by train from their campus:

> Because of the iPad, I can do more in non-traditional settings like my cabin and … at night but because you have to go on the field, which is the traditional kind of makes it a mixture. (Case 1a_Student 6)

Another student reinforced this view:

> It's traditional in the sense that you still go back to the school. You can't just go get up and say, I just need to put my foot on the mat and a dip in there …? You can't do that. (Case 1a_Student 7)

A third student had a more nuanced view, explaining the mixture of semi-formal and informal settings:

> We're on a fieldtrip ... it's also not in a classroom and we also have a lot of freedom in choosing where we want to do the learning, where we want to go and we can also do learning in our cabins, in our private space. So that's an informal setting. (Case 1a_Student 13)

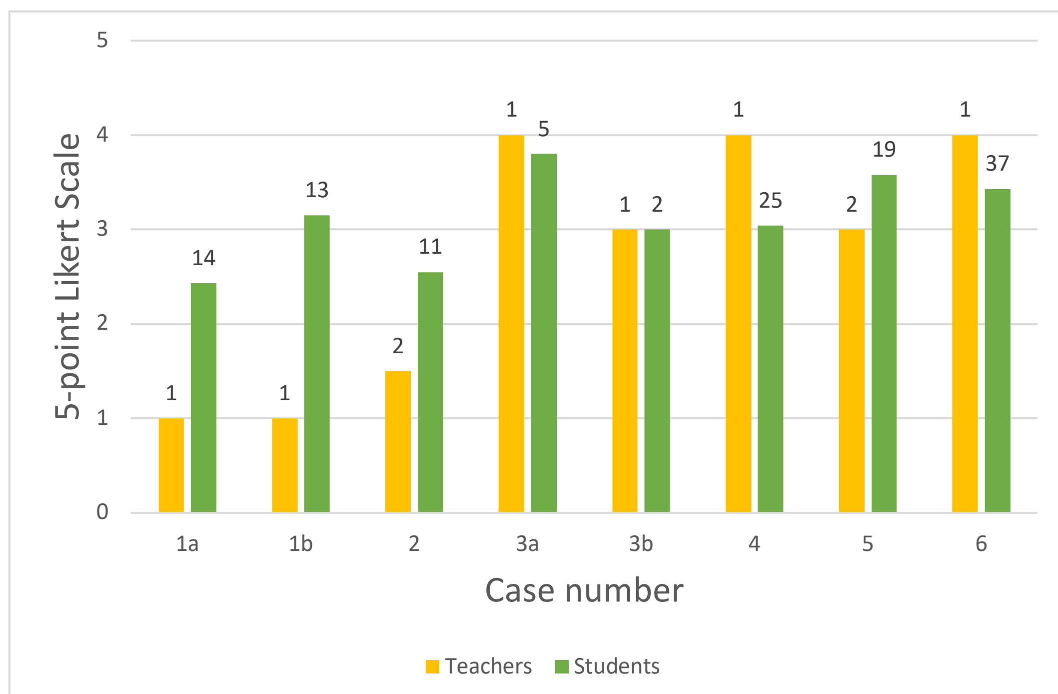
Therefore, the expectations of physical presence in designated field locations persisted. Overall, beside the flexibility of hybrid learning cases, the locations of the field trip and lab activities in this study remained the same.

b) Continuity of Traditional Teachers' Roles and Limited External Facilitators

While mobile technologies were implemented in university science learning episodes, the teachers' roles were largely unchanged, with minimal involvement of external facilitators. Figure 5.11 presents the participants' ratings for innovation item 3 in the surveys: "The range of stakeholders facilitating learning was greatly expanded." Although the students rated this item higher than their teachers (Students: M = 3.12 out of 5; Teachers: M = 2.69 out of 5), there was limited evidence to support their ratings.

Figure 5.11

Case Teachers' and Student Cohorts' Mean Ratings of the Innovation Item "The Range of Stakeholders Facilitating Learning Was Greatly Expanded" in Each Case



Note. The columns represent the rating scores from teachers (in yellow) and students (in green) for innovation item 3 in the survey in each case.

The use of tablets with location tracking enabled students to navigate field locations more efficiently, compared to traditional approaches without the use of mobile devices. These findings align with favourable survey ratings for the overall pedagogical innovation item 1 from the teacher (M = 5 out of 5) and students (M = 3.07 out of 5).

Moreover, some students rejected the idea that their teachers learnt alongside them, emphasising the instructors' disciplinary expertise:

> These [teachers] are extremely good structural geologists. They're not learning alongside us. They're designing to the very last detail what we're looking at. (Case 1b_Student 4)

Similar perspectives appeared in the lab case studies where the lab teachers provided timely support and feedback, guiding students through self-directed lab learning activities.

> I demonstrated everything … if they have questions, they ask me. (Case 2_Teacher 2).

Students valued the autonomy they had in the lab activities and appreciated their teachers' intervention when they encountered problems:

> Our instructor gives us a lot of our own individuality … to figure out how to do things but also will support when we have questions and help us work through things. (Case 2_Student 1)

> The tutors … are more like coaches for students to help them … navigate the experiments and help them learn. (Case 3b_Learning designer)

Students reinforced these perspectives, describing their lab activity as highly self-directed, with teachers intervening only when problems occurred:

> The teachers only really step in when we have a problem. (Case 3b_Student 1)

> I wouldn't say it's dominated by a teacher; teachers are there to help you. (Case 3b_Student 3)

Similarly, the facilitative approach was explicitly articulated by all participants in Case 6; for example:

> I'm more of there just guide the students to a correct answer … there's a lot of free learning as well. So it's just… prodding the students along. (Case 6_Teacher)

> We want them to be proactive and to answer or to take the lead for some of the things they're doing. So we're not there yet because it's a bit hard for them and it's also only week four. (Case 6_Learning designer)

> The class begins with a bit of…traditional [briefing] … But then from there, we kind of are on our own in a sense, and … the teacher is a guide from there. (Case 6_Student 1)

Consistent with the researcher's observation across all Phase Two case studies, there was a notable absence of participants reporting on the involvement of external participants in their learning activities. One lab teacher commented:

> I don't think [the range of stakeholders] was greatly expanded, … no one's going to go home and show their parents or friends. (Case 2_Teacher 1)

Collectively, these responses reinforce the idea that facilitation, though present, was widely seen as a standard pedagogical approach in undergraduate science education, rather than as a pedagogical innovation introduced through mobile technologies.

In hybrid lecture and workshop activities, teacher-led instruction remained dominant. Teachers would direct the flow of content, and student participation remained largely passive.

> The lecture time is similar to the traditional lecture time where you have to pass on the information to them. (Case 4_Teacher)

> The nature of the lecture is that there is a lecturer up here talking to us about the content. (Case 3a_Student 1)

Despite the teachers' efforts to shift towards facilitation, the actual classroom dynamics often pulled them back into traditional roles due to low student participation and interactions. The following data are from Case 5:

> I do try to facilitate, but ultimately, I have to dictate the pace and what's going on and the direction. (Case 5_Teacher 1)
>
> I try and be more of a facilitator. But … today in particular, I felt like a traditional teacher because … they were having to be led everywhere. So unfortunately, … I am kind of constantly leading them and coaxing them. (Case 5_Teacher 2)

These views were also expressed by students who recognised their teachers' efforts and pointed to broader motivational barriers among peers:

> Definitely [the teacher] was not learning along with us … He tried his hardest to make it more interactive, but … it's more the students and just a lack of willingness … to engage. (Case 5_Student 1)

In summary, while mobile devices were implemented into various undergraduate science learning activities, the data suggested that teachers' role remained largely unchanged, and the involvement of external facilitators was limited.

5.3 Chapter Summary

This chapter has shed light on how mobile practices were employed by university science teachers and learning designers to support student learning across six case studies. The findings reveal distinct mobile approaches in contemporary science education and offer multiple participants' insights on pedagogical innovation.

Thematic analysis revealed that teachers most frequently used mobile approaches emphasising collaborative face-to-face conversations *around* the mobile devices, where students shared their ideas with peers face-to-face, with less emphasis placed on conversations *through* the devices. Another strong theme was sharing of data with peers, while co-production of digital products was less common. A consistent theme across the case studies was the student-initiated use of mobile tools to supplement their learning, which reflected learners' autonomy. In out-of-classroom activities, students had greater control over how they learnt, while hybrid learning activities provided students flexibility in their

learning modes. Students also used realistic science apps to perform tasks that mirrored professional scientific practices, particularly in field trips and lab activities. However, only the field trip activity in Case 1a demonstrated strong customised and contextualised learning where students could tailor app settings and workflow in real-world settings. Furthermore, the use of mobile tools enabled asynchronous learning outside the scheduled activities.

While the educators in this study generally perceived a higher level of pedagogical innovation than did the students, the data revealed that many mobile practices remained rooted within traditional structures, similar to those practised for decades without the use of mobile devices. Although some features of innovative mobile practices were evident, most of the teachers continued to disseminate information in lectures and workshops. Their guidance and facilitation of students' learning in field or lab activities also mirrored existing approaches that did not use mobile devices. Likewise, while students had some choices in how they learnt, they typically had no freedom to choose what they learnt.

The next chapter synthesises findings from both Phase One (see Chapter 4) and Phase Two to provide a holistic overview of how mobile practices were employed by university science teachers. Furthermore, it explores how educators' mobile practices were perceived as pedagogically innovative by teachers, learning designers, and students.

Chapter 6
Discussion

This chapter synthesises the key findings from both phases of this study and discusses emerging issues related to distinctive and innovative mobile practices in undergraduate science education. This empirical study is driven by a sociocultural investigation of pedagogies associated with the use of mobile technologies, rather than an exploration of technology per se, through the lenses of the iPAC mobile pedagogical framework (Kearney et al., 2012) and digital pedagogical innovation criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005) (see Chapter 2).

A mixed-methods approach was employed to triangulate quantitative and qualitative data that emerged from the surveys, interviews, focus groups and observations. Chapter 4 presented results from an international survey of university science teachers (n=132) and Chapter 5 detailed the case studies of eight learning activities from four universities in New South Wales, Australia. These case studies highlighted insights from self-nominated science teachers, learning designers, and students – as described in Chapter 3. The analysis of these data sets addressed the overarching research question:

> How are mobile technologies being used in undergraduate science education to support teaching and learning?

and its four subsidiary research questions:

1. How are university science teachers using distinctive mobile pedagogies
2. How do learning designers view these mobile pedagogies?
3. How do students experience these mobile pedagogies?
4. To what extent are educators' mobile learning activities perceived as pedagogically innovative?

Taken collectively, these findings are significant because this study is among the first to examine distinctive mobile practices and pedagogical innovation in undergraduate science education from multiple perspectives, both internationally and within Australia. The findings offer valuable insights into the strategic use of mobile devices to support innovative mobile practices in university contexts. The next section summarises key findings from both study phases before further

discussion on distinctive mobile practices (Sections 6.2 to 6.4) and mobile pedagogical innovation (Section 6.5). Practical implications, limitations and directions for future research are also addressed in this chapter.

6.1 Summary of Key Findings

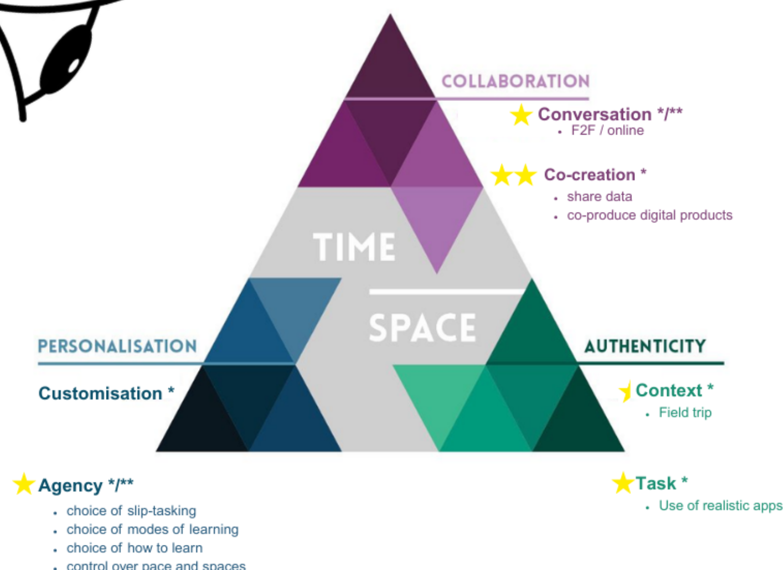
A conceptual diagram (see Figure 6.1, based on Kearney et al.'s (2012) iPAC framework) was developed to synthesise the findings from both phases of this study and to capture how distinctive mobile approaches were employed in a range of activity types in undergraduate science education (e.g., lectures, tutorials, laboratories, workshops or field trips). A strong theme that emerged across both phases was data sharing and co-production of digital products, pointing to the role of mobile devices in fostering collaborative learning in undergraduate science education. Learner control and conversations emerged as multifaceted subconstructs, reflecting both educator- and student-initiated practices. These practices highlighted the affordances of mobile devices in giving science students greater control over how, when and where they learn, either on or off-campus. Mobile practices supporting authentic learning were most evident when students used relevant, discipline-specific apps, mirroring professional science practices in real-world settings. While tailored app settings and workflow could have personalised individual student learning needs, such practices were not widespread across the learning contexts.

These insights are captured in Figure 6.1, where the "eye" icon reflects perceptions from educators (teachers and learning designers) and students. The central part of the triangle emphasises the influence of temporal and spatial arrangements in shaping how mobile tools support learning across formal, semi-formal and informal settings. The number of asterisks denotes whether the educators (*) or students (**) initiated the mobile practices. The number of yellow stars indicates the extent to which specific mobile practices were featured in this study.

Figure 6.1

Participants' Views of Distinctive Mobile Pedagogies in Undergraduate Science Education

- Educators * (Teachers and Learning Designers)
- Students **



Note. Adapted from the iPAC mobile pedagogical framework (Kearney et al., 2012) and reproduced by permission of the publisher, © 2020 by ipacmobilepedagogy.com

The findings also suggest that while the use of mobile devices in undergraduate science education supported new ways of learning, many nominated learning activities did not create new educational processes that fundamentally changed the existing traditional approaches to learning such as the settings, the roles of teachers and their relationships with students. Furthermore, there was limited involvement from external facilitators (such as science researchers, scientists or parents). Consequently, the participating students did not perceive their overall experiences as radically different from their typical science learning without the use of mobile devices. Discrepancies were also identified in the educators' and students' perceptions of pedagogical innovation. Additionally, statistical analysis from Phase One revealed that teachers who were more familiar with digital teaching perceived their practices as more innovative.

6.2 Mobile Pedagogical Practices in Undergraduate Science Education

By explicitly focusing on undergraduate science education and incorporating multiple participants' perspectives, this study advanced the understanding of distinctive mobile practices by highlighting their relevance and applicability in

various undergraduate science disciplines. The following sub-sections deepen the analysis by addressing subsidiary research questions 1 to 3. These findings are presented in the order of significance of the overarching themes combined from both phases of the study. In addition, other aspects of these practices that emerged from this analysis are discussed.

6.2.1 Co-Creation

Co-creation emerged as a prominent theme of this study, with many participants acknowledging its value in fostering student engagement through collaborative science tasks. As detailed in Chapters 4 and 5, findings from both phases consistently highlighted how data sharing and digital content production can support participatory learning in undergraduate science education. These results align with broader mobile learning research in science education that reinforced the importance of collaborative, inquiry-based, project-based and problem-based learning in developing higher-order thinking and communication skills (Afikah et al., 2022). The findings also resonated with prior studies demonstrating the effectiveness of mobile-mediated collaborative learning in diverse educational contexts, including school science (C. Liu et al., 2020), science and mathematics (Bano et al., 2018), university science education (Ly & Kearney, 2024) and broader higher education (Tlili et al., 2023).

In Phase One, the utilisation of science-specific, educational or generic mobile apps (see examples in Table 4.2) was instrumental in facilitating multimodal collaboration in science group projects (as reported in Section 4.2.2). Teachers described students working collaboratively in small groups on shared documents using Google Suite or Padlet, creating videos about scientific subjects and posting them on YouTube, or generating forensic media artefacts. In Phase Two, physics students from Case 3b used the Phyphox app on their phones to collect and analyse data related to rotational dynamics with peers. The inclusion of mobile devices altered traditional laboratory approaches by reducing reliance on specialised instruments. Students shared data in real time to co-construct and submit an online report within the lab schedule. These examples demonstrate how utilising mobile technologies can enrich collaborative scientific learning and foster student engagement, even in conventional university lab settings.

In Case 2, chemistry students performed different parts of the prescribed experiment and shared the data via email or self-initiated social media chat groups. In this way, within the 3-hour timeframe during which the entire

experiment could not otherwise be completed, students collected all the data required to complete the follow-up activities. Previous studies suggested that mobile learning not only enhances collaboration but also supports deeper engagement and peer learning by enabling students to manipulate and build upon each other's ideas (Fu & Hwang, 2018; Kearney et al., 2012; Zou et al., 2023). The structured design of mobile practices supporting co-creation in this case highlights a shift towards more student-centred and collaborative learning for undergraduate science learners.

This study provides empirical evidence supporting the growing body of literature advocating mobile practices supporting collaborative learning in higher education, such as in chemistry (Fonseca et al., 2021; Jones et al., 2018; Lee et al., 2021; Winter et al., 2016), sport sciences (Escamilla-Fajardo et al., 2021) and field-based learning (Jeno et al., 2020; Jeno et al., 2022; Jeno et al., 2017; Unger et al., 2021; Wang et al., 2020). These mobile practices are particularly valuable in science education where hands-on experiments and teamwork are core elements. While previous research has recognised the benefits of mobile practices supporting co-creation in mainstream schooling (Burke et al., 2025; Kearney et al., 2015; Kearney et al., 2020), teacher education (Burden & Kearney, 2017) and special education (Kearney et al., 2022), this study focused on their purposeful embedding into diverse undergraduate science learning activities from multiple perspectives.

In summary, this study has both affirmed the value of co-creation in undergraduate science and illustrated how these mobile practices can serve as powerful catalysts for sharing and co-producing science knowledge. By embedding co-creation into more science learning activities, educators can cultivate more collaborative learning experiences to fully utilise the benefits of mobile technologies.

6.2.2 Learner Control

Student agency was found to be multilayered. The participating students often extended their learning beyond the boundaries of the structured activities, particularly through choosing mobile tools or apps and hybrid activities. While many of the teachers and learning designers perceived limited student agency in their nominated activities in Phase Two, the students rated their own agency as the most positive subconstruct across all cases (M = 3.32 out of 5, n = 126). Despite the constraints of regimented university schedules, the students

exercised their device ownership in ways that educators seemed to not fully recognise.

As reported in Section 5.1.3, many students chose various educational, generic or social media apps to support their learning, not just those specifically recommended by the teachers. At first glance, this phenomenon may appear to observers as potential multi-tasking or as off-task behaviours (Pirani & Hussain, 2019; Small et al., 2020). Students seemed to engage in several digital tasks simultaneously, some of which could be perceived as irrelevant to the learning activities and possibly distracting to others (Tindell & Bohlander, 2011), thus potentially negatively impacting students' academic performance (Demirbilek & Talan, 2018; Felisoni & Godoi, 2018; Glass & Kang, 2019). However, the qualitative analysis of students' insights revealed that, in most cases, they were not disengaged or off-task. Instead, they leveraged different mobile tools to engage in self-initiated communication and research to support their learning while engaging in the same learning tasks. This aligns with a notion of "slip-tasking'' previously identified in research on tweens' use of mobile technologies (Agnew, 2020), where students' flow of actions using multiple apps and digital resources was integrated as part of the learning activity; they were not distracted but rather adding to the learning processes.

Even without explicit educator guidance, students independently chose diverse approaches on how to learn, such as note-taking, collecting data, and capturing photos or videos. They chose a range of ways to engage in rich multimodal communication via their choices of mobile tools, either communicating or exchanging results face-to-face "at" (or "around") or "through" mobile devices (Crook, 1999). Such self-initiated uses of social media have been shown to promote students' active exploration, construction, co-creation and distribution of knowledge in online learning environments (Blaschke & Hase, 2019).

Furthermore, these findings support those of Heinrich et al. (2022) that students appeared to value the informal and student-led use of chat tools (e.g., Discord) for information exchange. These student-led practices reinforce the value of mobile devices in fostering learner agency and collaborative learning, as highlighted by many researchers (Burke et al., 2022; FitzGerald et al., 2018; Kearney et al., 2020; Maguire et al., 2020). In summary, these findings point to a broader use of mobile devices to support more student-driven learning that extends far beyond conventional teacher-led activities.

Although the Phase One teachers rated student agency as the highest subconstruct, there was slightly less qualitative data to corroborate this occurring during synchronous on-campus activities (see Section 4.2.2). One such example within the activity timeframe was that students could control their pace in how fast or slow they go through the Nearpod content or whether to capture photos of their microscope views. Outside their class schedules, students often engaged with flipped learning content, such as lesson notes and videos on the learning management systems, before engaging more deeply in synchronous activities. The triangulation of Phase Two data confirmed that formal synchronous activities required students to be on-campus according to the university schedules, except for hybrid learning activities where students could choose to participate synchronously on campus or at home, or asynchronously by watching the lecture recordings at their own time. The hybrid learning mode was valued by students due to the flexibility and choices it offered (Bashir et al., 2021; Clifft & Assiouras, 2023). In this context, the widespread adoption of m-learning has been one of the key drivers of student agency by enabling learners to make meaningful decisions about how, when and where they learn (Marín et al., 2020; Traxler et al., 2016). This is particularly important for university students, many of whom may need to juggle academic duty alongside work, family, and other personal commitments.

During the field trip (Case 1a), students demonstrated greater agency in how they learnt, using mobile devices to collect and organise data within the given timeframe and spatial boundaries of the field. In Case 2, although teachers perceived students to have limited control over time and location in the campus-based lab, students shared that they could choose how to document their experimental results, either through notetaking, photos or videos. Similarly, in Case 1b, the teacher emphasised that the structured schedules and perceived learner agency were limited. However, his students enjoyed controlling the pace of their learning and making use of the microscope images after the lab session. These cases collectively highlight the importance of recognising higher education students' actual learning behaviours and how pedagogical design can enhance student agency in technology-enhanced learning environments (Marín et al., 2020).

Seamless learning. This study found limited but meaningful examples of seamless learning, where mobile devices helped bridge learning across different locations and times. In Phase One, teachers frequently selected multiple locations – such as lecture rooms, tutorial rooms, laboratories, and homes – for

their nominated learning activities. However, the qualitative data revealed that mobile devices primarily facilitated continuity *between* learning activities, rather than *within* a single activity. For example, students first learnt scientific theories and concepts informally at home, through videos, lecture notes or online quizzes, before participating in structured activities. This pattern was reinforced in Phase Two, where handheld devices sometimes facilitated transitions between synchronous and asynchronous learning activities. It is important to note that the researcher only observed the on-campus activities nominated by the participating teachers, except for Case 1a, which involved a one-week observation. Seamless learning was most evident in this case, where students used mobile devices to learn both during and outside the scheduled fieldwork activities, demonstrating science learning on the go.

The transitions between formal and informal learning episodes in this study highlight the fluid nature of seamless learning, where students learnt either synchronously or asynchronously across varied contexts, in and out-of-class (Burden & Kearney, 2016; Kearney et al., 2020; Looi et al., 2019; Schuck et al., 2017; Sharples, 2015; Toh et al., 2013; Wong et al., 2021). Indeed, Burden and Kearney (2016) argued that the ubiquity of mobile devices is an important feature of science education that empowers students to engage in scientific inquiries across multiple locations. This study has reinforced this argument by showing how the use of mobile devices can help students to extend learning beyond formal activities. Given the widespread ownership of mobile devices among higher education students (Elliott, 2023; Essel & Atagana, 2024; Kobus et al., 2013), m-learning has become a practical and powerful strategy to enable more seamless learning experiences for undergraduate science learners.

Other Aspects of Learner Control. A notable finding from both phases of this study is that the undergraduate science students had limited control over what they learnt, for example, selecting their content or questions for investigation. A learning designer shared:

> Absolutely not complete freedom, they have to learn what they have to learn [laugh]. But how they can learn and their own time is possible. (Case 5_Learning designer)

This finding is reflected in research into school mathematics and science education (Kearney et al., 2020), but it was somewhat unexpected given the

espoused rhetoric of student autonomy associated with guided and open inquiry-based learning (Banchi & Bell, 2008). As suggested by Trask and Cowie (2022), incorporating some degree of flexibility for students to learn on their own terms can make science learning more accessible and accommodate diverse students' interests and motivations. The stringent structure of university science curricula and other requirements are likely to contribute to this limitation (Q. Liu et al., 2020). University science programs typically adhere to standardised learning outcomes, leading teachers and learning designers to prioritise delivery over student-driven content.

Insights from a teacher in Case 3b and a learning designer in Case 2 suggest that, within the context of mobile learning, students' agency develops over the course of their science degrees. In first-year science laboratory activities, technology-mediated learning tasks were strategically designed to standardise foundational skills and safety protocols. As the students advanced, they were progressively given more autonomy to make decisions on designing their experiments with the use mobile devices. This developmental approach supports Killpack et al.'s (2020) finding that gradual scaffolding allows students to develop and apply scientific skills more independently. This suggests that strategically granting more agency can help students to gain experience and confidence, empowering them to take greater ownership over what and how they learn through by mobile-mediated practices.

The findings of the current study also align with other researchers' arguments that more control of and responsibility for technology use should be shifted to learners and that teacher-led mobile learning activities are the least effective in supporting students' science learning (Shi & Kopcha, 2022; Zhai et al., 2019). It has been argued that such instructionist approaches tend to position learners as passive recipients of information who might not actively engage in or understand what they are doing (Schneider & Renner, 1980; Sung et al., 2016). This shifting to learners can be achieved through student-led activities, such as inquiry-based or project-based learning, where students take active roles in hands-on tasks mediated by mobile devices to cultivate a deeper understanding of science concepts (C. Liu et al., 2020).

Overall, while the participating educators often viewed student agency as limited by formal structures, the students frequently personalised their learning beyond formal instructions they were given. The educators facilitated m-learning activities

that supported more structured synchronous learning while offering greater flexibility for asynchronous and hybrid approaches. Nevertheless, gaps remain in the empowering of students to choose what to learn.

6.2.3 Collaborative Peer Conversations

Drawing on Crook's (1999) definitions, conversations "at" (or "around") devices refer to in-person dialogues facilitated by mobile devices, whereas conversations "through" devices refer to online discussions such as chats or messages. It is important to note that the conversation items in the Phases One and Two surveys mainly focused on online rather than face-to-face conversations. As reported in Section 4.2.3, the Phase One teachers rated the conversation subconstruct as relatively low (M = 2.71 out of 5, n = 132). Some teachers reported that their students shared questions and ideas during a hybrid class using Padlet. These findings support the notion of students interacting with each other without the need for being physically in the same room and having to take notes from verbally shared ideas. Chat functions such as Teams or Zoom also enabled students in lectures or tutorials to ask questions in real time. Although some teachers mentioned students' use of the QQ app or Facebook group chats to communicate or share files, they did not specifically mention whether these interactions were prescribed by teachers or initiated by students.

A prominent theme that emerged from Phase Two was the teachers' reliance on face-to-face conversations and institutional discussion forums, and the students' preference for informal, self-selected communication platforms. Teachers predominantly used in-person discussions around the devices to stimulate spontaneous dialogue during lectures or workshops via tools such as Mentimeter, Kahoot and EchoPoll. Despite deliberate efforts by learning designers to embed institutional discussion forums to encourage out-of-class interactions, these were often underutilised. Instead, students favoured less formal and private communication channels such as Facebook or WhatsApp group chats. This may be due to concerns about privacy and potential peer judgment, which can influence students' reluctance to actively participate in these subject discussion platforms.

Despite being praised for enhancing student learning and engagement (Alzahrani, 2017), institutional discussion forums, even when accessed through the LMS app on a smartphone, are often perceived as overly formal for the communication needs of everyday teaching and learning (Heinrich et al., 2022).

In this study, the students' limited engagement with teacher-initiated online conversations reflects broader trends reported in m-learning research in school education (Kearney et al., 2015), special education (Kearney et al., 2022) and teacher education (Burden & Kearney, 2017). This pattern can also be attributed to potential academic distraction caused by the use of smartphones and social media (Demirbilek & Talan, 2018; Dontre, 2021), as well as a lack of effective strategies for promoting meaningful networked learning in higher education (Yang et al., 2024). These findings suggest that while mobile devices are embedded in science learning activities, their full potential for networked communication remains underexploited. Although the participating educators may have recognised their students' informal use of social media, they tended to prioritise structured, in-person interactions over the informal digital platforms that the students were already actively using.

Prior research has emphasised that student-initiated use of mobile technologies can enrich student learning experiences (Matsumoto, 2021; Milheim et al., 2021; Shi & Kopcha, 2022; Zhai et al., 2019). Participants in this study also reported that student-led conversations mainly occurred outside class schedules, rather than in lecture or workshop activities, thus highlighting a disconnect between the informal, student-driven conversations and formal, teacher-led online conversations. The limited online conversations implemented by the teachers might have overlooked the benefits of connectivist learning (Siemens, 2004), where the use of mobile technologies can facilitate real-time peer connections and collaborative knowledge construction (Ansari & Khan, 2020; Norris & Soloway, 2011; Peluso, 2012).

Furthermore, the data from both phases revealed that the students rarely engaged with people or communities outside their academic networks. This signals a missed opportunity to broaden technology-enhanced learning by fostering connections beyond the traditional university boundaries. Limited engagement and interactions with wider professional communities can potentially restrict students' exposure to real-world applications of theoretical knowledge, for example when teachers' have limited experience or lack of institutional support to facilitate external collaborations (European University Association, 2023; Venturewell, 2018).

In a recent study, Höffken and Lazendic-Galloway (2024) found that students value collaboration with external partners when it is relevant to their learning and

career progression, thus enhancing their motivation and learning experience. With explicit instructions and guidance from teachers, undergraduate students, particularly in science education, can become more aware of the benefits associated with external facilitators. When combined with mobile learning strategies, these partnerships can foster more engaging and real-world learning scenarios that support undergraduate students' academic success and employability. For example, engaging students with science learning on TikTok or Instagram social media platforms or conducting online interviews with professional scientists can engage student learning with broader networks and resources (Lowell & Tagare, 2023).

Overall, while the educators or students in this study could initiate conversations mediated by mobile devices, structured networked conversations and external facilitators engagement remained underutilised. Addressing such gaps could potentially amplify the benefits of m-learning in undergraduate science education. From a sociocultural perspective, learner-initiated practice would be an example of tool-mediated learning in which students can negotiate their choices and engage actively in knowledge construction. Formal instructions that anticipate student-driven digital behaviours could enhance student learning experiences by aligning educators' practices more closely with those of students.

6.2.4 Authentic M-Learning

Authentic learning is highly valued in science education due to its capacity to "situate learning tasks in the context of future use" (Herrington et al., 2014, p. 1), thereby mirroring the practices and processes of professional scientists. From a sociocultural perspective, learning is powerful when situated within meaningful activities mediated by social interaction and the effective use of tools (Vygotsky, 1978). Findings from this study affirm that mobile practices facilitated authentic engagement like those enacted by scientists predominantly in field-based contexts, and to a lesser extent in lab-based learning. However, there were limited instances of mobile practices supporting authentic learning in lecture or workshop activities.

Mobile practices leveraging authentic learning experiences were most effectively implemented in fieldwork settings where students performed tasks similar to practitioners. In Phase One, teachers reported that their students used subject-specific apps to collect data in an earth science or geology subjects or to identify animal and bird species in natural settings, bridging theoretical knowledge and

professional practices. The Broken Hill field trip in Case 1a serves as a powerful example of how mobile learning can enable authentic, seamless learning across multiple settings. Students engaged in meaningful in situ tasks, such as choosing app settings, controlling workflows, leveraging multimodal note-taking and collaborative discussions. These findings are consistent with Kearney et al.'s (2020) discussion of mobile practices supporting authentic learning, and with other field-based studies showing how science students used mobile devices to learn about plants and animal species (Bone et al., 2022; Jeno et al., 2020; Jeno et al., 2022; Jeno et al., 2017; Thomas & Fellowes, 2017; Unger et al., 2021) and to explore subjects like hydrology and climatology through field placements (Schwarzenbach et al., 2022).

Although less prevalent, lab-based activities also supported authentic m-learning in this study. Undergraduate science student participants used realistic tools such as LabArchives, SPARKvue or Labscope apps to collect and record the experiment results during lab activities. They also used simulation apps to measure physics parameters, simulate electronic circuits, and visualise molecular structures. These mobile practices mirrored real-world professional tasks and demonstrated the feasibility of implementing technology-mediated authentic learning experiences within the boundaries of the university curricula.

However, promoting authentic learning across all science disciplines and activity types remains challenging, as each discipline carries its distinct teaching and learning culture (Becher & Trowler, 2001). These differences stem from the nature of disciplinary practices. For example, a chemistry laboratory activity typically involves hands-on experiments in university labs, while a physics lecture activity often centres around theoretical knowledge and examples in lecture halls. As reported in Section 5.1.5, science educators often viewed their university laboratories as somewhat mirroring professional lab settings, due to their structured arrangement of experiment materials and the presence of scientific equipment such as microscopes or chemical reagents. However, many undergraduate students, who often lacked laboratory work experience, struggled to see the relevance of these lab activities in professional contexts.

University science laboratories typically represent simplified versions of professional environments that are designed to accommodate large student cohorts, which adds another layer of complexity to educators' efforts to foster authentic tasks and settings, even with the use of mobile devices. This could

hinder students’ readiness for professional roles and raise significant concerns about the effectiveness of traditional settings, such as lecture-based activities, in cultivating authentic learning, as discussed in past science education studies (Gallagher, 2018; Marcourt et al., 2022).

Mobile practices supporting authentic learning is important to ensure that undergraduate science education remains relevant and situated in professional disciplinary contexts to prepare students for the future workforce. However, the observed divergence across disciplinary and activity types in this study should prompt critical reflection on whether authentic learning can ever truly be achieved across all science disciplines, irrespective of the use of mobile devices. The data suggest that even with the presence of mobile tools, authentic inquiry in university learning contexts such as lecture halls or lab spaces may remain limited, unless these activities are explicitly redesigned to move beyond traditional, didactic formats. Embracing more authentic learning contexts could positively influence students’ learning experiences and to teachers’ perceptions of improved learning (Burke et al., 2025), thus bridging the gap between the theory and real-world applications.

Further complicating the authenticity of the task was the variability in the applicability and relevance of professional tools across the different undergraduate science disciplines. As mentioned in Section 5.1.4, while the use of the Labscope app in Case 1b supported microscopy learning and stimulated in-class discussion, it is not necessarily relevant to all geoscience specialisations. As geologists often specialise in distinct areas within the broader field of geology, the mobile practices in this case were more relevant for those who work with microscopes and describe mineral microstructures. However, they may be less applicable to other types of geologists, depending on the specific tasks students are likely to do in their future careers. This highlights the challenges posed by diverse disciplinary requirements within science education. Similarly, although the educators in Case 2 mentioned the LabArchives app was used by professional science researchers, the student cohorts rated the task authenticity items significantly lower, with limited explanation.

This discrepancy suggests some students may struggle to perceive the professional relevance of these discipline-specific mobile tools, thus highlighting the importance of teachers’ adequate conceptual explanations of professional usage to enhance students’ understanding of the relevance of these tools beyond

academic contexts (Fischer et al., 2022). Addressing this gap is essential to raising students' awareness of the relevance of the science mobile practices and their real-world applications, ultimately improving their motivation and readiness for future careers. With thoughtful planning and design, mobile practices supporting authentic learning could be achieved in less formal settings. The significance of authentic learning mediated by mobile devices is supported by extensive literature, for example in teacher education (Kearney & Maher, 2013) and school education (Kearney et al., 2015; Yates et al., 2021). The current study has highlighted the importance of incorporating multiple stakeholders' perspectives, especially science students, in m-learning research. Indeed, students need to be included in the development process of creating more authentic learning experiences so that they align with their own learning needs (Chiu et al., 2018).

Other Aspects of Mobile Practices Supporting Authentic Learning: Although emerging technologies, such as context-aware, AR and VR, can enhance student motivation and authenticity by simulating realistic environments (Marks & Thomas, 2022; Wang et al., 2020; Wang et al., 2015), their implementation in this study was limited, with only one teacher mentioning the use of VR in Phase One. Teachers predominantly favoured the use of science-specific or generic educational apps, possibly due to technological constraints, costs and pedagogical integration limitations (Al-Ansi et al., 2023; Lin et al., 2024; Matovu et al., 2023). This highlights a common occurrence in undergraduate science education: despite the potential of educational technologies, pedagogical feasibility and practical constraints shape educators' decisions. This could be explained by the widespread availability of education apps designed with underlying assumptions of "rote learning" through drill and practice (Murray & Olcese, 2011), inadvertently reinforcing traditional learning. The lack of knowledge about the range of apps available that could meet teachers' mobile pedagogical needs could also be a barrier to adopting authentic science practices (Ertmer et al., 2012; Zydney & Warner, 2016).

The existing literature has demonstrated promising ways to connect students with wider communities mediated by mobile devices (see examples in Akom et al., 2016; Barak & Ziv, 2013). Such initiatives support sociocultural views of learning as a community of practices, where collaborative and authentic learning can provide a stronger sense of connection and identity to learners, shifting learning across on-campus, online and real-world settings (Cochrane et al., 2022).

Authentic m-learning ideally involves students in community projects, cultivating broader educational and social relevance (Burden & Kearney, 2016). The limited evidence of this happening in the current study suggests university educators could further exploit the full potential of mobile devices by extending teaching beyond disciplinary tasks to include real-world activities that engage with external facilitators (e.g., professional scientists, family members) and benefit society. Reluctance to do this may be attributed to a combination of teachers' pedagogical beliefs and attitudes, where can be resistance to change can hinder the expansion of stakeholders beyond university networks (Ertmer, 2005; Ertmer et al., 2012; Romero-Rodriguez et al., 2020).

In summary, while mobile practices supporting authentic learning experiences have been successfully implemented in some field-based and lab-based contexts, their wider adoption across science disciplines and learning activities remains constrained by disciplinary norms, as well as logistical and pedagogical barriers. To effectively prepare undergraduate students for professional scientific careers, more mobile practices supporting authentic learning should be considered to ensure alignment with the professional practices and expectations of multiple stakeholders.

6.2.5 Customisation Challenges

The aim of personalisation is to enable learners' cultivation of their learning by better connecting it to their interests and prior experiences (Kucirkova et al., 2021). According to the iPAC framework (Kearney et al., 2012), customisation is a foundational element of personalisation that is intended to empower students by tailoring their individual learning needs. However, in this study there was a notable limitation in the utilisation of customisation practices within undergraduate science learning activities; the envisioned flexibility associated with m-learning – "just in time, just enough, just for me" – was almost unrecognised in the nominated learning activities. While the use of technologies has the potential to enhance personalised learning experiences in higher education (Ambele et al., 2022), the teachers' low ratings in both phases of the study and the lack of relevant qualitative data from all participants demonstrate that the students primarily engaged in passive forms of customised learning. Students typically received generalised information rather than actively configuring app settings or receiving tailored guidance based on their usage history. Such limited customisation potentially restricts students from enjoying a fully tailored educational experience.

Despite higher customisation ratings from students in Cases 3a, 3b and 5, the absence of qualitative evidence to substantiate these ratings suggests limited customisation opportunities. An exception was found in the Broken Hill field trip case, where all participants highly valued the use of the StraboSpot app to tailor workflows by using the default settings or choosing their own options (see Section 5.1.7). This case demonstrates that effective customisation can positively enhance learning experiences, particularly when tailored app settings are essential for effective data collection in field-based learning. Even so, the results of this study emphasise the urgent need for more apps explicitly customised for undergraduate science students.

Another factor limiting customisation in this study was the educators' reliance on structured and uniform mobile practices. In many instances, educators acknowledged their activities were not tailored to individual student needs, often employing the same instructional strategies and materials across the entire cohort. While these one-size-fits-all strategies can serve the purposes of consistency and scalability for large university cohorts (and have done so for centuries), they can hinder opportunities for creating individualised learning experiences. They can also create a tension between institutional efficiency and pedagogical aspirations for customisation if educators lack the knowledge to move beyond standardised approaches. Hence, there is a need for targeted professional development that supports science teachers with the tools and encouragement to tailor their subjects in ways that align more with their abilities and teaching beliefs (Holdsworth & Maynes, 2017; Wallace & Priestley, 2011).

The constrained customisation found in this study mirrors broader m-learning research in other educational contexts, such as teacher education (Burden & Kearney, 2017) and school education (Kearney et al., 2015), where factors such as device ownership, privacy concerns and online safety further complicate the implementation of personalised learning. The gap between the idealised vision of customisation mobile practices and its actual enactment could be attributed to student motivation, ease of use, and curriculum integration (Chopvitayakun et al., 2023), all of which are critical for the successful implementation of mobile practices supporting personalised learning. In addition, Li and Wong (2021) reported that effective personalisation strategies need to recognise learners' characteristics, including their abilities, interests and specific learning needs. Effective tailored mobile learning experiences might be more readily achievable

when systematically embedded within lesson designs, rather than being seen as supplementary to the learning process.

Overall, the investigation of distinctive mobile practices in undergraduate science education in this study has revealed an underutilisation of customisation typically associated with m-learning. As a result, the limited opportunities to personalise learning experiences or tailor activities to individual student needs restricted their abilities to fully benefit from the mobile technologies.

6.3 Dominance of Traditional Settings

This study has highlighted a continued dominance of formal, institutional settings (such as lectures, tutorials and laboratories) in undergraduate science learning activities (60% in Phase One and 88% in Phase Two). Students' homes also emerged as common additional settings, particularly for asynchronous and hybrid learning. Despite the ubiquity of mobile device usage on campus and at home, students' opportunities to harness the use of more contextualised settings remained underexploited. This observation is consistent with prior research that found widespread use of traditional settings across many educational contexts and levels in school, higher education and teacher education (Bano et al., 2018; Burke et al., 2022; Crompton & Burke, 2018; Kearney et al., 2020; Kearney & Maher, 2013; Ly & Kearney, 2024; Tlili et al., 2023). Often accompanied by rigid timetables and logistics constraints, such settings can prioritise institutional control over learners' choices of where and when to learn.

As noted in Section 6.2.4, of possible concern to higher education curriculum designers are teachers' and students' inconsistent perceptions of their science activities being situated in authentic settings. While the use of mobile devices can potentially transcend spatial and temporal barriers (Kearney et al., 2012) and seamlessly bridge formal and informal contexts (Burden & Kearney, 2016; Kearney et al., 2020; Looi et al., 2019; Schuck et al., 2017; Sharples, 2015; Toh et al., 2013; Wong et al., 2021), in this study the ongoing realities of traditional campus-based settings remained largely unchanged. This finding accentuates a broader tension between the affordances of mobile devices and their implementation in practice that can be explained by the tendency of university science educators to favour conventional practices on campus (Stains et al., 2018) and their need to tie particular activities to particular times or places (Traxler 2009).

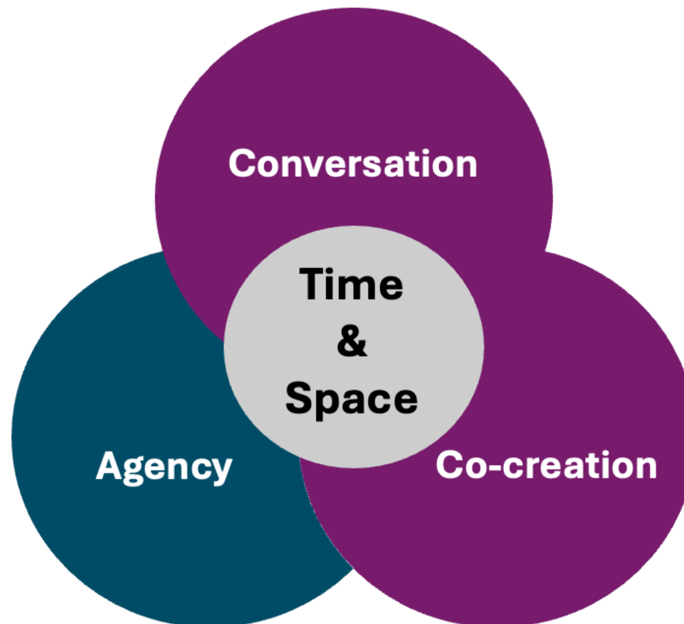
From a sociocultural standpoint, knowledge is constructed within cultural and physical contexts, and the use of mobile devices can enable this by bridging learning across physical and virtual settings. The continued reliance on traditional lecture settings, where students are passive recipients of information, can negatively impact learning outcomes (Cantillon, 2010; Huggett & Jeffries, 2021). Supported by Cameron's (2017) findings on low student engagement in lectures, this study has highlighted the need to rethink the role of lecture-based activities in favour of more asynchronous approaches. Lecture-based activities, particularly those that do not meaningfully utilise the affordances of mobile devices, could be phased out and replaced by interactive and asynchronous learning activities that enhance students' experiences and control outside of class time, along with more opportunities to collaborate during synchronous activities (Cochrane et al., 2022).

6.4 Concurrent Use of Mobile Practices (A Critique of the iPAC Framework)

As detailed in Section 5.1, the data revealed that m-learning in undergraduate science education often involves an interplay between the *agency*, *conversation* and *co-creation* subconstructs, rather than these practices occurring in isolation. From a sociocultural perspective (Vygotsky, 1978), this interplay reinforces the vital role of social interactions and tool mediation in supporting learning. Figure 6.2 illustrates the intertwining of these practices, with the central circle representing the influence of time and space in shaping how these practices are enacted.

Figure 6.2

Overlap of Agency, Conversation and Co-creation Practices Featured in This Study



Note. *Blue colour from the personalisation construct was used to represent the agency subconstruct. Purple colour from the collaboration construct was used to represent the conversation and co-creation subconstructs.*

Students demonstrated various approaches to personalised collaborative learning experiences, often choosing between face-to-face and social media platforms such as Messenger, Instagram or WhatsApp to share data, complete learning activities, and engage in peer conversations. Mobile tools were often focal points of collaboration and verbal interactions where students were "making rich networking connections to other people and resources mediated by a mobile device" (as cited in Kearney et al., 2012, p. 10). Such behaviour has also been recorded in prior research on the link of student agency in digital contexts within higher education (Aagaard & Lund, 2020; Stenalt, 2021). It also reflects broader collaborative trends in science learning such as the increasing use of popular social media apps, such as Instagram and TikTok (Jimola, 2023). These practices demonstrate how m-learning environments can foster both autonomy and social connectivity, moving learning beyond the institutional platforms and rigid schedules. As such, university educators should recognise the importance of

integrating student-preferred tools into formal curricula to enhance both agency and collaboration.

This study also found that the degrees of co-creation varied across groups and were shaped by factors such as group dynamics, digital literacy and willingness to share. As noted by participants in Case 6, some students actively contributed to the collaborative tasks, while others remained passive consumers of content. In some groups, students shared data via the collaborative space set by the learning designer in OneNote, whereas others preferred direct verbal sharing using information on their devices. These findings highlight how effective mobile practices must account for the social and interpersonal dynamics that influence the collaborative learning processes.

Previous research has identified diverse patterns of Internet and mobile device usage among university students, reflecting a wide range of user profiles and the importance of students being able to choose their most suitable modes of collaboration (Brandtzæg, 2010; Kalmus et al., 2011). This autonomy can both personalise students' learning experiences and develop their competencies in higher education (Zhampeissova et al., 2020). To this end, Handal et al. (2016) proposed a digital capability framework for teachers wanting to integrate digital citizenship into their teaching by equipping students with the attitudes, knowledge and academic skills needed to use technologies effectively. Moreover, Hwang et al. (2018) found that communication and collaboration to be important mediators between students' preferences for using technologies and their development of higher-order thinking skills, such as problem-solving, critical thinking and creativity. By encouraging more group discussion and collaboration in mobile learning activities, students are more likely to achieve higher levels of cognition (Crompton et al., 2019).

Importantly, the concurrent use of agency, conversation and co-creation identified in this study also highlights a limitation in the iPAC framework. While the three iPAC constructs – personalisation, authenticity and collaboration – and their associated subconstructs are valuable dimensions of mobile learning, they are often presented as separate from each other, with limited emphasis on their interaction in practice. This can lead to a compartmentalised view, where mobile learning is evaluated through isolated constructs/subconstructs rather than as a dynamic integrated system. In reality, as demonstrated in this study, teaching and learning are inherently messy, and mobile practices frequently overlap and "play

out" concurrently. The current version of the iPAC framework does not explicitly account for this interconnectedness; hence it may result in misinterpretations or narrow applications. Further discussion on these implications and directions for future research is provided at the end of this chapter.

6.5 Mobile Pedagogical Innovation in Undergraduate Science Education

As mentioned in Section 2.5, this study adopted the definition of "innovative" mobile practices as approaches that harness the unique affordances of mobile technologies to achieve educational outcomes that would otherwise be unattainable without such devices (Law et al., 2005) and to expand learning opportunities beyond traditional classroom boundaries (Schuck et al., 2017). Tlili et al. (2024) found that interactive hands-on simulations and experiments in STEM education, particularly those focusing on problem-solving and real-world applications, tended to help students understand complex scientific topics and focus more on real-world applications. Burke et al. (2025) also discovered that teachers are more likely to recognise improvements in student learning experiences when they implement innovative mobile practices in their teaching. Identifying and integrating innovative mobile practices are therefore essential for teachers who aim to improve student learning.

Given that innovation is defined as introducing new and effective practices, the inclusion of multiple perspectives is essential for stakeholders' understanding of what constitutes innovative mobile practices in undergraduate science education. Alongside students, collaborative efforts from teachers, learning designers, educational technology developers and researchers are therefore essential for the design and development of new mobile initiatives (Criollo-C et al., 2021; Jie & Sunze, 2023; Yeh et al., 2021). This makes the present study a valuable contribution to the broader discourse in the field of mobile pedagogical innovation.

The following sub-sections critical analyse how pedagogical innovation in educators' mobile learning activities was perceived by university science teachers, learning designers and students. It is guided by Burden, Kearney, Schuck, & Hall's (2019) and Law et al.'s (2005) criteria for innovative digital practices.

6.5.1 Prevalence of Limited Innovation

Although mobile pedagogies have long been anticipated to transform education (Kearney et al., 2012; Lindsay, 2016; McHaney, 2023; Norris & Soloway, 2011; Norris & Soloway, 2015; Pegrum et al., 2018), this study revealed only a partial realisation of that vision within undergraduate science education. Its findings suggested that educators' mobile practices have not fundamentally shifted existing paradigms. Rather, synchronous activities are often constrained by campus settings, the teachers' roles and their relationships with students.

While mobile devices were already integrated into the formal learning activities examined, the dominant physical settings, such as lecture halls, tutorials or and laboratory classrooms, remained largely unchanged. Teachers continued to play directive roles, particularly in lectures and workshops, where they primarily disseminated information. In laboratory settings, teachers typically provided brief introductory explanations before supporting students to perform relevant experiments based on the lab manuals. These facilitation roles reflected long-standing practices in conventional university science laboratories, and they were not altered by the use of mobile technologies. As such, mobile practices in this study primarily fall under the lower end of sustaining innovation and far from any form of radical, disruptive innovation (Christensen et al., 2008; Cranmer & Lewin, 2017; Fenwick, 2016). This finding aligns more closely with the notion of incremental innovation, an approach that is generally more achievable for educators. Table 6.1 presents a combined summary of teachers' and students' ratings of the innovation items across both phases of this study.

Table 6.1

Teachers and Students' Ratings for Innovation Survey Items (from Both Study Phases)

Innovation Measurement Items	Phase One Teachers (n=132)	Phase Two	
		Teaches (n=10)	Students (n=126)
Average	3.31	3.45	3.06
1. Use of a digital device fundamentally changed the way that learning occurs	3.57	3.88	3.38
2. The context of learning was radically different	3.43	3.00	3.10
3. The range of stakeholders facilitating learning was greatly expanded	2.77	2.69	3.12
4. Learners were granted significantly more agency than would normally be the case	3.39	3.88	3.07
5. Learners' overall experience was fundamentally different from what they would normally experience in science subject	3.39	3.81	2.63

Note. Participants rated their agreement level for the innovation items using a 5-point Likert scale (1= Strongly Disagree to 5= Strongly Agree).

Despite generally high mean scores for the innovation items, there was limited qualitative evidence to support the teachers' and students' ratings in many cases. For example, in Case 2, mobile practices had not revolutionised traditional science laboratory tasks but simply replaced traditional practice with digital equivalents.

> It's just a worksheet that's online. (Case 2_Teacher 1)

> It was still rather a standard scientific procedure that we were following. So, … nothing crazy. (Case 2_Student 1)

However, a student in a technology-enhanced microscope lab activity pointed out that standardisation does not necessarily equate to poor practice:

> I'd say low [innovation] because that kind of activity is just like standard. To be honest, I don't think that's a bad thing, right? You don't need to reinvent the wheel every time. (Case 1b_Student 2)

An exception was noted in Case 1a, where both quantitative and qualitative data pointed to higher levels of pedagogical innovation. While there were slight

variations in students' views regarding their choices, the teacher assigned a high mean rating to the innovation items (M = 4.42 out of 5). This rating was supported by several features of mobile pedagogical innovation identified in interviews and focus groups (see Section 5.2.1), and which aligned with the researcher's observation. Unlike many of the campus-based cases, students in Case 1a could choose how they undertook discipline-specific tasks in realistic semi-formal and informal settings. They utilised the in-built features of the StraboSpot app, including photos and videos, measurements, annotations and note-taking, thus mirroring the work of professional geologists. Despite the context and the teacher-student roles remaining unchanged, participants often described their experiences with unconventional tools as transformative, using words such as "game changing", "paradigm shifting" and "powerful".

These experiences reflect Vygotsky's (1978) sociocultural theory view of learning, where learners engage in meaningful mobile-mediated tasks to construct knowledge and personalise their learning paths. They also support Lowell and Tagare's (2023) emphasis on the importance of authentic m-learning tasks for fostering inquiry and allowing students to work like experts. Similarly, Burden, Kearney, Schuck and Burke (2019) reinforced student agency and the use of "real-world tools" to model "real-world processes" as fundamental to mobile pedagogical innovation. Teachers are more likely to perceive higher levels of pedagogical innovation when their mobile practices mirror scientific practices (Burke et al., 2025).

The findings point to pedagogical innovation as a relative rather than absolute concept. It should not be evaluated based on the general assumptions that low innovation is bad/negative and high innovation is good/positive. In fact, radical innovation may be seen as overly disruptive and thus challenging to implement across different education levels and contexts. This study affirmed that perceptions of innovation vary across participants and contexts and should therefore be evaluated using evidence-based criteria, such as those proposed by Law et al. (2005).

6.5.2 Discrepancies Between Teachers' and Students' Views

As can be seen from Table 6.1, the teachers consistently rated most innovation items higher than their students did, except for item 3, which measured the involvement of stakeholders in the learning. This discrepancy suggests they might have overestimated the innovative nature of their mobile practices. There

are three possible explanations for this. First, interpretations of pedagogical innovation are shaped by individual perceptions and contextual factors (Caldwell, 2018; Cranmer & Lewin, 2017). The teachers might have assumed the adoption of technology equates to pedagogical innovation, particularly when such practices appear to increase student engagement or collaboration (Winterhalder, 2017). However, simply “digitising” non-mobile activities alone does not automatically translate them into pedagogical innovation, especially when the learning settings and roles of stakeholders remain unchanged.

Second, during design of the learning activities the teachers might have viewed their approaches as innovative due to observable improvements in learning outcomes through mobile apps (Ateş & Garzón, 2022) and overlooked students’ perspectives. Buabeng-Andoh (2021) have supported the inclusion of student voices in higher education mobile learning initiatives and pedagogical design processes. Third, the teachers’ limited access to professional development in contemporary mobile pedagogies might explain their reliance on traditional approaches (Almofadi, 2020).

6.5.3 Feasibility and Barriers to Innovation

Incremental innovation refers to approaches that streamline existing tasks without fundamentally changing them, and scholars have argued that it is the most feasible form of innovation for educators to adopt (Cranmer & Lewin, 2017; Kampylis et al., 2013). In some ways, the silence on radical innovation in this study was unsurprising, given that incremental innovation is more likely to be achieved (Burden, Kearney, Schuck, & Hall, 2019; Law, 2003; Zhao et al., 2002). Indeed, Christensen et al. (2013) argued that “sustaining innovation”, the adaptation of existing approaches without fundamentally changing them, is vital for a healthy and robust education sector’s delivery of better services. It is also important to recognise that a practice that is feasible in one activity or at a particular university may not be applicable in another. This highlights how the context-dependent nature of pedagogical innovation is shaped by the perceptions of those involved.

A key strength of this study lies in its inclusion of the diverse perspectives of teachers, students, and learning designers. For example, while the use in Case 6 of Surface Pro to access professional microbiology resources online was perceived as a shift from manual information retrieval, the teacher perceived it as a way to streamline the large student cohort:

> The use of technology is more of a convenience than a really adaptive and disrupt or disruptive innovation to the subject itself. It just allows for the subjects to be more streamlined. (Case 6_Teacher)

The cultural, social, political and technological challenges (Sharples, 2013; Traxler, 2016) are more pronounced in undergraduate education within the science disciplines. Lack of innovation may stem from institutional barriers such as bureaucracy, politics, academics' research prioritisation, culture, and discipline, which often hinder technology adoption (Q. Liu et al., 2020). Other factors can include time constraints (Chen, 2023), technological challenges (Frank & Kapila, 2017) and teachers' knowledge of mobile practices (Ikwuanusi et al., 2017). In fact, many university science teachers commonly juggle multiple responsibilities as teachers and researchers alongside administrative, management and community service duties. Operating within a competitive university system that predominantly awards research achievements (Gehrtz et al., 2022; Parker, 2008; Stensaker et al., 2017) and tendency to resist substantial change in the teaching and learning process (Anderson, 2020), can further limit their ability and willingness to engage with mobile pedagogical change and prioritise research over teaching.

Criollo-C et al. (2021) noted that while curriculum and learning objectives were the most frequently analysed dimensions in studies on innovative mobile practices in higher education, few demonstrated innovation. Similarly, researchers in school education (Burden, Kearney, Schuck, & Hall, 2019) and distance education (Zhang & Yu, 2022) have shown that mobile technologies often replicate existing non-digital practices. Hence, when coupled with rigid university timetables and locations, introducing and sustaining disruptive innovation may prove difficult to accomplish (Cranmer & Lewin, 2017). Thus, designing mobile practices that are feasible, is more probable and practical for the current undergraduate science educational system.

This tension was evident in Phase Two of this study, where five out of the eight coordinators of the activities nominated themselves to be interviewed as learning designers. This finding highlights a common pattern in Australian science faculties, where subject coordinators are often responsible for curriculum design, coordination and teaching. Yet they may not receive sufficient support from specialist learning designers who possess both pedagogical expertise and disciplinary knowledge in science. In addition, although university science

teachers are typically subject matter experts, many often lack formal pedagogical training (Brownell & Tanner, 2012; Gehrtz et al., 2022; Schussler et al., 2015). Scholars have also highlighted the influence of teacher beliefs in shaping technology integration (Ertmer et al., 2012; Kim et al., 2013).

Overcoming these challenges should enable educators to design and implement more innovative mobile learning tasks that resonate more with students' experiences, extend learning outside of bounded classroom spaces and potentially enhance student learning (Burke et al., 2025; Tlili et al., 2024). If science educators aspire to "move beyond" existing practices, radical curriculum design is needed, including more project-based or community-based activities with external facilitators and shifting more control to students. Radical transformation requires pedagogical change alongside technological change (Sharples, 2019). These strategies align with the vision of innovative digital practices which challenge the status quo, as discussed by Law et al. (2005).

Ultimately, achieving mobile pedagogical innovation in undergraduate science education requires addressing institutional barriers, fostering pedagogical expertise among educators to empower greater student autonomy. In turn, teachers need to release some of their control which may be a difficult thing to do! Genuine pedagogical innovation will require more than just the substitution of mobile technologies into conventional tasks; it will demand major reconfigurations of learning contexts and redefinitions of the roles of stakeholders.

6.5.4 The Underutilised Role of External Facilitators

Beyond internal factors, external facilitation is another underexplored area of pedagogical innovation identified in this study. The digital pedagogical innovation criteria proposed by Burden, Kearney, Schuck, & Hall's (2019) and Law et al.'s (2005) include the expansion of stakeholders in the learning. As can be seen in Table 6.1, teachers from both phases rated lowest the innovation item "The range of stakeholders facilitating learning was greatly expanded". Despite the relatively high mean score from students, these perceptions were not supported by qualitative data from any of the interviews or focus groups. In the observed sessions, the presence of two or more lab demonstrators may explain the slightly high students' ratings in some of the lab cases. However, these individuals were either subject coordinators, teachers or lab demonstrators who were internal to the university, and thus not representative of external personnel. It is possible that the students perceived an expanded stakeholder presence or external

support that was not captured in this study. This highlights how opportunities for educators to engage broader external participants in mobile-mediated learning remain largely untapped, suggesting a valuable area for further research.

Disruptive mobile scenarios involve partnerships with broader social networks, such as family participation in inquiry projects (Toh et al., 2017), public engagement through data collection (Akom et al., 2016), and the dissemination of student work on social media platforms (Barak & Ziv, 2013). Such networks reflect a deeper alignment with sociocultural theory, which posits that participation in wider communities of scientific practice can enrich authentic and collaborative learning opportunities (Cochrane et al., 2022). If educators aspire to pursue more pedagogical innovation and broaden the involvement of external participants, they need to leverage the potential of mobile technologies by involving more real-world connections with professionals, communities and family members. This can potentially enhance community-wide perceptions of task authenticity, collaboration, and mobile pedagogical innovation.

6.5.5 Developing Innovative University Science Teachers

Davis (2019) mentioned that teachers are the "keystone" within the structure of the educational environment (p. 1), influencing both the pedagogical direction and technological integration. Teachers and learning designers (many of whom were also subject coordinator/teachers in Phase Two of this study) play critical roles in shaping the trajectory of digital pedagogical innovation in undergraduate science education. As mentioned in Section 4.5, teachers with more experience in digital practices reported innovation to be statistically significantly higher in their nominated m-learning activities than did inexperienced or occasional users. These teachers also perceived a higher adoption of mobile practices supporting student agency, customisation and authentic context. While experience alone does not guarantee innovation, such findings highlight the importance of digital pedagogical competence in shaping innovative mobile practices. The TPACK framework (Koehler & Mishra, 2009) offers a valuable lens to interpret this relationship. Within this framework, the Technological (T) component reflects digital competence, while Technological, Pedagogical and Content (TPC) represent broader digital pedagogical competence. In this study, teachers with more digital skills appeared to be more confident and familiar with integrating mobile technologies in transformative ways. These findings reinforce the need for ongoing professional development that explicitly combines technological and

pedagogical strategies, enabling university educators to be more confident in implementing new and effective mobile practices.

Burke et al. (2025) found that teachers who embedded agency, customisation and authentic context learning into their work were more likely to perceive their mobile practices as innovative. Cameron (2017) also argued that general knowledge of teaching practices is insufficient for ensuring high-quality teaching within specific university disciplines; and, as already mentioned elsewhere in this chapter, subject-matter expertise, while essential, is similarly insufficient. As identified by Fernández-Batanero et al. (2021), university teachers typically demonstrate a low level of digital competence.

It is imperative that university science teachers engage in ongoing professional development of their technological and pedagogical knowledge. Otherwise, even experienced teachers may struggle to implement any new and effective mobile practices. This issue is even more pronounced for university sessional teachers, who are often employed on a casual basis and may lack consistent access to professional development opportunities. There is also a danger that they may be inadvertently excluded from any mobile pedagogical innovation efforts and thus unintentionally continue to rely on familiar, didactic approaches shaped by their previous learning experiences. Technological and pedagogical professional development should not only build digital skills, but it should also be underpinned by robust sociocultural mobile frameworks such as the iPAC framework (Kearney et al., 2012) and the digital pedagogical innovation criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005).

Furthermore, as suggested by Loughlin et al. (2023), the presence of “change champions”, typically in senior leadership roles such as heads or deans of the science faculties, is essential for driving curriculum re-design and planning in STEM higher education. Without such backing, educators may struggle to move beyond the conventional approaches. In addition, addressing issues like workload, equitable access and policy development should contribute to the continuing uptake of mobile learning in tertiary education (Handal et al., 2013).

Importantly, mobile literacy, which is one of Pegrum et al.’s (2018) foci in their framework of digital literacies, is essential for educators and students to harness mobile devices across multiple contexts. Providing flexible training in mobile pedagogies through mobile devices will enable teachers to learn at times and in spaces convenient to their busy schedules (Miao et al., 2017; Wishart, 2018).

This study has highlighted the potential to enhance innovative mobile practices by leveraging the enthusiasm and expertise of digitally competent educators, particularly in faculties of science. Providing these educators with opportunities to showcase their practices in faculty seminars, mentorship programs or professional development sessions could cultivate a collaborative community of practice and promote the diffusion of mobile innovation across disciplines (Gómez & Suárez, 2021). These efforts would also align with the idea of developing 21st-century skills, such as critical thinking, problem-solving, communication and collaboration (P21, 2019), and support the broader education goals outlined in United Nations's Sustainable Development Agenda (Alonso-García et al., 2019).

6.6 Practical Implications

This section provides several practical implications for internal stakeholders, including science faculty teachers, learning designers, students and faculty leaders, as well as external stakeholders such as professional accrediting bodies and industry advisory boards. It highlights targeted action across three key areas.

6.6.1 Professional Development for Science Educators

The findings reinforce the urgent need for targeted professional development to build confidence among university science teachers in adopting distinctive science mobile practices. Hands-on, practical workshops that focus on mobile pedagogical strategies to support customised, authentic and networked learning can be particularly useful for casual and sessional teaching staff who often have limited institutional training and support. These opportunities should be ongoing and widely available across all science disciplines to ensure both current and new staff acquire the necessary knowledge and skills to effectively facilitate mobile-mediated curricula initiatives. Experienced educators can potentially play vital roles in promoting and disseminating innovative mobile practices, both within and across science faculties or institutions.

The adoption of mobile practices supporting customisation can be achieved by encouraging educational app developers to prioritise creating user-friendly, customised features that accommodate diverse undergraduate science learners' needs. To promote more authentic learning experiences, educators are encouraged to expand formal science curriculums to less formal, real-world settings, such as the home, community-based projects, and professional workplaces. To fully harness the affordances of m-learning for networked or

connectivist learning (Siemens, 2004), educators might consider extending online learning environments beyond formal learning management systems and incorporating social media and online communities. These tools can also foster greater student agency and promote interdisciplinary and industry collaboration.

Furthermore, institutions need to allocate adequate resources and funding to address these gaps. The success of implementing mobile technologies in universities is significantly influenced by the institutional support and the organisational culture. Institutions that provide adequate resources and professional development opportunities can empower teachers and learning designers to embrace new mobile practices more effectively and in ways that suit their teaching beliefs.

6.6.2 Promoting Student Agency

Student agency emerged as crucial for fully utilising the benefits of m-learning. Educators might benefit from recognising diverse cultural backgrounds among their undergraduate science students, as some students may be more accustomed to teacher-directed learning and therefore hesitate to take initiatives without explicit instructions. To assist students to be clear about the scope of their autonomy and feel more confident in exercising their agency, educators could provide clear verbal and written guidelines at the start of the semester, explicitly reassuring students that making independent choices regarding mobile tools, apps or ways to learn is acceptable and even expected. Similarly, the provision of alternative assessment strategies mediated by mobile devices, for instance, digital portfolios in inquiry-based or project-based learning contexts, would allow students to demonstrate and apply their knowledge in more authentic, self-regulated, and participative ways.

6.6.3 Strengthen Stakeholder Collaboration

Effective m-learning implementation will necessitate strategic partnerships among multiple stakeholders. Learning designers, who often act as subject coordinators in science faculties, can play vital roles in aligning educators' mobile practices with the expectations of students for learning through conversation and collaboration. Aligning educational aims and the needs of students and the broader society could be achievable through active collaboration among teachers, learning designers, students, and faculty leaders, as well as external facilitators such as professional accrediting bodies and industry advisory boards.

In addition, higher education science faculty leaders such as the faculty board, the academic board, and undergraduate science course coordinators might wish to proactively involve students in the development and implementation of m-learning policies. This would ensure stronger alignment between educational policies and actual student practices, and thus foster more relevant and future-focused science learning opportunities. Practical resources to support this alignment include the iPAC mobile pedagogy framework (www.ipacmobilepedagogy.com), which offers guidance on distinctive mobile practices and the Learning Designer tool (www.learningdesigner.org), which offers valuable resources for adapting and sharing effective learning designs (Laurillard et al., 2018). Furthermore, educators who are seeking innovative digital pedagogical strategies can explore new practical pedagogies from Sharples's (2019) and the annual *Innovating Pedagogy* report by the Open University, which offers regular insights into emerging educational trends.

Faculty leaders might also enhance authentic and networked learning experiences by actively collaborating with professional accrediting bodies and industry advisory boards through regular advisory meetings or collaborative projects. Practical steps could include expanding the number of off-campus and context-specific learning locations, and involving external facilitators from the industry, community, other disciplines or even from students' families. This would ensure pedagogies support learning that remains relevant to industry standards, fosters practical knowledge exchange, and promotes cross-disciplinary connections. This approach can potentially strengthen student preparedness for their profession and enhance their awareness of societal needs.

6.7 Limitations and Future Research Directions

This section acknowledges several limitations in methodology, sampling and generalisability of the study, while also presenting valuable directions for future research that emerged from these limitations to extend this work.

6.7.1 Methodological Limitations

This study focused specifically on distinctive mobile practices, as defined by the iPAC mobile framework, rather than attempting to capture all mobile approaches in undergraduate science education or address technical issues related to mobile device affordances. This purposeful focus allowed for a deeper exploration of the capacity of mobile tools to support personalisation, collaboration, and authentic

science learning tasks, as perceived by university science teachers, learning designers, and students.

The scope of the study was shaped by the activities nominated by the participating teachers. While it is likely that these teachers selected activities they felt most confident with and that best represented their practices, they potentially overlooked other equally valuable m-learning activities. Nevertheless, this focused design was necessary to maintain rigour and produce context-rich insights aligned with the study’s aims.

The research was also purposefully scoped to undergraduate science education and did not extend to other educational levels, such as school-based, vocational, diploma, or postgraduate programs. This decision was informed by the research gaps identified in the literature review and aimed to ensure focused, discipline-specific insights in the chosen educational context.

In both research phases, the number of learning activities examined was deliberately limited. Each teacher was asked to select only one activity in Phase One and one or two activities in Phase Two. This design enabled a comprehensive analysis of mobile practices within specific learning contexts, rather than aiming for breadth coverage. This approach allowed for richer, in-depth examination of diverse activity types (e.g., lectures, tutorials, laboratories and field trips) and science disciplines (e.g., life sciences, physical sciences) where mobile devices were likely to vary.

Additionally, the reliance on self-reported data in the Phase One survey introduced potential biases, as no supplementary data sources were available to triangulate the responses. It is also acknowledged that only interested parties were more inclined to participate. Nevertheless, this approach was deemed appropriate for the international scope and exploratory nature of Phase One. The depth of qualitative insights was limited by the survey including only two open-ended questions asking for (1) the name of the main app(s) used and (2) how students would use that/those app(s) in the nominated activities. However, this limitation was addressed in the Phase Two case studies. Future studies would benefit from including open-ended questions for the core iPAC and innovation items in the validated iPAC teacher and student surveys to allow participants to elaborate in more detail on their responses and experiences.

This study primarily utilised a case study approach within the mixed method design, which inherently presented limitations in terms of replicability and

reliability (Bryman, 2012; Cohen et al., 2011). Nevertheless, these limitations were consciously addressed through a rigorous methodological design that included data triangulation across multiple sources and stakeholders. This study did not attempt to produce findings that would be generalisable to all university science education contexts. Rather, it sought to generate in-depth, contextual insights into distinctive science mobile practices and pedagogical innovations from multiple perspectives.

Due to time and resource constraints, most Phase Two case studies were observed only once, except in instances where multiple observations were offered by educators. While the researcher had access to hybrid learning recordings and a learning management site in one case, other unobserved activities might have offered additional insights. As well, two discrepancies emerged during Phase Two data collection. First, some students who completed the survey did not participate in the focus group, leading to occasional inconsistencies between quantitative and qualitative responses. Second, in a few cases, only a small number of students participated in the survey or focus group, potentially limiting the representation of the wider student cohort. To mitigate these limitations and strengthen the findings, this research employed robust triangulation of multiple data sources and inputs from teachers, learning designers, and students, as well as the researcher's observations.

Although emerging mobile technologies such as virtual reality, augmented reality or wearable devices are increasingly being recognised in education, their absence in this study reflected the participants' limited use of them in undergraduate science education. As such, these technologies were beyond the scope of this research. Future research could explicitly include these technologies in their selection criteria and explore how distinctive mobile pedagogical innovation is interpreted through their use.

Future research is also recommended to further develop and refine the iPAC framework in a range of contexts within and beyond science education by further exploring its sociocultural dimensions. This would help ensure the framework remains aligned with the realities of contemporary learning and the evolving landscape of educational technologies and learners' needs.

6.7.2 Sampling and Generalisability

The teachers participating in Phase Two were nominated by their faculty leaders, which may have introduced bias towards more confident or experienced

practitioners. While this sampling method does not reflect the broader population of science educators, it is aligned with the context-rich exploratory nature of the case study component of this research.

Phase One involved 132 valid teacher survey responses from 14 countries, with most respondents from Australia, and Phase Two consisted of six case studies across four universities within New South Wales, Australia. While the sample size and geographic focus of this study may limit its applicability to other contexts, they are consistent with the case study approach, which prioritises the in-depth investigation of phenomena in specific contexts. The adoption of such methodologies might benefit future comparative studies across countries, disciplines, and educational levels, as well as research exploring the links between student learning outcomes, the iPAC constructs, and mobile pedagogical innovation.

While this study was suitable for capturing the student participants' immediate real-time experiences and perspectives of their teachers' nominated activities, rather than tracking their learning over time, future research could collect data longitudinally over one or more semesters to capture potential changes in mobile practices across semesters. In addition, since this study was situated in the context of formal undergraduate science curricula, it did not specifically focus on learning in informal settings. Future investigations of how students leverage mobile devices for science learning in less structured environments, such as at-home experiments and community-based or citizen-science projects, could enrich understandings of mobile practices beyond formal or semi-formal settings.

Furthermore, the under-explored role in m-learning of external facilitators, such as science experts, influencers, community or family members warrants further attention. Future researchers could consider how these non-university participants can contribute to science collaborative and authentic m-learning episodes.

Finally, with the rapid emergence of generative artificial intelligence (GenAI) in higher education, especially among undergraduate students (Crompton & Burke, 2023), future researchers and other informed decision-makers could examine how AI tools might be integrated into mobile digital pedagogy to foster student agency and creativity (Mishra et al., 2025), and how the traditional human–human collaboration central to a sociocultural framework may be extended to

human–AI partnerships, where AI acts as a collaborator or facilitator to support learning in ethical ways.

6.8 Chapter Summary

This chapter discussed the key findings from both phases of this study in response to the overarching research question:

> How are mobile technologies being used in undergraduate science education to support teaching and learning?

This thesis contributes to the limited body of literature on distinctive and innovative mobile practices in university science education. Drawing on the perspectives of university science teachers, learning designers and students, the study examined how teaching and learning are evolving within an increasingly mobile and digital educational landscape. These diverse viewpoints were synthesised using rich, triangulated data collected through a range of research instruments across both phases. By adopting a mixed methods approach, the study uncovered the complex ways in which mobile practices were enacted in various undergraduate science learning contexts, as well as the extent of pedagogical innovation perceived by the participants. Importantly, this study has also drawn attention to a broad spectrum of mobile pedagogical innovations and provided insights into what constitutes feasible and scalable innovation in undergraduate science education. The next chapter concludes this thesis by outlining its contribution, with a focus on addressing the research questions.

Chapter 7
Conclusion

Underpinned by sociocultural theory, this study investigated how distinctive mobile practices, namely Personalisation (agency and customisation), Authenticity (task and context) and Collaboration (co-creation and conversation) as defined by Kearney et al.'s (2012) iPAC mobile framework, are enacted in undergraduate science education. It also investigated digital pedagogical innovation based on the criteria of Burden, Kearney, Schuck, & Hall (2019) and Law et al. (2005). Its findings offer nuanced insights into the use of distinctive and innovative mobile practices in undergraduate science education. This chapter presents the key findings of this study, addressing the research questions and highlighting the study's contributions and significance

7.1 Key Findings

This research has highlighted the prominence of mobile pedagogies in fostering student engagement through collaborative data sharing and digital content production in undergraduate science education. The use of mobile technologies was found to be instrumental in supporting real-time, multimodal collaboration, particularly in science laboratory settings. A distinction emerged between educator-structured and student-initiated mobile practices. Despite regimented university structures, the participating students exercised a high degree of agency in their science learning with mobile devices, often engaging in "slip-tasking" by fluidly switching between mobile tools and apps to support their learning needs.

While there was evidence of networked learning for synchronous and asynchronous science activities using tools such as Padlet, Teams and Zoom, this study identified a disconnection between institutional online forums and students' preferred communication platforms. Informal tools such as social media and messaging apps were favoured over formal platforms for communication, indicating missed opportunities for science educators to foster networked learning and thus leverage the full potential of mobile devices. Such student-led mobile practices also extended beyond formal learning activities, highlighting the broader benefits of m-learning.

Mobile practices supporting students' authentic learning experiences were highly valued but inconsistently implemented across science subjects and activities.

While the participating teachers effectively utilised mobile technologies during field trips to support realistic science learning tasks and contexts, such use remained limited in traditional settings. Mobile practices supporting customised learning were also scarce, highlighting a mismatch between the theoretical vision of tailored learning versus its practical execution.

The participating teachers typically reinforced existing educational paradigms, predominantly implemented mobile practices in conventional settings such as lectures, tutorials and laboratory classrooms. Their didactic roles in lectures and tutorials, as well as their facilitative roles in laboratories and field trips, remained relatively unchanged. Although mobile practices are widely implemented in undergraduate science education, they are yet to fundamentally disrupt traditional learning approaches that do not use them. Genuine mobile pedagogical innovation requires more than just the substitution of mobile tools; it calls for a holistic rethinking of pedagogical designs that challenge the contexts of learning, the roles of teachers and students, and the involvement of external participants.

7.2 Revisiting the Research Questions

This study was guided by the following primary research question and four subsidiary research questions.

Primary research question:

> How are mobile technologies being used in undergraduate science education to support teaching and learning?

The four subsidiary research questions:

> **RQ1:** How are university science teachers using distinctive mobile pedagogies?
> **RQ2:** How do learning designers view these mobile pedagogies?
> **RQ3:** How do students experience these mobile pedagogies?
> **RQ4**: To what extent are educators' mobile learning activities perceived as pedagogically innovative?

There were two phases in this study. Phase One investigated university science teachers' mobile practices worldwide through a global survey. Phase Two examined six case studies from Australian universities, with each case involving

researcher observations, teacher and student surveys; teacher and learning designer interviews; and student focus groups.

The findings from both phases indicate that the implementation of mobile practices had enriched undergraduate science learners' experiences. Their use of mobile tools facilitated data sharing and co-creation by fostering collaborative learning. Mobile practices appeared to support student agency, facilitate learning conversations, empower them to exert greater control over how, when and where they learned, particularly in asynchronous and hybrid learning contexts. Mobile practices supporting authentic learning were most prominent in field-based learning, where the students used discipline-specific apps to perform realistic professional tasks in real-world contexts. Although customisation practice was less widespread, its potential to tailor individual learning was recognised in the students' field-based learning.

While the use of mobile technologies did not radically transform existing non-mobile pedagogies, it enhanced the students' undergraduate science learning experiences. This study thus highlights the potential to adopt mobile practices that might strengthen undergraduate students' scientific inquiry and professional skills by reconsidering the learning settings, the roles of teachers and their relationship with students, as well as external participants' involvement.

The four subsidiary research questions were informed by the distinctive mobile practices from the iPAC framework (Kearney et al., 2012) and the digital pedagogical innovation criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005). Each led to key insights.

RQ1: How are university science teachers using distinctive mobile pedagogies?

The aim of this question was to identify key themes emerging from the mobile practices of university science teachers globally and in Australia. Data was collected from the validated teacher survey (Kearney et al., 2019) administered in both phases of this study. This survey was specifically designed to measure teachers' mobile practices in their nominated learning activities.

The participating teachers effectively implemented mobile practices supporting co-creation, primarily in lab settings to support data exchange and co-production of digital content. While asynchronous and hybrid activities allowed for greater student control regarding when, where, and how to learn, on-campus activities remained constrained by university schedules and locations. Mobile practices

supporting authentic learning experiences were most evident in field-based learning, where students used professional apps to simulate scientists' work in real-world contexts. While lab-based activities showed some authentic use of subject-specific apps such as simulation and digital lab notebooks, they were often confined to structured university environments, and therefore only partially reflected real-world professional practices and contexts in science disciplines and career paths.

In formal activities, the teachers often utilised platforms like Microsoft Teams or Zoom for synchronous online activities and relied on face-to-face conversations for in-person sessions. Institutional discussion forums were often embedded by the teachers for out-of-class conversations, although these were not always fully utilised by their students. There was minimal exposure to authentic professional engagement and networked learning through the external involvement of others in the learning activities. Further, while the teachers recognised the value of customisation to personalise learning in their university science subjects, constraints such as large student cohorts and rigid curricula made them challenging to implement.

RQ2: How do learning designers view these mobile pedagogies?

Learning designers were not included as participants in Phase One, as the scope of this study did not involve collecting data from learning designers globally. Further, the validated survey used in Phase One of this study was specifically designed for teachers who implemented the mobile learning activities (see Chapter 3 for research methodology). The perspectives of learning designers were therefore drawn exclusively from the Phase Two case studies.

In Phase Two of this study, most subject coordinators held dual roles as both learning designers and teachers. Specifically, five subject coordinators and one first-year lab director self-nominated to participate in this study as learning designers. These participants designed and taught the activities, although they were not formally designated as learning designers. The remaining two participants self-identified explicitly as learning designers. Given the close collaboration between the teachers and learning designers, and the frequent overlap in their roles, their perspectives were closely aligned. Even those learning designers not directly involved in teaching expressed views that were relatively consistent with those of the teacher-designers.

Similar to the Phase Two teachers, and based on the types of activities, the learning designers affirmed the value of mobile-mediated conversations (predominantly face-to-face), data sharing and co-production in fostering collaborative learning. Mobile devices were perceived as instrumental in supporting student choice regarding modes of learning, how to learn, and control over the pace and the spaces of their learning. Students often chose self-initiated informal communication channels over institutional platforms for networked learning. The learning designers perceived the students' m-learning as most authentic during field-based activities where students used professional apps in real-life contexts and to a lesser extent in lab activities, which were bound by regimented lab schedules and settings. No evidence emerged for external facilitators' involvement in the nominated activities. The limited use of mobile practices that supported customised learning in lecture and laboratory activities restricted the students' opportunities to tailor their individual learning needs.

RQ3: How do students experience these mobile pedagogies?

Students were not included as participants in Phase One, as it was not the scope of this study. Similar to the learning designers, their critical perspectives were gathered exclusively through the Phase Two case studies (see Section 3.4 for research methods)

The students' views of mobile practices generally reflected their teachers' views in the nominated activities. These included an emphasis on face-to-face conversations, data exchange, co-production, learner choice and control, use of realistic apps in laboratory activities, and learning in real-world contexts across multiple spaces with the use of tailored apps, mainly in field-based settings. However, there were two key exceptions: a stronger emphasis (by students) on student-initiated slip tasking and informal online conversations. Students highly valued the autonomy afforded by mobile devices, often selecting their own educational or generic tools to supplement their learning. They also valued the regular use of informal platforms such as Facebook Messenger, Instagram, and WhatsApp to collaborate and communicate with peers. These students' views highlight opportunities for educators to move beyond prescribed platforms and support greater learner agency by allowing students to choose their own conversational apps. Embracing flexibility in the use of informal tools, such as social media platforms, can foster more student-driven authentic collaboration in mobile-mediated learning environments.

RQ4: To what extent are educators' mobile learning activities perceived as pedagogically innovative?

The findings of this question were derived primarily from the six case studies conducted in Phase Two, which captured the combined voices of the participating teachers, learning designers, and students. Additionally, insights were drawn from the teachers' responses to the quantitative digital pedagogical innovation items in the Phase One global survey.

As mentioned in the literature review, the term innovative mobile pedagogies refer to new approaches that leverage the unique affordances of mobile devices to enable effective learning in ways that would not be possible without them. According to the digital pedagogical innovation criteria (Burden, Kearney, Schuck, & Hall, 2019; Law et al., 2005), many of the nominated learning activities were not perceived as radically innovative by the Phase Two participants. Most educators reported on their implementation of mobile technologies into existing activities, without altering traditional means such as settings and teacher-student roles or by challenging the status quo to introduce new approaches that might transform undergraduate science education. The Phase Two teachers often rated their mobile practices as more innovative than their students did, highlighting discrepancies in perceptions of mobile pedagogical innovation. Most students in Phase Two reported that their m-learning experiences were consistent with their typical science activities, indicating that mobile technologies were embedded in familiar ways. Importantly, this study found that pedagogical innovation does not necessarily require radical shifts or "disruption". Rather, incremental innovations appear more practical and feasible for enhancing teaching and learning with mobile devices, especially within the constraints of undergraduate science education.

By providing deeper insights into the participants' perspectives on mobile pedagogical innovation, this study has identified how university science teachers implement distinctive aspects of m-learning practices, how learning designers view these practices, and how students experience them. It also identified specific learning episodes where mobile practices were used effectively to foster meaningful collaboration and promote personalised engagement and authentic scientific inquiries. Ultimately, this study has demonstrated that m-learning experiences can transcend traditional classroom boundaries by immersing

students in collaborative real-world practices, which are essential for preparing them for their professional careers and lifelong learning.

7.3 Contributions to the Literature

This thesis makes an original contribution to the growing body of literature on m-learning in higher education by offering empirically rich insights into distinctive mobile practices in undergraduate science education. Given the urgent global demands for science educators to redesign pedagogies that have not kept pace with the rapid changes of technologies, economies, and societies (Christensen et al., 2008; Department of Industry Science and Resources, 2024; OECD, 2024b, 2025; Office of the Chief Scientist, 2020), this research is timely. It offers an understanding of the possibilities and challenges that enhance or prevent the implementation of distinctive and innovative mobile practices in undergraduate science education and more broadly in higher education and educational policy reforms. It also contributes to the research lacunae identified in the literature review (see Chapter 2) by responding to calls from researchers in the m-learning field for further exploration of science mobile practices in higher education (Crompton & Burke, 2018; Crompton et al., 2016; Pimmer et al., 2016).

This thesis also contributes to the limited literature on innovative science mobile learning practices by highlighting the wide spectrum of contextual conditions under which pedagogical innovation is feasible. It reinforces calls to move beyond formal university-based science learning settings toward more informal, authentic environments that fully leverage the affordances of mobile technologies. Unlike previous research in this area, which mostly focused on one or two stakeholder groups (see Section 2.4.2), this study drew on the unique perspectives of higher education science teachers, learning designers, and students that included multiple science disciplines such as physics, chemistry, geology, and medical and health science.

Rather than examining general experiences in undergraduate science contexts, this research centred on specific m-learning episodes nominated by teachers and on the behaviours of students during those activities. Grounded in sociocultural theory, specifically the iPAC mobile framework (Kearney et al., 2012), its analysis of science mobile practices highlighted co-creation, face-to-face conversations, and student agency, in addition to the underexplored dimensions of customisation and online conversations. It also identified perceived challenges,

including the implementation of authentic learning tasks in realistic settings with the use of mobile devices.

Methodologically, this study has broken new ground through its specific mixed methods design. It is the first known research to adopt the validated iPAC teacher survey (Kearney et al, 2019) and student survey (Burke et al., 2022), as well as to employ both the iPAC and innovation sliders (Kearney et al., 2020) together as interview and focus group stimuli. It not only triangulated multiple data sources but also included the voices of teachers, learning designers, and students across multiple universities. This approach was considered essential for enabling learning designers and students to also express their views on teachers' mobile practices. Such multiple perspectives have often been overlooked by educators when implementing new m-learning activities.

These comprehensive approaches enhanced the validity of the study and created new avenues for future research to connect digital pedagogical theory with real-world practices.

7.4 Significance of the Study

This thesis provides a contemporary, evidence-based understanding of how the use of mobile devices is shaping the digital learning culture of undergraduate science students in both global and Australian contexts. The study is significant for its interrogation of the phenomena through a multi-perspective analysis involving teachers, learning designers and students. The sociocultural theoretical lens enabled an exploration of mobile learning as a socially mediated process, highlighting the roles of contexts, tools and interactions in shaping learning experiences. The findings show how the mobile practices of teachers and learning designers can influence students' experiences across diverse science learning activities, and how students can exercise their own agency when collaborating and conversing with peers, thus exemplifying the socially embedded nature of technology-enhanced learning.

Through its examination of the interplay between pedagogical strategies and the affordances of mobile technologies, this study offers actionable insights for professional development initiatives and curriculum design in undergraduate science education. Its transformative potential includes encouragement for science educators to reimagine m-leaning as a vehicle for supporting customised, authentic and networked learning that transcends conventional classroom boundaries.

Another key contribution of this study is the extension of the theoretical application of the iPAC mobile framework by revealing the inherently dynamic interplay between student agency, co-creation, and conversations within mobile practices. As discussed in Section 6.4, these practices frequently overlapped in the interconnected nature of m-learning rather than functioning in isolation. The study challenges iPAC's current static representation, where constructs and subconstructs can be depicted as distinct components without clear indications of their concurrent and interactive nature. While the current triangular visual illustration provides a valuable foundation for analysing m-learning, it does not fully represent the way mobile pedagogies play out in the complex reality of mobile-mediated learning environments. This study has demonstrated that student agency, co-creation, and conversation mobile practices are inherently intertwined and mutually reinforced in practice.

These insights reinforce the central roles of social interaction and tool mediation in shaping effective learning, aligning with sociocultural theory (Vygotsky, 1978). Hence, a revised version of the iPAC framework that explicitly captures the dynamic interplay among its constructs and subconstructs could enhance its theoretical robustness and practical relevance. Such a revision would provide practitioners and researchers with a more accurate lens for evaluating and designing m-learning experiences.

Importantly, this study adds to the limited body of literature addressing mobile pedagogical innovation, particularly in the science disciplines and undergraduate education space. It provides a contemporary understanding of university science teachers', learning designers' and students' perspectives of innovative mobile practices. The findings reveal that feasible, incremental digital pedagogical innovation is more likely in the current context of undergraduate science education. However, moving beyond simple replication of non-mobile practices will require reconsideration of how mobile pedagogical innovation is understood and valued. It is important to recognise the inherent context specificity of innovation because one group's perception of what is innovative may vary from another's; for example, teachers and students may have different cultural backgrounds or disciplines.

7.5 Chapter Summary

This chapter has summarised the study's evidence-based insights into mobile practices and pedagogical innovation in undergraduate science education from

the perspectives of teachers, learning designers, and students. Through an expanded understanding of m-learning and the iPAC mobile framework, the study revealed how mobile technologies can promote co-creation, face-to-face conversations, and student agency. Recognising the complex interplay between these distinctive mobile practices and incorporating them into learning activities is essential for creating effective student-centred m-learning experiences.

This thesis has also captured a snapshot of the current status of mobile pedagogical innovations in undergraduate science education and identified key areas for future advancement. By examining how educators' m-learning activities were perceived as pedagogically innovative, this research has revealed the transformative potential of mobile practices for addressing the evolving needs of 21st-century science learners. It calls for a rethinking of traditional university science classroom settings and roles whilst preserving pedagogical rigour in an increasingly digital and connected age.

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Appendices

Appendix A: Participant Information Sheet (Phase One Teacher Survey) – English Version

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

WHO IS CONDUCTING THIS RESEARCH?
My name is Le Quan Ly and I am a doctoral student at University of Technology Sydney, Australia. My contact detail is le.q.ly@student.uts.edu.au. My supervisors are Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

WHAT IS THIS RESEARCH ABOUT?
The research project investigates the use of digital learning in undergraduate university science education. Implementing this survey is Phase One of this project. The survey seeks to find out how you used digital devices in your teaching in one recent task to enhance your undergraduate students' science learning. The task may have been implemented in and/or outside of class (e.g., on campus, at home or on a field trip).

WHY HAVE I BEEN INVITED?
You have been invited to participate because you are an undergraduate university science teacher. I hope you will find the survey useful for your professional development. The outcomes of this research will contribute to the existing knowledge on the use of digital learning in undergraduate university science education. It also assists universities' decision-making and policy development associate with pedagogies supported by digital technologies.

WHAT DOES MY PARTICIPATION INVOLVE?
If you choose to do the survey, it will take approximately 15 mins of your time. At the start of it, I will seek your permission to use the anonymous data generated from your responses for my research. Participants have a chance to win one of the two $50 AUD gift cards.

ARE THERE ANY RISKS/INCONVENIENCE?
Participating in this survey has no risk to the participants. The results of the survey will inform enhanced use of digital devices for science teaching practices.

DO I HAVE TO TAKE PART IN THIS RESEARCH PROJECT?
Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT IF I WITHDRAW FROM THIS RESEARCH PROJECT?
If you change your mind about participation during the survey, simply exit the survey and I will not use your data. If you decide not to participate, it will not affect your relationship with the researcher or the University of Technology Sydney.

WHAT WILL HAPPEN TO INFORMATION ABOUT ME?
By proceeding to page two of this online survey (after the opening information page), you consent to the research team collecting and using anonymous survey information for the research project. All this information will be treated confidentially. No information will be collected about your identity or your university's identity. The survey platform entirely de-identifies and make your responses entirely anonymous.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?
If you have concerns about the research that you think I can help you with, please feel free to contact me on le.q.ly@student.uts.edu.au, or my supervisors Professor Matthew

Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

NOTE: This study has been approved in line with the University of Technology Sydney Human Research Ethics Committee [UTS HREC] guidelines. If you have any concerns or complaints about any aspect of the conduct of this research that you wish to raise independently of the research team, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number ETH22-7239. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Appendix B: Participant Information Sheet (Phase One Teacher Survey) – Chinese Version

参与者信息表

（悉尼科技大学人类研究伦理委员会批准号： ETH22-7239）

大学自然科学教育中使用数字化学习

谁在进行这项研究？

我叫Le Quan Ly，是澳大利亚悉尼科技大学的一名博士生。我的联系方式是：le.q.ly@student.uts.edu.au。我的导师是Matthew Kearney教授（matthew.kearney@uts.edu.au）和Tracey-Ann Palmer博士（tracey-ann.palmer@uts.edu.au）。

这项研究是关于什么的？

这项研究探讨大学本科老师们如何在教学中使用数字设备教导自然科学学生，实施这项调查是本项目的第一阶段。

该调查旨在了解您在最近的一项活动中是如何使用数字设备来提高本科学生的自然科学学习。该项活动可以是在课内和/或课外实施的（例如，在校园，在家里或实地考察）。

为什么我被邀请？

您被邀请参加调查是因为您是一名大学自然科学教师。我希望这项调查对您的专业发展有帮助。这项研究的结果将有助于加深理解数字化学习在大学自然科学教育中的作用。进而为大学本科自然科学教师对数字化技术用在教学方面的决策和政策制定提供参考 。

我的参与会涉及什么？

如果您选择参与本项调查，将需要您大约15分钟。在调查开始时，我将征求您的同意使用您匿名的回答于本研究项目。两名参与者将有机会赢得一张$50澳元礼品卡 。

是否有任何风险/不便之处？

参与这项调查对参与者没有任何风险。本项调查的结果只用于为大学本科自然科学教师在教学中是否应使用移动设备提供参考 。

我一定要参加这个研究项目吗？

参与这项研究是自愿的。是否参加完全取决于您自己 。

如果我退出这个研究项目怎么办？

如果您在调查过程中改变主意，只需退出调查既可。我将不会使用您的数据。如果您决定不参与，这不会影响您与研究者或悉尼科技大学的关系 。

关于我的信息将如何处理？

在在线调查的第二页（介绍信息页之后），您将允许研究小组为研究项目收集和使用您匿名的调查信息。所有这些信息将被保密处理。我们不会收集任何关于您或您的大学身份的信息。该调查平台会完全移除您的身份识别，使您的回答完全匿名 。

如果我有担忧或投诉怎么办？

如果您对此研究有疑虑，请随时联系我 Le Quan Ly (le.q.ly@student.uts.edu.au) 或我的导师 Matthew Kearney教授（matthew.kearney@uts.edu.au）和Tracey-Ann Palmer博士（tracey-ann.palmer@uts.edu.au）。

注意。
本研究已按照悉尼科技大学人类研究伦理委员会[UTS HREC]的指导方针获得批准。 如果您对本研究的任何方面有任何疑虑或投诉，并希望独立于研究小组提出，请联系伦理秘书处，电话: +61 2 9514 2478或发送电子邮件。Research.Ethics@uts.edu.au]，并注明UTS HREC的参考号ETH22-7239。 任何提出的问题都将得到保密处理，并对其进行调查，您将被告知结果。

Appendix C: Phase One Survey (English version)

UTS HREC Approval No. ETH22-7239
Digital Learning Evaluation for University Science Teachers: Undergraduate Task Survey

Welcome to this short survey. The survey investigates how portable digital devices are being used to support your undergraduate science students' learning.

This survey asks you to choose ONE specific science task (or activity) where your undergraduate science students used a digital device (any portable devices such as mobile phone, laptop, tablet etc.) to support their learning. The activity may be a short task within a lesson, or a longer task taking several days. I am especially interested in activities which are implemented in and/or outside of class (e.g., on campus, at home, or on a field trip).

Upon completion of the survey, you will have a chance to win one of the two AUD $50 gift cards.

Participation in this survey is voluntary and confidential. Your anonymous responses may be used for research purposes (UTS HREC Approval No. ETH22-7239). See Teacher Information sheet. If you have any queries about the survey or this doctoral research, please contact Le Quan Ly (le.q.ly@student.uts.edu.au) or my University of Technology Sydney, supervisors Professor Matthew Kearney (matthew.kearney@uts.edu.au) or Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

It is important that you choose ONE task (only) that you have recently implemented with your students. The survey should take approximately 15 minutes to complete, your answers will be completely anonymous and entirely de-identified by our survey software. In undertaking questions, please DO NOT USE the 'Back' and 'Forward' buttons in your browser. Please use the buttons at the bottom of each screen.

There are no 'right' or 'wrong' answers! The response options are not necessarily linked to the quality of the task or the learning outcomes. Please complete all questions as honestly as possible.

Thank you.

Q1
Please choose one of the following options.

○ I have read the above details and agree that my anonymous survey responses may be used for research purposes (1)

○ I have read the above details and do not agree to complete this survey. (2)

BACKGROUND ITEMS

Q2
What country do you teach university science subject(s)?

▼ Afghanistan (1) ... Zimbabwe (1357)

Q3
How many years in total have you been teaching university science subject(s)?

○ less than 2 years (1)

○ 2-9 years (2)

○ 10-20 years (3)

○ 20+ years (4)

Q4
How experienced are you with using digital technologies in teaching university science subject(s)?

○ Inexperienced (1)

○ Occasional user (2)

○ Experienced (3)

○ Very experienced (4)

In this survey you will consider the use of digital technologies in ONE ACTIVITY you have recently implemented in your *undergraduate* university science teaching.

Q5
What is the science discipline area of your chosen digital learning activity? *Please select the closest match.*

○ Anatomy (1)

○ Astronomy (2)

○ Biology (3)

○ Biochemistry (4)

◯ Biomedical science (5)

◯ Chemistry (6)

◯ Earth science (7)

◯ Ecology (8)

◯ Environmental science (9)

◯ Forensic science (10)

◯ Geology (11)

◯ Physics (12)

◯ Statistics (13)

◯ Plants science （14）

◯ Animal science (15)

◯ Other (please specify) (16) ________________

Q6
What was the main undergraduate level that you implemented your chosen science digital learning activity?

◯ First year (1)

◯ Second year (2)

◯ Third year (3)

◯ Fourth year (4)

◯ Other (please specify) (5)____________

Q7
What type(s) of *portable* digital device did your students use in this activity? Choose all that applied.

- ○ A smart phone (1)
- ○ Tablet device e.g., iPad (2)
- ○ A laptop (3)
- ○ Two-in-one device (4)
- ○ Other (please specify) (5)__________

INTRODUCTION

In the following section, you will be presented with certain questions about the behaviour of your undergraduate science students in your chosen digital learning activity.

Please respond to the items to the best of your ability. Select the option that best describes your response to each statement on a scale of 1 to 5, where "1" means "Strongly disagree" (SD) and "5" means "Strongly agree" (SA)

Q8
Collaboration using digital devices > Conversation

Collaboration means that learners use their digital devices to make rich connections to other people and resources. The networking capability of digital devices can potentially create shared, socially interactive environments.

The following 3 items focus on the extent to which learners in your chosen activity held conversations through the digital device with peers, teachers and other experts.

When my students in used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Discussed the work online with their friends/peers e.g., discussed ideas via email, SMS, Zoom, Twitter, Microsoft Teams, WeChat, Facebook etc. (1)	○	○	○	○	○
Discussed the work online with people they don't know e.g., discussed with a librarian, a work professional such as a researcher (2)	○	○	○	○	○
Communicated with others using texts, image or video e.g., by SMS, Facebook, Instagram, Twitter (3)	○	○	○	○	○

Q9

Collaboration using digital devices > Co-creation

The following 3 items focus on the extent to which learners in your chosen activity co-created digital content and shared information.

When my students used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Worked together to create a digital product e.g., a video, podcast, document, PowerPoint (1)	○	○	○	○	○
Shared digital content e.g., a video, podcast, photo, document (2)	○	○	○	○	○
Contributed to existing digital content e.g., tagged a photo, commented on discussion forum (3)	○	○	○	○	○

Q10

Personalisation using digital devices > Agency

Personalisation includes pedagogical features such as learner choice, autonomy and customisation.

The following 3 items focus on the extent to which learners in your chosen activity had control over the place (physical and/or virtual), pace and time they learn, and autonomy over their learning content.

When my students used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Choose the place to do the activity e.g., on the bus, at home, in the library (1)	○	○	○	○	○
Determined the pace at which they did the activity (2)	○	○	○	○	○
Decided what they wanted to learn e.g., chose the modules, questions, or projects to explore (3)	○	○	○	○	○

Q11
Personalisation using digital devices > Customisation

The following 4 items focus on the extent to which learners in your chosen activity could customise their m-learning experience, both at the level of the tool (e.g., an app) and the activity itself.

When my students used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Were guided by the app(s) based on *their* past use e.g., by previous game challenge levels, YouTube recommendations prompted by their previous views (1)	○	○	○	○	○
Tailored app(s) settings to their preferences e.g., customised location on/off, camera/microphone access, time limit settings (2)	○	○	○	○	○
Received *individualised* information through the app(s) about themselves e.g., information or feedback about their submitted answers (3)	○	○	○	○	○
Customised feeds and links for *their* learning needs e.g., tailored social media or notification feeds (4)	○	○	○	○	○

Q12
Authenticity using digital devices > Context
Authenticity means that the digital learning experience provides real-world relevance and personal meaning to the learner.

The following 3 items focus on the extent to which learners' digital learning experiences in your chosen activity were enhanced by realistic, meaningful contexts, such as through 'in situ' learning in relevant physical or virtual settings.

When my students used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Learned in a place *suggested by the topic* e.g., learned about plants in the botanic garden, stars under the night sky (1)	○	○	○	○	○
Learned in a *realistic/* virtual space e.g., use of context-aware, augmented (AR) or virtual reality (VR) apps, science simulation (2)	○	○	○	○	○
Learned at a time *suggested by the topic* e.g., night-time observation of stars; observe animal behavior on a field trip over a few days (3)	○	○	○	○	○

Q13
Authenticity using digital devices > Task

The following 4 items focus on the extent to which the digital learning tasks are realistic and offer problems relevant to the real world; and the extent to which the tasks and associated processes require use of apps and tools that replicate those of real-world practitioners.
When my students in used digital devices to learn in this activity, they:
Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Worked *like an expert* e.g., used a data collection app like a scientist; identified plants species using an app like a botanist (1)	○	○	○	○	○
Participated in *real-world* activities that benefit society e.g., environmental projects such as monitoring waste systems or water quality (2)	○	○	○	○	○
Learned *serendipitously* in an *unplanned* way e.g., during a game, research prompted by an unexpected query (3)	○	○	○	○	○
Engaged in activities related to *everyday life* e.g., use of statistical information from news or a report (4)	○	○	○	○	○

Q14
My undergraduate science students' overall experience in this activity using digital devices.

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Using digital devices improved my students' science learning (1)	○	○	○	○	○
My students enjoyed using digital devices to learn about science (2)	○	○	○	○	○
My students found it difficult learning science using digital devices (3)	○	○	○	○	○
Using digital devices helped my students to understand concepts in science (4)	○	○	○	○	○
Using digital devices helped my students to practise science skills (5)	○	○	○	○	○

Innovation

Q15
Consider the approaches used in this science digital learning activity, and how different they are to *your typical* approaches *without digital devices*.

In this digital learning activity:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Use of a digital device *fundamentally* changed the way that learning occurs (1)	○	○	○	○	○
The context of learning was *radically* different (in terms of setting, time or mode of task) (2)	○	○	○	○	○
The range of stakeholders facilitating learning was *greatly* expanded (e.g., teachers, family, community members and other experts) (3)	○	○	○	○	○
Learners were granted *significantly* more agency than would normally be the case (4)	○	○	○	○	○
Learners' overall experience was *fundamentally* different from what they would normally experience in science subject (5)	○	○	○	○	○

Q16
In your chosen digital learning activity in my undergraduate science students worked: (*Can tick more than one option*)

- ▢ In the lecture room (1)
- ▢ In the tutorial classroom (2)
- ▢ In the laboratory (3)
- ▢ In the computer lab (4)
- ▢ Out of the classroom, but on campus e.g., hall, student breakout spaces (5)
- ▢ In educational setting outside of campus e.g., excursion/field trip, museum (6)
- ▢ At home (7)
- ▢ In other places e.g., on the bus, in coffee shop, shopping centre (8)
- ▢ Other (please specify) (9) __________

Q17
What were the main applications (or apps) used by your science students in your chosen digital learning activity?

Q18
Briefly describe how your science students used these apps in your chosen digital learning activity?

Appendix D: Phase One Survey (Chinese version)

大学科学教师的数字化学习评估：本科生任务调查

悉尼科技大学人类研究伦理委员会批准号： ETH22-7239

欢迎参加这个简短的调查。本调查旨在了解便携式数字化设备是如何支持大学本科科学学生的学习。

本调查要求您选择一项具体的本科科学学生实践活动，评估这项活动如何利用数码科技（任何便携式设备，例如手机、笔记本电脑、平板电脑等）教学的独特和创新特点来支持学生的学习。该活动可以是一节课内的活动，也可以是一个需要几天时间的较长活动。其中，我对课内和/或课外实施的（例如，在校园，在家里或实地考察 ）。

完成调查后，您将有机会赢得两张50澳元礼品卡中的其中一张。

参与这项调查是自愿的和保密的。您的匿名回答将被用于研究目的（悉尼科技大学人类研究伦理委员会批准号：ETH22-7239）。详细内容请看第一阶段教师信息表。如果您对本次调查或本博士研究项目有任何疑问，请联系Le Quan Ly (le.q.ly@student.uts.edu.au) 或我的导师 Matthew Kearney教授（matthew.kearney@uts.edu.au）和Tracey-Ann Palmer博士（tracey-ann.palmer@uts.edu.au）。.

您要选择一项您最近与您的学生一起实施的活动。调查需要大约15分钟完成，您的答案将是完全匿名的。在回答问题时，请不要使用浏览器中的 "返回 "和 "前进 "按钮。请使用每个屏幕底部的按钮。
回答选项与活动的质量或学习成果没有联系，请尽可能诚实地填写所有问题。

谢谢您。

问题1
请选择以下选项之一。

○ 我已经阅读了上述细节，并同意我的匿名调查回复可用于研究目的 (1)

○ 我已经阅读了上述细节，不同意完成此调查。 (2)

背景调查
问题2
您在哪个国家教授大学科学科目?
▼ 阿富汗（1）...津巴布韦（1357）

问题 3
您从事大学科学科目教学总共有多少年?

- 少于2年 (1)

- ○ 2-9年 (2)
- ○ 10-20年 (3)
- ○ 20年以上 (4)

问题 4
您有在大学科学教学中使用数字化科技的经验吗?
- ○ 没有经验(1)
- ○ 偶尔使用 (2)
- ○ 有经验 (3)
- ○ 非常有经验(4)

在这个调查中，您将考虑在您的本科科学教学中实施的一项活动中使用数字化科技的情况。

问题 5
您选择的数字化学习活动的科学领域是什么？请选择最接近的匹配。
- ○ 解剖学 (1)
- ○ 天文学 (2)
- ○ 生物 (3)
- ○ 生物化学 (4)
- ○ 生物医学 (5)
- ○ 化学 (6)
- ○ 地球科学 (7)
- ○ 生态学 (8)
- ○ 环境科学 (9)
- ○ 法医科学 (10)
- ○ 地质学 (11)
- ○ 物理 (12)
- ○ 统计学 (13)
- ○ 植物学 （14）
- ○ 动物科学 （15）
- ○ 其他（请注明） (16) ________________________________

问题 6
您主要在哪个本科阶段实施您所选择的数码科技学习活动的?

- ○ 一年级 (1)
- ○ 二年级 (2)
- ○ 三年级 (3)
- ○ 四年级 (4)
- ○ 其他（请注明）(5)__________

问题7
您的学生在这活动中使用了什么类型的便携式数字化设备？此题多选。

- ○ 智能手机 (1)
- ○ 平板设备，如：iPad (2)
- ○ 笔记本电脑 (3)
- ○ 二合一的设备 (4)
- ○ 其他（请注明） (5)___________

简介
在下面的部分中，您将会看到一些关于您的本科科学学生用您选择的活动数字化学习过程中的行为问题。

请尽您所能回答这些问题。请选择最能说明您对每个陈述的反应的选项，评分标准为1至5，其中 "1 "表示 "非常不同意"，"5 "表示 "非常同意"。

问题 8
使用数码设备进行合作： 会话
合作意味着学生使用他们的数码设备与其他人和资源建立丰富的联系。数码设备的联网能力可以潜在地创造出共享的、社会性的互动环境。

以下3个项目集中反映了在您选择的活动中，学生使用数码设备与同伴、教师和其他人进行对话的程度。
当我的学生在这个活动中使用数码设备进行学习时，他们：
请每行选择一个答案。

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
与他们的朋友/同学在网上讨论工作或想法，例如电子邮件、短信、Zoom、Twitter、Microsoft Teams、Wechat, Facebook 等 (1)	○	○	○	○	○
与他们不认识的人在网上讨论，例如，图书管理员，专业人士如研究员 (2)	○	○	○	○	○
使用文字、图像或视频与他人交流，例如短信、Facebook、Instagram、Twitter(3)	○	○	○	○	○

问题 9
使用数码设备进行合作 > 共同创作

以下3个项目主要关注学生在您选择的活动中共同创作数码内容和分享信息的程度。 当我的学生在这个活动中使用数码设备进行学习时，他们。

请每行选择一个答案。

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
共同创作数字作品，如共同创作视频、播客、文件，幻灯片(1)	○	○	○	○	○
分享数字内容，如视频、播客、图片、文件(2)	○	○	○	○	○
对现有的数字内容做出贡献，例如给照片贴上标签，在论云上发表评论（3）。	○	○	○	○	○

问题 10
利用数码设备实现个性化学习 > 机构

个性化学习拥有让学生自主选择课程，定制课程等教学特点。

以下3个项目主要关注在您所选择的活动中，学习者对学习地点（在线/面对面）、节奏和时间的控制程度，以及对学习内容的选择权。

当我的学生在这个活动中使用数码设备进行学习时，他们：

请每行选择一个答案

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
选择做活动的地点，例如，在巴士上、在家里、在图书馆 (1)	○	○	○	○	○
决定了他们学习的节奏 (2)	○	○	○	○	○
决定他们想学什么，例如，选择他们自己的、问题或项目来探索(3)	○	○	○	○	○

问题 11

利用数码设备实现个性化学习： 定制

个性化学习拥有让学生自主选择课程，定制课程等教学特点。

以下4个项目主要关注学生在您所选择的活动中能够在多大程度上定制他们的移动学习体验，包括在工具（如应用程序）和活动本身的层面。

当我的学生在这个活动中使用数码设备进行学习时，他们:
请每行选择一个答案。

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
根据他们过去的使用情况被应用引导，例如通过以前的游戏挑战级别，根据他们以前的观看偏好推荐Youtube视频（1）	○	○	○	○	○
根据他们的喜好对应用程序进行设置，例如，开启/关闭定位服务、相机/麦克风访问权限、时间限制设置(2)	○	○	○	○	○
通过应用程序接收关于他们自己的个性化信息，例如关于他们提交答案的信息或反馈（3）	○	○	○	○	○
为他们的学习需求推送信息和链接，例如，定制的社交媒体或通知信息 (4)	○	○	○	○	○

问题 12
数码设备的使用场景>情景

使用场景是指数码学习为学生的线下学习提供附加价值和深刻体验。

以下3个项目主要关注学习者在您所选择的活动中的数码学习经验在多大程度上被现实的、有引导性的情景所加强，比如通过在相关的现实或虚拟环境中的 "现场 "学习。

当我的学生在这个活动中使用数码设备进行学习时，他们。
请每行选择一个答案。

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
在课题相关的地方学习，例如，在植物园学习植物，在夜空下学习星星(1)	○	○	○	○	○
在一个现实/虚拟的空间中学习，例如，使用情境感知、增强现实（AR）或虚拟现实（VR）应用程序，科学模拟（2）。	○	○	○	○	○
在课题建议的时间段学习，如夜间观察星星；在几天的实地考察中观察动物行为(3)	○	○	○	○	○

问题 13

使用数码设备的真实性 > 任务

真实性是指数码学习体验为学习者提供现实世界的相关性和个人意义。

以下4个项目着重于数码学习任务的现实程度和提供与现实相关的问题；以及任务和相关过程需要使用复制现实世界从业者的应用和工具的程度。

当我的学生在这个活动中使用数码设备进行学习时，他们。

请每行选择一个答案。

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
使用专业的工具，例如，像科学家一样使用数据收集应用程序；像植物学家一样识别植物种类（1）	○	○	○	○	○
参与有益于社会的实际活动，例如，环境项目如监测废物系统或水质(2)	○	○	○	○	○
以意外的方式学习，例如，在游戏中，由一个意外的询问所引发的研究 (3)	○	○	○	○	○
参与与日常生活有关的活动，例如，使用新闻或报告中的统计信息 (4)	○	○	○	○	○

问题 14

我的本科科学学生在这个活动中使用数码设备的总体体验

请每行选择一个答案。

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
使用数码设备提升了学生的科学学习效果(1)	○	○	○	○	○
我的学生喜欢使用数码设备来学习科学（2）	○	○	○	○	○
我的学生认为使用数码设备学习科学很困难（3）。	○	○	○	○	○
使用数码设备有助于我的学生更好地理解科学概念（4）。	○	○	○	○	○
使用数码设备有助于我的学生练习科学专业技能（5）。	○	○	○	○	○

创新

问题 15

考虑在这个数码学习活动中使用的方法，以及没有数码设备的传统方法有何不同。

在这个数码学习活动中。

请每行选择一个答案。

	1 非常不同意 (1)	2 (2)	3 (3)	4 (4)	5 非常同意 (5)
数码设备的使用从根本上改变了学习的方式 (1)	○	○	○	○	○
学习的环境完全不同（在情景、时间或任务模式方面）(2)	○	○	○	○	○
极大地促进学生与更多行业相关者交流（例如，教师、家庭、社区成员和其他专家）(3)	○	○	○	○	○
学习者被赋予了比通常情况下更多的自主权 (4)	○	○	○	○	○
学习者的整体体验与他们的通常体验有根本的不同（5）。	○	○	○	○	○

问题 16

在您选择的数码学习活动中，我的学生在_____学习：（可以勾选多个选项）

▢ 在讲堂上 (1)

▢ 在辅导教室里 (2)

▢ 在实验室里 (3)

▢ 在计算机实验室里 (4)

▢ 在教室外，但在校园里，如大厅、学生休息区 (5)

▢ 在校园外的教育环境中，例如，游览/实地考察，博物馆 (6)

▢ 在家里 (7)

▢ 在公共场所，例如在公共汽车上，在咖啡馆，购物中心 (8)

▢ 其他（请说明） (9) ____________

问题 17

在您选择的数码学习活动中，您的科学学生使用的主要应用（或应用程序）是什么？

问题 18

简要描述一下您的科学学生在您选择的数码学习活动中如何使用这些应用程序？

Appendix E: Participant Information Sheet (Phase Two – University)

UTS HREC Approval No. ETH22-7239

Use of Digital Learning in University Science Education

WHO IS CONDUCTING THIS RESEARCH?

My name is Le Quan Ly (le.q.ly@student.uts.du.au) and I am a doctoral student at the University of Technology Sydney, Australia. My supervisors are Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

WHAT IS THIS RESEARCH ABOUT?

This research project investigates the use of digital learning in undergraduate university science education. The first phase is a global survey. This second phase investigates the use of digital learning in several Australian universities. Participants include undergraduate science teachers, learning designers, and science students in Faculty of Science. The study will generate a robust insight into how digital learning can mediate and transform university science students' learning experiences. The outcomes will contribute to existing knowledge on the use of digital learning and innovative pedagogical practices in university science education. The study will also assist decision-making and policy development on digital pedagogies in Faculties of Science.

I am seeking one or more undergraduate science teachers from your Science Faculty with an exemplary reputation for using digital technologies in teaching science. Approaches supporting their students' learning may have been implemented inside and/or outside of class (e.g., on campus, at home and/or on excursion).

I plan to conduct one activity observation, a follow-up short interview and a brief questionnaire with your nominated science teacher(s). Students in this activity observation will also complete a brief questionnaire. I will also invite the teacher(s) to seek for 8-10 students from the observed class to participate in a brief focus group (*students need to be above 18 years old*). If possible, I also seek a learning designer who has worked with your faculty to participate in an interview.

WHY I HAVE BEEN INVITED?

As mentioned above, I hope that this study's findings can be used by Faculties of Science to improve digital pedagogical approaches. I also hope that university science teachers and learning designers will find this study useful for their professional development.

WHAT DOES MY PARTICIPATION INVOLVE?

If your nominated teacher(s) decide to participate, the location and length of the task observation is dependent on the teacher's chosen activity; the questionnaire will take 10 mins, the interview is approximately 20 minutes and artefact submission is optional (e.g., lesson plans, photos, videos or annotations).

If your nominated learning designer(s) decide to participate, the interview is approximately 20 minutes at their university campus or via Zoom meeting.

If students decide to participate, the questionnaire is approximately 10 minutes, 20-30 minutes for the focus group at the students' university campus and optional artefact submission (e.g., portfolio, journal or annotation of students' learning activities).

ARE THERE ANY RISKS/INCONVENIENCE?

Teacher participants may feel judged or uncomfortable, and this can be managed by being aware that no judgement will be made during the observation or interview. The researcher will be discreet in the activity.

Learning designer participants may feel judged. This risk is managed by no judgement will be made.

Student participants may feel uncomfortable. This can be managed by being informed in advance of in what manner and when the activity will take place. The focus groups will be conducted in the presence of students' classmates. All the response is de-identified, the teacher(s) do not have access to the responses of this phase. No judgement will be made in this focus group.

DO I HAVE TO TAKE PART IN THIS RESEARCH PROJECT?

Participation in this study is voluntary. It is completely up to you as to whether or not you decide to take part. If you decide not to participate, or to withdraw from the study, it will not affect your relationship with the researchers or the University of Technology Sydney or your organisation.

WHAT IF I WITHDRAW FROM THIS RESEARCH PROJECT?

If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting me on le.q.ly@student.uts.edu.au. If you withdraw from the study, I will not use your data.

WHAT WILL HAPPEN TO INFORMATION ABOUT ME?

By signing the consent form, you consent to the research team collecting and using de-identified information about you for the research project. All this information will be treated confidentially. All data will be de-identified for analysis and reporting.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified, except with your permission.

WHAT IF I HAVE ANY QUERIES OR A CONCERNS?

If you have concerns about the research that you think we can help you with, please feel free to contact me on le.q.ly@student.uts.edu.au, or my supervisors Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

You are given a copy of this form to keep.

NOTE:

This study has been approved in line with the University of Technology Sydney Human Research Ethics Committee [UTS HREC] guidelines. If you have any concerns or complaints about any aspect of the conduct of this research that you wish to raise independently of the research team, please contact the Ethics Secretariat on ph: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number ETH22-7239. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

CONSENT FORM

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

I ________________________ [participant's name] agree to participate in the research project being conducted by Le Quan from University of Technology Sydney (15 Broadway, Ultimo NSW 2007, Australia). Contact detail is le.q.ly@student.uts.edu.au.

I have read the Participant Information Sheet or someone has read it to me in language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney or my university.

I understand that I will be given a signed copy of this document to keep.

I am aware that I can contact Le Quan if I have any concerns about the research.

In any publication and/or presentation, please select one of the below options:
▢ I DO NOT wish to be identifiable.
▢ I wish to be identifiable.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

Appendix F: Participant Information Sheet (Phase Two – Teachers)

UTS HREC Approval No. ETH22-7239

Use of Digital Learning in University Science Education

WHO IS CONDUCTING THIS RESEARCH?

My name is Le Quan Ly and I am a doctoral student at University of Technology Sydney, Australia. My contact detail is le.q.ly@student.uts.edu.au. My supervisors are Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

WHAT IS THE RESEARCH ABOUT?

The research project investigates the use of digital learning in undergraduate university science education. The second phase involves observation of one activity and a follow-up short questionnaire and interview. This phase seeks to find out further information about how you use digital devices in your teaching to enhance your students' science learning. Your approaches may have been implemented in and/or outside of class (e.g., in tutorial, at home and/or on excursion).

WHY HAVE I BEEN INVITED?

You have been invited to participate because you were nominated by your university, and you expressed your interest in this study. Your contact details were obtained from your university.

I hope you will find this study useful for your professional development. The outcomes of this research will contribute to the existing knowledge on the use of digital learning in university science education. It also assists universities' decision-making and policy development associate with pedagogies supported by digital technologies.

WHAT DOES MY PARTICIPATION INVOLVE?

If you decide to participate, you will allow the researcher to observe one of your lessons. You will also be invited to participate

- a questionnaire that will take 10 mins to complete about the observed activity.
- a 20-minute semi-structured interview to seek further insights about the observed activity. This interview will be audio recorded and transcribed to capture the content of the interview.
- optional artefact submission (e.g., lesson plans, photos, videos or annotations) will be analysed to address the research questions.

ARE THERE ANY RISKS/INCONVENIENCE?

Participants may feel judged or discomfort during the activity observation or interview. This risk is managed by no judgement will be made. The researcher will be discreet in the activity. The results of the study will inform enhanced use of digital devices for science teaching practices.

DO I HAVE TO TAKE PART IN THIS RESEARCH PROJECT?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part. If you decide not to participate, or to withdraw from the study, it will not affect your relationship with the researchers or the University of Technology Sydney or your organisation.

WHAT IF I WITHDRAW FROM THIS RESEARCH PROJECT?

If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting me on le.q.ly@student.uts.edu.au. If you withdraw from the study, I will not use your data.

WHAT WILL HAPPEN TO INFORMATION ABOUT ME?

By signing the consent form you consent to the research team collecting and using de-identified information about you for the research project. All this information will be treated confidentially. All data will be de-identified for analysis and reporting.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified, except with your permission.

WHAT IF I HAVE ANY QUERIES OR CONCERNS?

If you have concerns about the research that you think we can help you with, please feel free to contact me on le.q.ly@student.uts.edu.au, or my supervisors Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

You will be given a copy of this form to keep.

NOTE:

This study has been approved in line with the University of Technology Sydney Human Research Ethics Committee [UTS HREC] guidelines. If you have any concerns or complaints about any aspect of the conduct of this research that you wish to raise independently of the research team, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number ETH22-7239. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

CONSENT FORM

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

I ____________________ [participant's name] agree to participate in the research project being conducted by Le Quan from University of Technology Sydney (15 Broadway, Ultimo NSW 2007, Australia). Contact detail is le.q.ly@student.uts.edu.au.

I have read the Participant Information Sheet or someone has read it to me in language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney or my university.

I understand that I will be given a signed copy of this document to keep.

I am aware that I can contact Le Quan if I have any concerns about the research.

In any publication and/or presentation, please select one of the below options:
▢ I DO NOT wish to be identifiable.
▢ I wish to be identifiable.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

Appendix G: Participant Information Sheet (Phase Two – Learning Designers)

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

WHO IS CONDUCTING THIS RESEARCH?

My name is Le Quan Ly and I am a doctoral student at University of Technology Sydney, Australia. My contact detail is le.q.ly@student.uts.edu.au. My supervisors are Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

WHAT IS THE RESEARCH ABOUT?

The purpose of this research is to investigate the use of digital learning in undergraduate university science education. This phase seeks to find out how you use digital devices in your curriculum design to enhance students' science learning experience. Your approaches may have been implemented in and/or outside of class (e.g., on campus, at home and/or on excursion).

WHY HAVE I BEEN INVITED?

You have been invited to participate because you were nominated by your university, and you expressed your interest in this study. Your contact details were obtained from your university. I hope you will find this study useful for your professional development. The outcomes of this research will contribute to the existing knowledge on the use of digital learning in university science education. It also assists universities' decision-making and policy development associate with pedagogies supported by digital technologies.

WHAT DOES MY PARTICIPATION INVOLVE?

You will be invited to participate in a semi-structured interview. This will take about 20-minute of your time and I will ask you about how you use digital devices in your curriculum design to enhance undergraduate science students learning experience. This interview will be audio recorded and transcribed to capture the content of the interview.

ARE THERE ANY RISKS/INCONVENIENCE?

Participants may feel judged during the interview. This risk is managed by no judgement will be made. The results of the study will inform enhanced use of digital devices for science teaching practices.

DO I HAVE TO TAKE PART IN THIS RESEARCH PROJECT?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part. If you decide not to participate, or to withdraw from the study, it will not affect your relationship with the researchers or the University of Technology Sydney or your organisation.

WHAT IF I WITHDRAW FROM THIS RESEARCH PROJECT?

If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting me on le.q.ly@student.uts.edu.au. If you withdraw from the study, I will not use your data.

WHAT WILL HAPPEN TO INFORMATION ABOUT ME?

By signing the consent form, you consent to the research team collecting and using de-identified information about you for the research project. All this information will be treated confidentially. All data will be de-identified for analysis and reporting.
It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified, except with your permission.

WHAT IF I HAVE ANY QUERIES OR CONCERNS?

If you have concerns about the research that you think we can help you with, please feel free to contact me on le.q.ly@student.uts.edu.au, or my supervisors Matthew.Kearney@uts.edu.au or Tracey-Ann.Palmer@uts.edu.au.

You will be given a copy of this form to keep.

NOTE:
This study has been approved in line with the University of Technology Sydney Human Research Ethics Committee [UTS HREC] guidelines. If you have any concerns or complaints about any aspect of the conduct of this research that you wish to raise independently of the research team, please contact the Ethics Secretariat on ph: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number ETH22-7239. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

CONSENT FORM

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

I ________________________ [participant's name] agree to participate in the research project being conducted by Le Quan from University of Technology Sydney (15 Broadway, Ultimo NSW 2007, Australia). Contact detail is le.q.ly@student.uts.edu.au.

I have read the Participant Information Sheet or someone has read it to me in language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney or my university.

I understand that I will be given a signed copy of this document to keep.

I am aware that I can contact Le Quan if I have any concerns about the research.

In any publication and/or presentation, please select one of the below options:
▢ I DO NOT wish to be identifiable.
▢ I wish to be identifiable.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

Appendix H: Participant Information Sheet (Phase Two – Activity Observation)

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

WHO IS CONDUCTING THIS RESEARCH?

My name is Le Quan Ly and I am a doctoral student at University of Technology Sydney, Australia. My contact detail is le.q.ly@student.uts.edu.au. My supervisors are Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

WHAT IS THIS RESEARCH ABOUT?

The research project investigates the use of digital learning in university science education. This second phase involves observation of one activity designed by your teacher. I seek to find out further information about how you use digital devices for your science learning in this activity.

WHY HAVE I BEEN INVITED?

You have been invited to participate because you are a university science student and your teacher(s) have agreed for the researcher to observe one of your science lessons. The outcomes of this research will contribute to improving students' science learning experiences involving the use of digital learning in university science education. Before you decide to participate in this research study, please check the selection criteria that you must be above 18 years old.

WHAT DOES MY PARTICIPATION INVOLVE?

If you decide to participate, you will allow the researcher to observe one of your science lessons. The duration and location of the activity is depended on the activity chosen by your teacher. There will be no recording, the researcher will only write notes on the observation.

ARE THERE ANY RISKS/INCONVENIENCE?

Participants may feel uncomfortable. The researcher will manage this by informing the participants in advance of in what manner and when the activity will take place. No judgement will be made about the activity being observed. The results of this study will inform enhanced use of digital devices for university science.

DO I HAVE TO TAKE PART IN THIS RESEARCH PROJECT?

Participation in this study is voluntary. It is completely up to you as to whether or not you decide to take part. If you decide not to participate, or to withdraw from the study, it will not affect your relationship with the researchers or the University of Technology Sydney or your university.

WHAT IF I WITHDRAW FROM THIS RESEARCH PROJECT?

If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting me on le.q.ly@student.uts.edu.au. If you withdraw from the study, I will not use your data. Your teacher will not know about your decision to withdraw from the study.

WHAT WILL HAPPEN TO INFORMATION ABOUT ME?

By signing the consent form, you consent to the research team collecting and using de-identified information about you for the research project. All this information will be treated confidentially. All data will be de-identified for analysis and reporting.

WHAT IF I HAVE ANY QUERIES OR CONCERNS?

If you have concerns about the research that you think we can help you with, please feel free to contact me on le.q.ly@student.uts.edu.au, or my supervisors Professor Matthew Kearney (matthew.kearney@uts.edu.au) or Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

You will be given a copy of this form to keep.

NOTE:
This study has been approved in line with the University of Technology Sydney Human Research Ethics Committee [UTS HREC] guidelines. If you have any concerns or complaints about any aspect of the conduct of this research that you wish to raise independently of the research team, please contact the Ethics Secretariat on ph: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number ETH22-7239. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

CONSENT FORM

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

I _________________________[participant's name] agree to participate in the research project being conducted by Le Quan from University of Technology Sydney (15 Broadway, Ultimo NSW 2007, Australia). Contact detail is le.q.ly@student.uts.edu.au.

I have read the Participant Information Sheet or someone has read it to me in language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney or my university.

I understand that I will be given a signed copy of this document to keep.

I am aware that I can contact Le Quan if I have any concerns about the research.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

Appendix I: Participant Information Sheet (Phase Two – Student Questionnaire)

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

WHO IS CONDUCTING THIS RESEARCH?

My name is Le Quan Ly and I am a doctoral student at University of Technology Sydney, Australia. My contact detail is le.q.ly@student.uts.edu.au. My supervisors are Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

WHAT IS THIS RESEARCH ABOUT?

The research project investigates the use of digital learning in university science education. This second phase involves observation of one activity designed by your teacher. I seek to find out further information about how you use digital devices for your science learning after the activity observation.

WHY HAVE I BEEN INVITED?

You have been invited to participate because you are a science student in university, and you will have participated in an activity that I recently observed. The outcomes of this research will contribute to improving students' science learning experiences involving the use of digital learning in university science education. Before you decide to participate in this research study, please check the selection criteria that you must be above 18 years old.

WHAT DOES MY PARTICIPATION INVOLVE?

If you decide to participate, the student questionnaire is approximately 10 minutes. Participants who completed the questionnaire will have a chance to win one of the two 50$ AUD gift cards.

ARE THERE ANY RISKS/INCONVENIENCE?

Participating in this questionnaire has no risk to the participants. The questionnaire is anonymous, your teacher(s) do not have access to the responses of this questionnaire. The results of this study will inform enhanced use of digital devices for university science.

DO I HAVE TO TAKE PART IN THIS RESEARCH PROJECT?

Participation in this study is voluntary. It is completely up to you as to whether or not you decide to take part. If you decide not to participate, or to withdraw from the study, it will not affect your relationship with the researchers or the University of Technology Sydney or your university.

WHAT IF I WITHDRAW FROM THIS RESEARCH PROJECT?

If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by exiting the questionnaire. If you withdraw from the study, I will not use your data. Your teacher will not know about your decision to withdraw from the study.

WHAT WILL HAPPEN TO INFORMATION ABOUT ME?

By proceeding to page two of the online questionnaire (after the opening information page), you consent to the research team collecting and using anonymous questionnaire information for the research project. All this information will be treated confidentially. No information will be collected about your identity or your university's identity. The questionnaire platform entirely de-identifies and make your responses entirely anonymous.

WHAT IF I HAVE ANY QUERIES OR CONCERNS?

If you have concerns about the research that you think we can help you with, please feel free to contact me on le.q.ly@student.uts.edu.au, or my supervisors Professor Matthew Kearney (matthew.kearney@uts.edu.au) or Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

You are given a copy of this form to keep.

NOTE:
This study has been approved in line with the University of Technology Sydney Human Research Ethics Committee [UTS HREC] guidelines. If you have any concerns or complaints about any aspect of the conduct of this research that you wish to raise independently of the research team, please contact the Ethics Secretariat on ph: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number ETH22-7239. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Appendix J: Participant Information Sheet (Phase Two – Student Focus Group)

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

WHO IS CONDUCTING THIS RESEARCH?

My name is Le Quan Ly and I am a doctoral student at University of Technology Sydney, Australia. My contact detail is le.q.ly@student.uts.edu.au. My supervisors are Professor Matthew Kearney (matthew.kearney@uts.edu.au) and Dr Tracey-Ann Palmer (tracey-ann.palmer@uts.edu.au).

WHAT IS THIS RESEARCH ABOUT?

The research project investigates the use of digital learning in university science education. This second phase involves observation of one activity designed by your teacher. I seek to find out further information about how you use digital devices for your science learning in this activity.

WHY HAVE I BEEN INVITED?

You have been invited to participate because you are a university science student and your teacher(s) agreed for the researcher to observe one of your science lessons. You have expressed your interest to participate in this brief focus group. Before you decide to participate in this research study, please check the selection criteria that you must be above 18 years old.

WHAT DOES MY PARTICIPATION INVOLVE?

If you participate in the focus group, it will take approximately 20-30 minutes of your time. It will be held in non-teaching hours on your campus. You will collect and submit the artefacts online (e.g., portfolios, journal, annotation of your daily science learning activities, especially outside classroom time and space) before the focus group. These artefacts will be use in the focus group discussion. This focus group will be audio recorded and transcribed to capture the discussion content.

ARE THERE ANY RISKS/INCONVENIENCE?

Participants may feel uncomfortable. The researcher will manage by informing the participants in advance of in what manner and when the activity will take place. The focus group will be conducted in the presence of your classmates. All the response is de-identified, your teacher(s) do not have access to the responses of this phase. No judgement will be made in this focus group. The results of this study will inform enhanced use of digital devices for university science.

DO I HAVE TO TAKE PART IN THIS RESEARCH PROJECT?

Participation in this study is voluntary. It is completely up to you as to whether or not you decide to take part. If you decide not to participate, or to withdraw from the study, it will not affect your relationship with the researchers or the University of Technology Sydney or your organisation.

WHAT IF I WITHDRAW FROM THIS RESEARCH PROJECT?

If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting me on le.q.ly@student.uts.edu.au. If you withdraw from the study, I will not use your data. Your teacher will not know about your decision to withdraw from the study.

WHAT WILL HAPPEN TO INFORMATION ABOUT ME?

By signing the consent form, you consent to the research team collecting and using de-identified information about you for the research project. All this information will be treated confidentially. All data will be de-identified for analysis and reporting.

WHAT IF I HAVE ANY QUERIES OR CONCERNS?

If you have concerns about the research that you think we can help you with, please feel free to contact me on le.q.ly@student.uts.edu.au, or my supervisors Matthew.Kearney@uts.edu.au or Tracey-Ann.Palmer@uts.edu.au.

You will be given a copy of this form to keep.

NOTE:

This study has been approved in line with the University of Technology Sydney Human Research Ethics Committee [UTS HREC] guidelines. If you have any concerns or complaints about any aspect of the conduct of this research that you wish to raise independently of the research team, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number ETH22-7239. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

CONSENT FORM

UTS HREC Approval No. ETH22-7239
Use of Digital Learning in University Science Education

I ________________________[participant's name] agree to participate in the research project being conducted by Le Quan from University of Technology Sydney (15 Broadway, Ultimo NSW 2007, Australia). Contact detail is le.q.ly@student.uts.edu.au.

I have read the Participant Information Sheet or someone has read it to me in language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney or my university.

I understand that I will be given a signed copy of this document to keep.

I am aware that I can contact Le Quan if I have any concerns about the research.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

Appendix K: Phase Two Activity Observation – Sample Notes

<table>
<tr><td>Observation No.</td><td>8</td><td>Observation date</td><td colspan="2">24 Aug 2023</td><td>Teachers</td><td colspan="3">Coordinator (lead teacher) and four lab demonstrators</td></tr>
<tr><td>Location</td><td>University D</td><td>Observation time</td><td colspan="2">5-8 pm</td><td>Activity type</td><td colspan="3">lab</td></tr>
<tr><td>Subject name</td><td colspan="8">Microbiology</td></tr>
<tr><td>Activity topic</td><td>Urinary tract infection (UTI)</td><td colspan="2">Semi-structured interviews</td><td colspan="5">Teacher: Case 6_Teacher
Learning designer: Case 6_Learning designer</td></tr>
<tr><td>Student no.</td><td>66</td><td>Observation consented</td><td>19</td><td>Questionnaires</td><td>37</td><td>Focus groups</td><td>3</td></tr>
</table>

<table>
<tr><th colspan="3">Indicators</th><th>Notes</th></tr>
<tr><td rowspan="6">iPAC</td><td rowspan="2">Personalisation</td><td>Agency</td><td>• Students attended their schedule lab time on campus
• During the lab duration, students followed the lab experiment procedure
• Students could access to their learning materials and lab notes in and outside of lab time via OneNote and Canvas</td></tr>
<tr><td>Customisation</td><td>• It is a one size fit all activity</td></tr>
<tr><td rowspan="2">Authenticity</td><td>Task</td><td>• Students worked in groups to perform experiments. They used the Surface Pro to access the learning resources and record their results</td></tr>
<tr><td>Settings</td><td>• It was in a PC2-standard science laboratory classroom</td></tr>
<tr><td rowspan="2">Collaboration</td><td rowspan="2">Conversation</td><td rowspan="2">• F2f class, students performed the experiments using the instruction available on OneNote
• There was lots of collaboration and discussion throughout the lab between teachers and students
• Students were enrolled by teachers; teachers have access to student results.
• Students had space on OneNote to collaborate</td></tr>
<tr></tr>
</table>

		Co-creation	• F2f class, students performed the experiments and record results in groups using the instructions available on OneNote • Students collaborated between different stations based on different experiment activities
Innovation	Purpose of learning		• The mobile device was used to facilitate the collaboration and learning experiences
	Context of learning		• It was in the science laboratory classroom with specialised high-tech audio-visual facilities
	Role of teachers and relationship with students		• The lead teacher provided instructions at the start of the class • Teachers supported students during the activity • There were no external facilitators
	Role of students		• Students used Surface Pro and OneNote in the scheduled on-campus lab

Appendix L: Phase Two Teacher Questionnaire

Phase Two Digital Learning Evaluation for University Science Teachers: Specific Task Questionnaire
(UTS HREC Approval No. ETH22-7239)

Welcome to this short questionnaire. The questionnaire asked you questions about the science activity task that you just implemented and how portable devices were used to support your science students' learning.

The questionnaire should take approximately 10 minutes to complete. In undertaking questions, please DO NOT USE the 'Back' and 'Forward' buttons in your browser. Please use the buttons at the bottom of each screen.

There are no 'right' or 'wrong' answers! The response options are not necessarily linked to the quality of the task or the learning outcomes. Please complete all questions as honestly as possible.

Thank you.

BACKGROUND ITEMS

Q1
How many years in total have you been teaching science subject(s) in universities?

○ less than 2 years (1)

○ 2-9 years (2)

○ 10-20 years (3)

○ 20+ years (4)

Q2
How experienced are you with using digital technologies in your science teaching in universities?

○ Inexperienced (1)

○ Occasional user (2)

○ Experienced (3)

○ Very experienced (4)

Q3
In this questionnaire, you will consider the use of digital technologies in the activity that you have just implemented in your teaching. What type of *portable* digital device did your students use in this activity? Choose all that applied.A smart phone (1)

○ Tablet device e.g., iPad (2)

○ A laptop (3)

○ Two-in-one device (4)

○ Other (please specify) (5) ________________

INTRODUCTION

In the following section, you will be presented with certain questions about the behaviour of your students in the activity you just implemented.

Please respond to the items to the best of your ability. Select the option that best describes your response to each statement on a scale of 1 to 5, where "1" means "Strongly disagree" (SD) and "5" means "Strongly agree" (SA).

Q4

Collaboration using digital devices > Conversation

Collaboration means that learners use their digital device to make rich connections to other people and resources. The networking capability of digital devices can potentially create shared, socially interactive environments.

The following 3 items focus on the extent to which learners in your chosen activity held conversations through the digital device with peers, teachers and other experts.

When my students used digital devices to learn in the activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Discussed the work online with their friends/peers e.g., discussed ideas via email, SMS, Zoom, Twitter, Microsoft Teams, Facebook etc. (1)	○	○	○	○	○
Discussed the work online with people they don't know e.g., discussed with a librarian, a work professional such as a scientist (2)	○	○	○	○	○
Communicated with others using a variety of text, image or video modes e.g., by using SMS, Facebook, Instagram, Twitter (3)	○	○	○	○	○

Q5
Collaboration using digital devices > Co-creation

The following 3 items focus on the extent to which learners in your chosen activity co-created digital content and shared information.

When my students used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Worked together to create a digital product e.g., co-created a video, podcast, photo, document (1)	○	○	○	○	○
Shared digital content e.g., shared a video, podcast, photo, document (2)	○	○	○	○	○
Contributed to existing digital content e.g., tagged a photo, commented on a blog post, played a multi-player game (3)	○	○	○	○	○

Q6
Personalisation using digital devices > Agency

Personalisation includes pedagogical features such as learner choice, autonomy and customisation.

The following 3 items focus on the extent to which learners in your chosen activity had control over the place (physical and/or virtual), pace and time they learn, and autonomy over their learning content.

When my students in used digital devices to learn in this activity, they:
Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Choose the place to do the activity e.g., choose to work on the bus, at home, in the library or museum (1)	○	○	○	○	○
Determined the pace at which they did the activity (2)	○	○	○	○	○
Decided what they wanted to learn e.g., chose their own question, problem or project to explore (3)	○	○	○	○	○

Q7
Personalisation using digital devices > Customisation

The following 4 items focus on the extent to which learners in your chosen activity could customise their m-learning experience, both at the level of the tool (e.g., an app) and the activity itself.

When my students used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Were guided by the app(s) based on *their* past use e.g., by previous game challenge levels, YouTube recommendations prompted by their previous views (1)	○	○	○	○	○
Tailored app(s) settings to their preferences e.g., customised location on/off, camera/microphone access, time limit settings (2)	○	○	○	○	○
Received *individualised* information through the app(s) about themselves e.g., information about the number of steps walked, calories eaten, hours slept (3)	○	○	○	○	○
Customised feeds and links for *their* learning needs e.g., tailored social media or news feeds (4)	○	○	○	○	○

Q8
Authenticity using digital devices > Context

Authenticity means that the digital learning experience provides real-world relevance and personal meaning to the learner.

The following 3 items focus on the extent to which learners' digital learning experiences in your chosen activity were enhanced by realistic, meaningful contexts, such as through 'in situ' learning in relevant physical or virtual settings.

When my students used digital devices to learn in this activity, they:
Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Learned in a place suggested by the topic e.g., learned about plants in the botanic garden, science in a museum, ecology in national park stars under the night sky(1)	○	○	○	○	○
Learned in a realistic, virtual space e.g., use of context-aware, augmented (AR) or virtual reality (VR) apps, science simulation (2)	○	○	○	○	○
Learned at a time suggested by the topic e.g., night-time observation of stars; observe animal behavior on a field trip over the weekend (3)	○	○	○	○	○

Q9
Authenticity using digital devices > Task

The following 4 items focus on the extent to which the digital learning tasks are realistic and offer problems relevant to the real world; and the extent to which the tasks and associated processes require use of apps and tools that replicate those of real-world practitioners.

When my students used digital devices to learn in this activity, they:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Worked *like an expert* e.g., collected data using GPS like a scientist; identified plants species like a botanist (1)	○	○	○	○	○
Participated in *real-world* activities that benefit society e.g., environmental projects such as waste management system or monitored water quality (2)	○	○	○	○	○
Learned *serendipitously* in an *unplanned* way e.g., during a game, research prompted by an unexpected query (3)	○	○	○	○	○
Engaged in activities related to *everyday life* e.g., informed decision based on provided data, interpreted statistics from a newspaper or report (4)	○	○	○	○	○

Q10
My students' overall experience in this activity using digital devices

Please select one answer per row.

	1 SD (1	2 (2)	3 (3)	4 (4)	5 SA (5)
Using digital devices improved my students' science learning (1)	○	○	○	○	○
My students enjoyed using digital devices to learn science (2)	○	○	○	○	○
My students found it difficult to learn science in using digital devices (3)	○	○	○	○	○
Using digital devices helped my students to understand concepts in science (4)	○	○	○	○	○
Using digital devices helped my students to practise science skills (5)	○	○	○	○	○

Innovation

Q11
Consider the approaches used in this activity, and how different they are to *your typical* approaches *without the use of digital devices* in the same activity:

In this digital learning activity:
Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Use of a digital device *fundamentally* changed the way that learning occurs (1)	○	○	○	○	○
The context of learning was *radically* different (in terms of setting, time, or mode of task) (2)	○	○	○	○	○
The range of stakeholders facilitating learning was *greatly* expanded (e.g., teachers, family, community members and other experts) (3)	○	○	○	○	○
Learners were granted *significantly* more agency than would normally be the case (4)	○	○	○	○	○
Learners' overall experience was *fundamentally* different from what they would normally experience (5)	○	○	○	○	○

Q12
In this digital learning activity, my students worked: (*Can tick more than one option.*)

- In the lecture (1)
- In the tutorial (2)
- In the laboratory classroom (3)
- In the computer lab (4)
- Out of the classroom, but on campus e.g., hall, student breakout spaces (5)
- In educational setting outside of campus e.g., excursion/field trip, museum (6)
- At home (7)
- In other places e.g., on the bus, in coffee shop, shopping centre (8)
- Other (please specify) (9)

Q13
What were the main applications (or apps) used by your students in your chosen digital learning activity?

Q14
Briefly describe how your students used these apps in your chosen digital learning activity?

Appendix M: Phase Two Student Questionnaire

Phase Two Digital Learning Evaluation for University Science Student: Specific Task Questionnaire
(UTS HREC Approval No. ETH22-7239)

Welcome to this short questionnaire about your use of digital devices for a science activity that you just completed which nominated by your university science teacher. Your responses will help us understand how you used a digital device to help you learn in this activity. The questionnaire should take approximately 10 minutes to complete.

Participation in this questionnaire is voluntary and confidential. Your anonymous responses may be used for research purposes (UTS HREC Approval No. ETH22-7239). See Phase Two Student Information sheet (Questionnaire). If you have any queries about the questionnaire or this doctoral research, please contact Le Quan Ly (le.q.ly@student.uts.edu.au) or my University of Technology Sydney, supervisors Professor Matthew Kearney (Matthew.Kearney@uts.edu.au) or Dr Tracey-Ann Palmer (Tracey-Ann.Palmer@uts.edu.au).

There are no 'right' or 'wrong' answers! Please complete all of the questions as honestly as possible. If you do not wish to complete the questionnaire or change your mind about participation during the questionnaire, simply exit the questionnaire. Your teacher will not know if you completed the questionnaire, so your decision to participate will not affect your relationship with your teacher or your assessments in any way.

Upon completion of the questionnaire, you will have a chance to win one of the two AUD $50 gift cards by sending an email to le.q.ly@student.uts.edu.au. There is no way your email can be linked to your questionnaire responses, i.e., your questionnaire responses will remain anonymous.

Q1
Please choose one of the following options.

○ I have read the above details and agree that my anonymous questionnaire responses may be used for research purposes (1)

○ I have read the above details and do not agree to complete this questionnaire. (2)

BACKGROUND ITEMS

Q2
What undergraduate year group are you currently enrolled in at university?

○ First year (1)

○ Second year (2)

○ Third year (3)

○ Fourth year (4)

○ Other (please specify) (5) ________________________________

Q3
In this questionnaire you will think about your use of a digital device in the activity you just participated.

What type of digital device did you use in this activity? Choose all that applied.

◯ A smart phone (1)

◯ Tablet device e.g., iPad (2)

◯ A laptop (3)

◯ Two-in-one device (4)

◯ Other (please specify) (5)__________

Q4
How confident are you about using digital devices to help you learn at university?

	Not confident at all (1)	2 (2)	3 (3)	4 (4)	Very confident (5)
Tick one	◯	◯	◯	◯	◯

MY EXPERIENCES LEARNING WITH A DIGITAL DEVICE in this activity

In the following sections, you will be asked questions about your experiences using a digital device during this activity.

Select the option that best describes your response to each statement on a scale of 1 to 5, where "1" means "Strongly disagree" (SD) and "5" means "Strongly agree" (SA)

Q5
Working together using digital devices

When I used a digital device during this activity, I used it to:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Talk about the work displayed on the screen with others next to me e.g., talking with a friend next to me about homework shown on the screen (1)	○	○	○	○	○
Discuss the work with friends online e.g., discussing ideas with peers via email, SMS, Zoom , Microsoft Teams, Facebook etc. (2)	○	○	○	○	○
Discuss the work online with people I don't know e.g., a librarian, interview a work professional such as a scientist (3)	○	○	○	○	○

Q6
Working together using digital devices *continued*

When I used a digital device during this activity, I used it to:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Make something together with friends e.g., make a video, photo, document, wiki; collaborate on Padlet, sharing document on One drive, Google drive (1)	○	○	○	○	○
Exchange something with others online e.g., playing a multi-player game, tagging a video, commenting on a photo (2)	○	○	○	○	○
Share and compare items generated on my device with others e.g., Fitbit data such as 'steps walked', share a photo or file (3)	○	○	○	○	○

Q7
Personal learning using digital devices

When I used a digital device during this activity:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
I *chose* the place(s) to work (1)	○	○	○	○	○
I *decided* the time to work (2)	○	○	○	○	○
I *chose* what I wanted to learn (3)	○	○	○	○	○
I *chose* my own ways to work (4)	○	○	○	○	○
I *selected* my own apps to help me learn (5)	○	○	○	○	○

Q8
Personal learning using digital devices *continued*

When I used a digital device during this activity:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
I *customised* the settings on the app/device (without an administrator) e.g., location on/off, camera/microphone access; time limits; background photo (1)	○	○	○	○	○
The app/device *guided* me, based on *my* past use e.g., chemistry game challenge levels, YouTube recommendations (2)	○	○	○	○	○
The app/device gave me special information *about me* e.g., my heart rate; the number of steps I walked; the route I took, real-time weather data for my location (3)	○	○	○	○	○

Q9
Relevant and meaningful learning using digital devices *continued*

When I used a digital device during this activity, I used it to:

Please select one answer per row.

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Learn through a *community* activity/project e.g., science projects that include real scientists, such as environmental projects such as waste management system or monitor water quality (1)	○	○	○	○	○
Make my learning *relevant* to my life e.g., measure blood glucose level, heartbeat (2)	○	○	○	○	○
Work more *like an expert* e.g., collect data using GPS, compass or map; identify plant species using an app (3)	○	○	○	○	○
Consider *experts' views* on the topic e.g., from a TED-Ed Talk, expert's YouTube channel or guest speakers (4)	○	○	○	○	○

Q10
My overall learning experience with a digital device in this activity

Please select one answer per row, from "Strongly Disagree" (1) to "Strongly Agree" (5).

In this activity:

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Using a digital device improved my university science learning (1)	○	○	○	○	○
I enjoyed using a digital device to learn about university science (2)	○	○	○	○	○
Using a digital device to learn about university science was a lot of fun (3)	○	○	○	○	○

Q11
My overall learning experience with a digital device in this activity cont.

Please select one answer per row, from "Strongly Disagree" (1) to "Strongly Agree" (5).

In this activity:

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
I found it difficult learning university science using a digital device (1)	○	○	○	○	○
Using a digital device helped me to understand science concepts in university (2)	○	○	○	○	○
Using a digital device helped me to practise university science skills (3)	○	○	○	○	○

Q12
Overall learning experience with a digital device in this activity cont.

Consider your overall experience learning science *with a digital device* in this activity, and how different it was to the usual way you learn in university *without a digital device*.

Please select one answer per row, from "Strongly Disagree" (1) to "Strongly Agree" (5).

In this activity:

	1 SD (1)	2 (2)	3 (3)	4 (4)	5 SA (5)
Use of a digital device *fundamentally* changed the way I learn science (1)	○	○	○	○	○
The place and time in which I learned science was *radically* different (2)	○	○	○	○	○
My science learning was supported by people *other than just* my teacher e.g., family, community members and external experts (3)	○	○	○	○	○
I had *complete* freedom in the choice of science task and the way I did it (4)	○	○	○	○	○
My overall experience was *totally different* from any science task I have ever done before (5)	○	○	○	○	○

Q13
What were the main applications (or apps) you used during this activity?

____

Q14
Briefly describe how you used these apps during this activity?

Appendix N: Phase Two Teacher Semi-structured Interview Questions

Use of Digital Learning in University Science Education
(UTS HREC Approval No. ETH22-7239)

Please complete this questionnaire before the interview.

1. What is the aim of the task for student learning?
2. What is your role as a teacher in this task to support students' learning?
3. Can you talk about the students' use of technology and how that supports their learning?
4. Use iPAC slider as a stimulus to talk about the iPAC dimensions. Explain each dimension answer decision?
5. In what way do you think this task is innovative? Use Innovation slider to explain each dimension?

Appendix O: Phase Two Student Focus Group Questions

Use of Digital Learning in University Science Education
(UTS HREC Approval No. ETH22-7239)

The participants are the driver of the conversation in this focus group session. Through direct discussion, students will share their artefacts, screentime information and/or other visual stimulus to reflect about their experiences when using digital devices to learn.

1. Briefly describe what apps do you use and how you use these apps during this activity?
2. How do you think the use of these apps supports your learning?
3. Which app(s) do you use outside of your class time? What do you use it for?

The researcher will explain the iPAC dimension to students before asking the following questions:

4. Use the iPAC slider as a stimulus to talk about the dimensions. Explain each dimension answer decision? Would you like to talk about your experiences of these approaches (1-2 dimensions of these sliders).

The researcher will explain the terminology “innovation” to students before asking the following questions:

5. Do you think this task is innovative? Use innovation slider to answer and explain why?
6. In what ways does your use of digital technologies to learn different to the way you normally learn?

Appendix P: Phase Two Learning Designers Semi-structured Interview Questions

Use of Digital Learning in University Science Education
(UTS HREC Approval No. ETH22-7239)

1. How do you think your learning design practices enhance students’ science learning?
2. What is your perception of a teacher in their learning design to support students’ learning?
3. What is your view of students’ use of technologies to support their science learning?
4. Use iPAC slider as a stimulus to talk about the dimensions in typical lesson design. Explain each dimension answer decision.
5. Can you share one of the tasks that you think is innovative? In what way do you think this task is innovative? Use Innovation slider to explain.

Appendix Q: iPAC Slider

Use of Digital Learning in University Science Education
(UTS HREC Approval No. ETH22-7239)

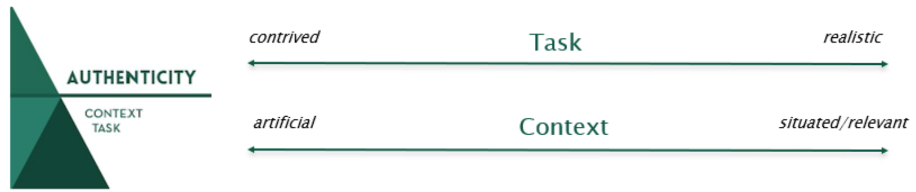
Question 1
Please choose your role below:

- Teacher
- Learning designer
- Student

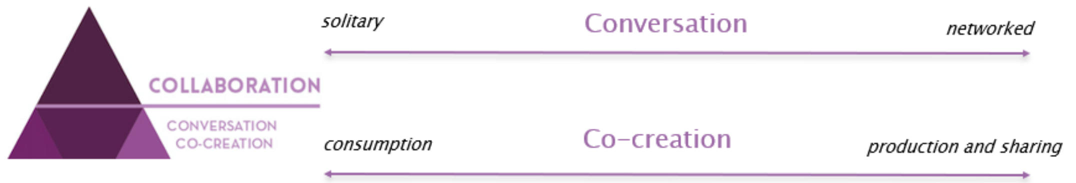
Question 2

Figure: iPAC framework

Please rate your activity using the Personalisation, Authenticity and Collaboration sliders below:


AUTHENTICITY
CONTEXT
TASK
contrived
Task
realistic
artificial
Context
situated/relevant

LOW presence
HIGH presence
Task
Context


COLLABORATION
CONVERSATION
CO-CREATION
solitary
Conversation
networked
consumption
Co-creation
production and sharing

LOW presence
HIGH presence
Conversation
Co-creation

Appendix R: Innovation Slider

Use of Digital Learning in University Science Education
(UTS HREC Approval No. ETH22-7239)

Question 1
Please choose your role below:

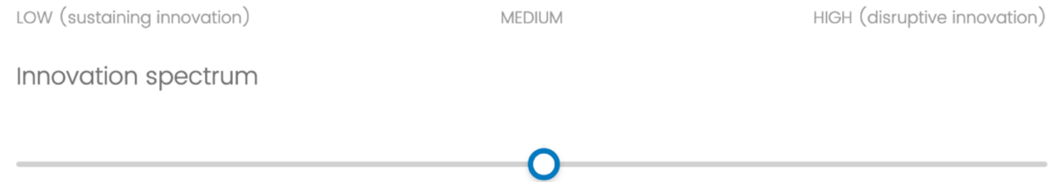
- Teacher
- Learning designer
- Student

Question 2
Please use the slider below to rate the level of innovation of the activity.

Criteria A: Purpose of the Learning
This criteria is used to measure how innovative or transformational the m-learning activity is. This could include the nature of the curriculum, the learning objectives that are set. It might also include the nature of the task or activity that students undertake. Crucially,
it also includes the extent to which the use of a mobile device is embedded or integral to the task (see below for further details)

Characteristics of this criteria

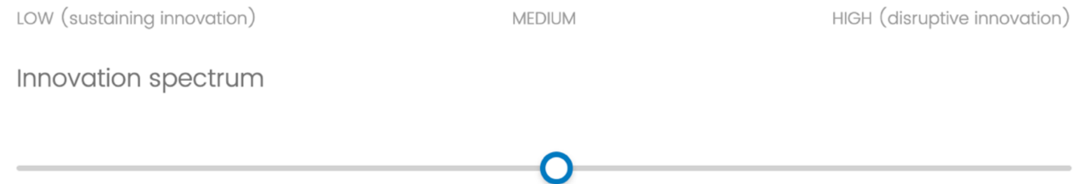
Low (1)	Medium (2)	High (3)
• Learning activity/task is adapted from existing practices or approaches to make them more effective or efficient, but not to radically change them; • adapts existing pedagogies, practices or structures to make them more efficient/effective	• The learning activity/tasks modifies or adds something new, but this does not in itself fundamentally challenge or alter the underlying approaches to learning	• The learning activity/task changes the existing paradigm. • It creates new educational purposes or processes and challenges and fundamentally alters existing approaches and practices • It enables learning that could not occur without a mobile device.



Criteria B: Context of the Learning

This criteria is used to measure how innovative or transformational the context for the m-learning task is. This includes the place in which the m-learning task takes place and the time.

Low (1)	Medium (2)	High (3)
• Traditional or existing context (e.g., entirely undertaken in classroom)	• A mixture	• Radical departure for context (e.g., entirely undertaken in an informal setting)



Criteria C: Role of the teacher and their relationship with students

This criteria is used to measure the extent to which the role of the teacher and their relationship with students is different from a traditional teacher centred model in which the teacher is a disseminator of knowledge and students are passive recipients of information.

Low (1)	Medium (2)	High (3)
• Activity dominated by teacher • Teacher in traditional role - disseminator of information/objectives, etc.		• Teacher as facilitator/guide • Facilitator may not be a teacher - could be an external expert/member of the community • Teacher may be a learner alongside students (co-authoring)

LOW (sustaining innovation) MEDIUM HIGH (disruptive innovation)

Innovation spectrum

Criteria D: Role of the learner

This criteria is used to measure the extent to which the m-learning activity enables the learner to exercise choice about what and how they learn and undertake the task.

Low (1)	Medium (2)	High (3)
• Learners have little or no choice about how they use the mobiles to undertake learning tasks	• Learners have choice of how they undertake the task (e.g., at their own pace; in their own time)	• Learners have freedom to choose what they learn (e.g., the objectives)

LOW (sustaining innovation) MEDIUM HIGH (disruptive innovation)

Innovation spectrum

Appendix S: Phase One Survey Results from SPSS (Samples)

1. Descriptive Statistics

Descriptive Statistics

	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
P_A_chooseplace	132	1	5	3.58	.119	1.365
P_A_determinepace	132	1	5	3.70	.104	1.191
P_A_decidewhat	132	1	5	2.83	.121	1.388
P_C_guidedbyapp	132	1	5	2.40	.121	1.386
P_C_tailorsetting	132	1	5	2.76	.124	1.420
P_C_receivedindividualinfo	132	1	5	2.98	.126	1.451
P_C_customisedfeeds	132	1	5	2.45	.120	1.383
A_C_placesuggested	132	1	5	2.65	.132	1.518
A_C_realisiticspace	132	1	5	2.30	.129	1.487
A_C_suggestedtime	132	1	5	2.38	.127	1.460
A_T_likeanexpert	132	1	5	3.15	.120	1.373
A_T_realworldactivities	132	1	5	2.69	.122	1.404
A_T_likeanexpert	132	1	5	2.70	.112	1.283
A_T_dailyactivity	132	1	5	2.93	.118	1.360
C_Con_onlinepeer	132	1	5	3.20	.126	1.449
C_Con_onlineunknown	132	1	5	2.07	.105	1.212
C_Con_textimage	132	1	5	2.86	.129	1.482
C_Cocreate_digitalproduct	132	1	5	3.31	.138	1.588
C_Cocreate_sharecontent	132	1	5	3.46	.127	1.464
C_Cocreate_contribute existing	132	1	5	2.88	.129	1.483
Innovation_fundamentally changed	132	1	5	3.57	.109	1.249
radicallydifferent	132	1	5	3.43	.103	1.186
stakeholder	132	1	5	2.77	.123	1.419
moreagency	132	1	5	3.39	.101	1.163
differentoveralexperience	132	1	5	3.39	.099	1.137
Overal_improve	132	1	5	4.02	.080	.925
S_enjoy	132	1	5	4.05	.075	.859
S_founddifficulty	132	1	5	2.25	.091	1.044
Overal_helpunderstand	132	1	5	3.90	.083	.956
Overal_helppractise	132	1	5	3.68	.091	1.043
Valid N (listwise)	132					

2. Results for scale: all variables

Case Processing Summary

		N	%
Cases	Valid	132	100.0
	Excluded[a]	0	.0
	Total	132	100.0

3. Results of Personalisation (Agency) Subconstruct Analyses

Reliability Statistics

Cronbach's Alpha	N of Items
.655	3

Communalities

	Initial	Extraction
P_A_chooseplace	1.000	.634
P_A_determinepace	1.000	.641
P_A_decidewhat	1.000	.513

Extraction Method: Principal Component Analysis.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.788	59.604	59.604	1.788	59.604	59.604
2	.683	22.768	82.372			
3	.529	17.628	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component 1
P_A_chooseplace	.796
P_A_determinepace	.801
P_A_decidewhat	.716

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Composite Reliability

Item Number	Standardized Loading	Error Variance	Item R-Square	
1	.796	0.366	0.634	
2	.801	0.358	0.642	Delete
3	.716	0.487	0.513	Delete

Add Item

Composite Reliability: 0.815

Reset Form

4. Results of Personalisation (Customisation) Subconstruct Analyses

Reliability Statistics

Cronbach's Alpha	N of Items
.810	4

Factor Analysis

Communalities

	Initial	Extraction
P_C_guidedbyapp	1.000	.658
P_C_tailorsetting	1.000	.663
P_C_receivedindividualinfo	1.000	.488
P_C_customisedfeeds	1.000	.759

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.567	64.185	64.185	2.567	64.185	64.185
2	.680	16.988	81.174			
3	.455	11.381	92.554			
4	.298	7.446	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component 1
P_C_guidedbyapp	.811
P_C_tailorsetting	.814
P_C_receivedindividualinfo	.698
P_C_customisedfeeds	.871

Extraction Method: Principal Component Analysis.
a. 1 components extracted.

Composite Reliability

Item Number	Standardized Loading	Error Variance	Item R-Square	
1	0.811	0.342	0.658	
2	0.814	0.337	0.663	Delete
3	0.698	0.513	0.487	Delete
4	0.871	0.241	0.759	Delete

Add Item

Composite Reliability: 0.877

Reset Form

5. Results of Authenticity (Context) Subconstruct Analyses

Reliability Statistics

Cronbach's Alpha	N of Items
.781	3

Factor analysis

Communalities

	Initial	Extraction
A_C_placesuggested	1.000	.726
A_C_realisiticspace	1.000	.557
A_C_suggestedtime	1.000	.814

Extraction Method: Principal Component Analysis.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.096	69.876	69.876	2.096	69.876	69.876
2	.622	20.734	90.611			
3	.282	9.389	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component
	1
A_C_placesuggested	.852
A_C_realisiticspace	.746
A_C_suggestedtime	.902

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Composite Reliability

Item Number	Standardized Loading	Error Variance	Item R-Square	
1	0.852	0.274	0.726	
2	0.746	0.443	0.557	Delete
3	0.902	0.186	0.814	Delete

Add Item

Composite Reliability: 0.874

Reset Form

6. Results of Authenticity (Task) Subconstruct Analyses

Reliability Statistics

Cronbach's Alpha	N of Items
.768	4

Communalities

	Initial	Extraction
A_T_likeanexpert	1.000	.424
A_T_realworldactivities	1.000	.706
A_T_likeanexpert	1.000	.602
A_T_dailyactivity	1.000	.643

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.375	59.381	59.381	2.375	59.381	59.381
2	.875	21.877	81.258			
3	.394	9.853	91.111			
4	.356	8.889	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component
	1
A_T_likeanexpert	.651
A_T_realworldactivities	.840
A_T_likeanexpert	.776
A_T_dailyactivity	.802

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Composite Reliability

Item Number	Standardized Loading	Error Variance	Item R-Square	
1	0.651	0.576	0.424	
2	0.840	0.294	0.706	Delete
3	0.776	0.398	0.602	Delete
4	0.802	0.357	0.643	Delete

Add Item

Composite Reliability: 0.853

Reset Form

7. Results of Co-creation (Conversations) Subconstruct Analyses

Reliability Statistics

Cronbach's Alpha	N of Items
.785	3

Factor Analysis

Communalities

	Initial	Extraction
C_Con_onlinepeer	1.000	.723
C_Con_onlineunknown	1.000	.571
C_Con_textimage	1.000	.804

Extraction Method: Principal Component Analysis.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.098	69.927	69.927	2.098	69.927	69.927
2	.606	20.212	90.139			
3	.296	9.861	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component
	1
C_Con_onlinepeer	.850
C_Con_onlineunknown	.756
C_Con_textimage	.897

Extraction Method: Principal Component Analysis.
a. 1 components extracted.

Composite Reliability

Item Number	Standardized Loading	Error Variance	Item R-Square	
1	.850	0.278	0.722	
2	.756	0.428	0.572	Delete
3	.897	0.195	0.805	Delete

Add Item

Composite Reliability: 0.874

Reset Form

8: Results of Collaboration (Co-creation) Subconstruct Analyses

Reliability Statistics

Cronbach's Alpha	N of Items
.767	3

Communalities

	Initial	Extraction
C_Cocreate_digitalproduct	1.000	.716
C_Cocreate_sharecontent	1.000	.776
C_Cocreate_contribute existing	1.000	.563

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.055	68.491	68.491	2.055	68.491	68.491
2	.611	20.371	88.862			
3	.334	11.138	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component
	1
C_Cocreate_digitalproduct	.846
C_Cocreate_sharecontent	.881
C_Cocreate_contribute existing	.751

Extraction Method: Principal Component Analysis.
a. 1 components extracted.

Composite Reliability

Item Number	Standardized Loading	Error Variance	Item R-Square	
1	0.846	0.284	0.716	
2	0.881	0.224	0.776	Delete
3	0.751	0.436	0.564	Delete

Add Item

Composite Reliability: 0.867

Reset Form

9. Results of ANOVA test for Years of Teaching

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
aggregateP_A	Between Groups	.115	2	.058	.055	.946
	Within Groups	134.473	129	1.042		
	Total	134.588	131			
aggregateP_C	Between Groups	.676	2	.338	.263	.769
	Within Groups	165.432	129	1.282		
	Total	166.107	131			
aggregateA_C	Between Groups	2.153	2	1.076	.696	.500
	Within Groups	199.513	129	1.547		
	Total	201.666	131			
aggregateA_T	Between Groups	.559	2	.280	.255	.775
	Within Groups	141.499	129	1.097		
	Total	142.058	131			
aggregateC_Con	Between Groups	1.340	2	.670	.495	.611
	Within Groups	174.528	129	1.353		
	Total	175.868	131			
aggregateC_Cocreate	Between Groups	4.403	2	2.201	1.420	.246
	Within Groups	200.038	129	1.551		
	Total	204.441	131			
aggregate_Innovation	Between Groups	4.681	2	2.340	2.671	.073
	Within Groups	113.032	129	.876		
	Total	117.712	131			

ANOVA Effect Sizes[a,b]

		Point Estimate	95% Confidence Interval	
			Lower	Upper
aggregateP_A	Eta-squared	.001	.000	.012
	Epsilon-squared	-.015	-.016	-.004
	Omega-squared Fixed-effect	-.015	-.015	-.004
	Omega-squared Random-effect	-.007	-.008	-.002
aggregateP_C	Eta-squared	.004	.000	.037
	Epsilon-squared	-.011	-.016	.022
	Omega-squared Fixed-effect	-.011	-.015	.022
	Omega-squared Random-effect	-.006	-.008	.011
aggregateA_C	Eta-squared	.011	.000	.058
	Epsilon-squared	-.005	-.016	.044
	Omega-squared Fixed-effect	-.005	-.015	.044
	Omega-squared Random-effect	-.002	-.008	.022
aggregateA_T	Eta-squared	.004	.000	.036
	Epsilon-squared	-.012	-.016	.021
	Omega-squared Fixed-effect	-.011	-.015	.021
	Omega-squared Random-effect	-.006	-.008	.011
aggregateC_Con	Eta-squared	.008	.000	.050
	Epsilon-squared	-.008	-.016	.035
	Omega-squared Fixed-effect	-.008	-.015	.035
	Omega-squared Random-effect	-.004	-.008	.018
aggregateC_Cocreate	Eta-squared	.022	.000	.082
	Epsilon-squared	.006	-.016	.068
	Omega-squared Fixed-effect	.006	-.015	.068
	Omega-squared Random-effect	.003	-.008	.035
aggregate_Innovation	Eta-squared	.040	.000	.114
	Epsilon-squared	.025	-.016	.100
	Omega-squared Fixed-effect	.025	-.015	.100
	Omega-squared Random-effect	.013	-.008	.053

a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.
b. Negative but less biased estimates are retained, not rounded to zero.

10. Results of ANOVA test for Experiences with Digital Teaching

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
aggregateP_A	Between Groups	4.600	1	4.600	4.601	.034
	Within Groups	129.988	130	1.000		
	Total	134.588	131			
aggregateP_C	Between Groups	7.935	1	7.935	6.522	.012
	Within Groups	158.173	130	1.217		
	Total	166.107	131			
aggregateA_C	Between Groups	6.694	1	6.694	4.463	.037
	Within Groups	194.972	130	1.500		
	Total	201.666	131			
aggregateA_T	Between Groups	2.659	1	2.659	2.480	.118
	Within Groups	139.399	130	1.072		
	Total	142.058	131			
aggregateC_Con	Between Groups	2.559	1	2.559	1.920	.168
	Within Groups	173.309	130	1.333		
	Total	175.868	131			
aggregateC_Cocreate	Between Groups	2.425	1	2.425	1.560	.214
	Within Groups	202.016	130	1.554		
	Total	204.441	131			
aggregate_Innovation	Between Groups	6.327	1	6.327	7.385	.007
	Within Groups	111.385	130	.857		
	Total	117.712	131			

ANOVA Effect Sizes[a,b]

		Point Estimate	95% Confidence Interval Lower	Upper
aggregateP_A	Eta-squared	.034	.000	.114
	Epsilon-squared	.027	-.008	.107
	Omega-squared Fixed-effect	.027	-.008	.106
	Omega-squared Random-effect	.027	-.008	.106
aggregateP_C	Eta-squared	.048	.002	.135
	Epsilon-squared	.040	-.005	.128
	Omega-squared Fixed-effect	.040	-.005	.127
	Omega-squared Random-effect	.040	-.005	.127
aggregateA_C	Eta-squared	.033	.000	.112
	Epsilon-squared	.026	-.008	.105
	Omega-squared Fixed-effect	.026	-.008	.105
	Omega-squared Random-effect	.026	-.008	.105
aggregateA_T	Eta-squared	.019	.000	.087
	Epsilon-squared	.011	-.008	.080
	Omega-squared Fixed-effect	.011	-.008	.079
	Omega-squared Random-effect	.011	-.008	.079
aggregateC_Con	Eta-squared	.015	.000	.078
	Epsilon-squared	.007	-.008	.071
	Omega-squared Fixed-effect	.007	-.008	.071
	Omega-squared Random-effect	.007	-.008	.071
aggregateC_Cocreate	Eta-squared	.012	.000	.073
	Epsilon-squared	.004	-.008	.065
	Omega-squared Fixed-effect	.004	-.008	.065
	Omega-squared Random-effect	.004	-.008	.065
aggregate_Innovation	Eta-squared	.054	.004	.143
	Epsilon-squared	.046	-.004	.137
	Omega-squared Fixed-effect	.046	-.004	.136
	Omega-squared Random-effect	.046	-.004	.136

a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.
b. Negative but less biased estimates are retained, not rounded to zero.

Appendix T: Sample of Transcripts

Transcripts	Codes
Researcher: So now we will use the iPAC slider to talk about the activity. Do you think in this activity your students have the agency so they can control the place, the pace and the time of their learning?	
Case 1a_Learning designer: Yes, they do. Although the area is specified in the field, they can go wherever they want, whenever they want. I mean, within the eight hours that we are in the field, but they can organise their day however they want.	Freedom in space and time, structured schedule, student-led
Researcher: So, you ask them what is your plan today?	
Case 1a_Learning designer: Yes. So, every morning we discuss, we do the morning briefing where we explain what is the focus, the aim of the day and then we discuss with each group, where they want to go every day, and there is a discussion there if we think that we need to say our opinion, we do that. If not, it's fine. But then they're on themselves. They can design their day the way they want.	Teacher facilitation, student planning, decision-making
Researcher: Okay. Thank you. Do you think this activity is tailored to your student learning need or is that one size fit everyone?	
Case 1a_Learning designer: I think it is tailored because at the end, the student can, they can use the app in different ways. Like, for example, a student can keep taking notes by hand if they wish. A student, if they wish, they can collect data with a compass. They can take photos with their phones. They can do whatever they want, but in the end of the day, they need to import everything to the app because when we mark what we see into the app, because we log into to the account of each student and we can, we access what the data, the observations that they collected. So, at the end, everything has to go there, but when you're in the field, they can use it however they want.	Multiple data collection methods, personalise preferences, task requirement
Researcher: In the app, do they have access to the setting if they want to customise anything they want to see?	
Case 1a_Learning designer: Yeah, there are so many settings that, there are different ways. There are fundamentally different ways that you can work with this app. Like, for example, when you	Customised app settings, varied

describe your rocks, when you do the rock ID in the field identification. There are different ways, for example, you can make a list of the rocks that you will encounter and then start adding from that list, or you can make the list as you go, or you have the option not to make the list, then the description of your data. There are different levels at which you can go and describe your data. You can stay at the surface or you can go very deep into the description of the data. So, all these, you know, there are different levels in almost every aspect of the app.	workflow
Researcher: Okay, and then we talk about the authenticity of the task. So do you think the task itself, it is realistic and connects to geologists?	
Case 1a_Learning designer: Yes, certainly. It's 100 percent realistic and, you know, when they're going to work as professional geologists, most likely they will be using an app to collect data, not the same app, but a similar app. So, it's a way to introduce them to the profession way with professional practice of geology.	Professional tasks, authentic tools, workplace practices
Researcher: Do you think the context, the place where the activity take place, is it also authentic as well?	
Case 1a_Learning designer: I mean, we are in a place where it's the largest lead ore deposit in the world. So, it's a place where geologists have been working here for decades, I think for a century. So, it's a place where many universities used and still come in this place to train their students. So, it's definitely a place where it's approximated the reward conditions.	Real-world settings, authentic field context

Appendix U: Summary of the Findings of the Thematic Analysis

1. Codes	2. Categories	3. Theme generated	4. Themes revised and mapped under the theory
• Enhancing visual communication • Collaborative data comparison • Sharing perspectives verbally around the devices • Facilitating discussion	• Technology-supported in-person discussion • Collaborative data interpretation • Verbal peer collaboration	Face-to-face discussion around the devices for in-person students	**Conversations around and through the devices:** Face-to-face conversations around devices
• Online conversations • Messaging peers with texts, photos or videos • Use of social media • Combining digital and verbal communication • Teacher or student-initiated	• Discuss work online with peers • Communicate with others using texts, image or videos with teacher or student-initiated apps	Discussion through the devices	**Conversations around and through the device:** Conversations through devices (teacher or student-initiated)
• Share experiment results via apps • Create collaboration spaces • Exchanging digital notes • Messaging for collaboration • Sharing digital data	• Collaborative data sharing • Peer collaboration and support • Digital note and document exchange	Share data and results with peers	**Sharing of data and co-production of digital product:** Exchange data

• Data analysis in groups • Sharing documents across multiple devices • Use of shared digital logbooks • Workload distribution and teamwork	• Collaborative document creation • Teamwork and task distribution	Collaborate to create digital products	**Sharing of data and co-production of digital products:** Co-produce digital products
• Data entry • Note-taking • Writing reports • Reading instructions • Reviewing materials • Searching for information • Gathering data • Conducting research • Accessing online resources • Exploring scientific concepts • Processing and analysing data • Performing calculations • Recording measurements • Annotating diagrams • Collaborating with peers • Communicating • Sharing results	• Information input • Content access and review • Research and gather information • Data processing and analysis • Collaboration and communication • Organisation and task management	Students choose additional mobile tools to support their learning	**Learners' choices and control:** Choice of slip-tasking (student-initiated)

• Hybrid learning • Synchronous learning on campus or online • Asynchronous learning	• Flexibility in learning modes	Students choose how to learn in hybrid activities	**Learners' choices and control:** Choice of mode of learning
• Flexibility in method of learning and workflow • Ownership of learning tools • Collaboration preferences	• On how to learn • On use of multimodal notetaking	Students make decisions on how to learn	**Learners' choices and control:** Choice of how to learn
• Planning and organisation • Flexible time management • Control over action and pace	• Student autonomy in spaces and paces	Students control their activity location and pace	**Learners' choices and control:** Control over pace and space
• Task relevance to place and space • Realistic app for professional work • Preparation for research and real-world applications	• Contextual relevance • Real-world applications • Professional alignment • Career readiness	Use realistic apps to perform discipline-specific tasks	Use of realistic apps
• Relevance, professional settings • Realistic contexts	• Authentic locations • Real-world settings	Learn in realistic and relevant context	Use of real-world contexts

• Temporal and spatial flexibility for asynchronous and hybrid learning • Multiple learning spaces • Flexible locations • Learning continuity • Seamless transitions	• Seamless learning across semiformal and informal spaces	Use of time and space	Learning across multiple spaces
• Customising tools • Tailoring learning experiences • Diverse options for data handling • Personalising workflow	• Personalise app settings and workflow	Students tailor mobile tools to suit their learning needs	Tailored app settings and workflow
• Choosing locations within constraints • Freedom to explore with time limits • Structuring own learning path • Limited freedom in what to learn • Self-paced content review • Structured tasks, flexible methods	• Structured tasks with flexible methods • Student-led data collection • Technology as a facilitative tool • Engagement flexibility within fixed content	Engaging in learning that is guided and self-regulated	**Features of Mobile Pedagogical Innovation:** Self-directed learning through structured autonomy
• Use of mobile apps to perform realistic tasks	• Use mobile devices to perform professional tasks	Students use mobile tools to perform professional tasks	**Features of Mobile Pedagogical Innovation:**

• Increased accuracy in data collection and analysis • Real-time tracking of field coverage • Accurate and real-time data collection	• Use mobile devices to perform data collection and analysis		Authentic learning tasks
• Improving workflow but not core tasks • Streamlining existing activities • Mobile devices replaced paper-based version • For convenience and access • Adding multimedia such as texts, photos and videos	• Workflow enhancement • Replacement of traditional tools • Improved access and convenience • Incremental, not transformation	Mobile practices did not substantially alter the existing paradigms.	**Features of Mobile Pedagogical Innovation:** Incremental innovation
• Learning still required physical presence • Activities remained to formal settings • Technology added flexibility, but did not change the existing settings, excepts for hybrid learning	• Fixed physical learning requirements • Dominance of formal and campus spaces • Supplemented, not replaced by technology • Partial adoption of hybrid learning	Except for hybrid learning, synchronous learning activities largely remained in formal settings regardless of the use of mobile tools	**Perceived barriers to mobile pedagogical innovation:** Persistence of traditional settings

• Teacher-led during lectures and workshops • In labs and field trips: teachers facilitated but also dictate pace when needed • Students were given some independence, but teacher remains central • Limited external facilitators outside university	• Teachers maintained traditional roles • Limited external facilitators	Teachers' roles remain largely unchanged even with the use of mobile devices, with minimal involvement of external facilitators	**Perceived barriers to mobile pedagogical innovation:** Continuity of traditional teachers' roles and limited external facilitators

Appendix V: Ethics Approval Letter

Subject: HREC Approval Granted - ETH22-7239
Date: Thursday, 5 January 2023 at 1:21:50 pm Australian Eastern Daylight Time
From: Research.Ethics@uts.edu.au
To: [redacted]
Attachments: Ethics Application.pdf

Dear Applicant

Re: ETH22-7239 - "Use of digital learning in university science education"

Thank you for your response to the Committee's comments for your project. The Committee agreed that this application now meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application.

The following special conditions apply to your approval:

- Finalised versions of phase 2 data collection materials must be provided in the event that these require modification following the conclusion of phase 1. Substantive changes may require further review by the Committee.

You are reminded that this letter constitutes ethics approval only. This research project must also be undertaken in accordance with all UTS policies and guidelines including the Research Management Policy.

Your approval number is UTS HREC REF NO. ETH22-7239.

Approval will be for a period of five (5) years from the date of this correspondence subject to the submission of annual progress reports.

The following standard conditions apply to your approval:

- Your approval number must be included in all participant material and advertisements. Any advertisements on Staff Connect without an approval number will be removed.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project to the Ethics Secretariat.
- The Principal Investigator will notify the Committee of any event that requires a modification to the protocol or other project documents, and submit any required amendments prior to implementation. Instructions on how to submit an amendment application can be found here.
- The Principal Investigator will promptly report adverse events to the Ethics Secretariat. An adverse event is any event (anticipated or otherwise) that has a negative impact on participants, researchers or the reputation of the University. Adverse events can also include privacy breaches, loss of data and damage to property.
- The Principal Investigator will report to the UTS HREC or UTS MREC annually and notify the Committee when the project is completed at all sites. The Principal Investigator will notify the Committee of any plan to extend the duration of the project past the approval period listed above.
- The Principal Investigator will obtain any additional approvals or authorisations as required (e.g. from other ethics committees, collaborating institutions, supporting organisations).
- The Principal Investigator will notify the Committee of his or her inability to continue as Principal Investigator including the name of and contact information for a replacement.

This research must be undertaken in compliance with the Australian Code for the Responsible

Conduct of Research and National Statement on Ethical Conduct in Human Research.

You should consider this your official letter of approval. If you require a hardcopy please contact the Ethics Secretariat.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please don't hesitate to contact the Ethics Secretariat and quote the ethics application number (e.g. ETH20-xxxx) in all correspondence.

Yours sincerely,
The Research Ethics Secretariat

On behalf of the UTS Human Research Ethics Committees
C/- Research Office
University of Technology Sydney
E: Research.Ethics@uts.edu.au

Ref: E38