The Australian Curriculum and Inquiry-Based Learning in the Senior Secondary Science Classroom

by Deborah de Ridder

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Doctor of Philosophy

under the supervision of Dr Damian Maher
and Professor Nick Hopwood

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Faculty of Arts and Social Sciences

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Certificate of Original Authorship

I, Deborah Lea de Ridder, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of International Studies and Education, Faculty of Arts and Social Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. 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.

This research is supported by the Australian Government Training Program.

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> *"Scientific principles and laws do not lie on the surface of nature. They are hidden and must be wrested from nature by an active and elaborate technique of inquiry."* (John Dewy, 1920)

Although this thesis is complete, it is a part of a continuing journey of learning how best to support science teachers who continually reinvent their craft and adapt to a changing education environment.

As a part time student, I have received support from a range of supervisors along this journey. My greatest thank you goes to Prof Matthew Kearney and Dr Tracey-Ann Palmer who gave me unwavering support and encouragement along the way. Their support in delivering conference presentations, writing a paper and their patience at times was invaluable. Earlier in my candidature Dr Kimberley Pressick-Kilborn and A/Prof Wan Ng provided valuable support and inspiration. Finally, Dr Damian Maher and Prof Nick Hopwood have led me to the 'finish line' and I am immensely grateful. For Chapters 1, 6, and 7, I acknowledge the assistance of professional editor Dr Terry Fitzgerald, whose academic area is Education.

My heartfelt thank you to all who have participated in this study, including the education leaders, the four expert teachers, and the additional four teachers and their students at the case study schools, who gave their time freely.

Finally, thank you to my family for your patience and allowing me to pursue this work as a part-time student over the past six years.

Abstract

This study researches the perceptions and practices of educators implementing Inquiry-Based Learning (IBL) in senior secondary science in New South Wales (NSW), Australia. Prior to this research, the NSW jurisdiction enacted the Australian Curriculum (2012) through syllabus documents (NESA a,b,c,d), which set the standard for what should be taught in Australian schools. At the time of the release of the Australian Years 11 and 12 science curriculum significant emphasis was placed on science inquiry skills. Within the context of the NSW jurisdiction, science inquiry skills were embedded in a curriculum requirement named the 'Depth Study' in the syllabus documents (NESA, 2017 a,b,c,d), which all NSW schools implemented, and is the context of this research. This research addresses a notable gap in the literature, as there has been limited exploration into how these curriculum requirements have been operationalised in practice.

The positive value of learning about the nature of science through IBL in science education is recognised in this research by the research participants and promoted in curricula across the globe (Cheng et al., 2010; Concannon et al., 2020; de Jong et al., 2023; Furtak et al., 2012; Lazonder & Harmsen, 2016). Despite this positive value, some educators in this study reported challenges in implementing IBL. In contrast, the expert teacher study participants expressed confidence in their classroom practice in IBL.

An inductive and interpretive study was selected using a systematic Grounded Theory Design (GTD) methodology, situated in two study phases to deeply interpret the phenomena. Phase A of the study included semi-structured interviews of ten science education leaders. Phase B developed the findings of Phase A by deeply investigating the practices of four expert teachers using multiple qualitative data sources, which included classroom observations, interviews, student focus groups, artefacts, and documentary evidence. The qualitative data analysis involved systematic coding and thematic analysis to determine the core themes.

The findings provide timely and contemporary insight into the perceptions and practices of teachers who implemented IBL in senior secondary science through a compulsory curriculum requirement. The pedagogical practice was complex, influenced by the curriculum, underpinned by evaluation of practice, collaborative planning, and highly differentiated. The complexity of these interacting components is represented as theory (Chapter 7) by representing the interactions of pedagogical practice and curriculum influences. Emerging from the theory, this research's findings suggest a new conceptual framework, the Guided Inquiry Science Teaching (GIST) framework, which is presented as a summary of the findings.

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Preface

The following publication and conference papers are developed from aspects of this thesis:

Journal Article

de Ridder, D. (2021). Inquiry-based learning in years 11 and 12 secondary science. Teaching science, 67(2), 11-21.

Conference Presentations

de Ridder, D (2021, July) *Inquiry-based learning in Years 11 and 12 Science: Seeking a model for open-inquiry*. Paper presented at the 53rd Conference of the Australasian Science Education Research Association, Adelaide, Australia

de Ridder, D (2022, July) *Inquiry-Based Learning in Senior Secondary Science: 'What are Expert Teacher Practices?'* Paper presented at the 54th Conference of the Australasian Science Education Research Association, Perth, Australia

de Ridder, D (2023, July) *Investigating the Teacher Role That Supports Inquiry-Based Learning.* Paper presented at the 55th Conference of the Australasian Science Education Research Association, Cairns, Australia

Teacher Conference Presentations

de Ridder, D (2021, May) *Inquiry-Based Learning in Years 11 and 12 Science: A Grounded Theory study.* Workshop session presented at the Research Conversations Conference, St Andrews Cathedral School.

de Ridder, D (2022, October) *How much do you guide inquiry? (Depth Studies*). Workshop session presented at the Heads of Science Conference, Association of Independent Schools NSW, Sydney, Australia.

de Ridder, D (2023, October) *How much do you guide inquiry? (Depth Studies).* Workshop session presented at the Year 11 and 12 Conference, Science Teachers Association of NSW, Sydney, Australia.

de Ridder, D (2024, October) *Depth Studies: Get the GIST? (Guided Inquiry Science Teaching)* Workshop session presented at the Year 11 and 12 Conference, Science Teachers Association of NSW, Sydney, Australia.

Chapter 1

Introduction to the Thesis

1.1 Chapter Overview

Inquiry-based learning (IBL) is a valued learning approach in secondary school science education that has been adopted by education jurisdictions across the globe (Concannon et al., 2020; de Jong et al., 2023; Furtak et al., 2012; Lazonder & Harmsen, 2016). In the context of science education, IBL mirrors the nature of science by inviting students to pose questions and engage in scientific investigations with some independence (Duncan et al., 2021; Furtak et al., 2012). In school-based science education, IBL is important for preparing students for the future workforce of science-related employment, thus becoming informed world citizens (Tytler, 2007).

This study was situated in the context of New South Wales (NSW) Australia, where IBL has been implemented through the requirements of the Australian Curriculum (2012) and by the NSW science syllabuses (NESA, 2017 a,b,c,d) as part of the "Depth Studies" curriculum requirement in senior secondary science. Despite the intentions of the curriculum, little is known about contemporary pedagogical practices in senior secondary science that support students in completing practical scientific investigations in this context. The intended curriculum has been reported to be implemented inconsistently in other jurisdictions such as the US (Haag & Megowan, 2015; Miller et al., 2018; McLaughlin & MacFadden, 2014) and Canada (Scott et al., 2018), and it is likely that teachers in Australia may experience similar challenges.

The aspirational goal of this study is to develop a model of contemporary teacher practice from the empirical data. This chapter begins by introducing the researcher's personal orientation as the researcher. IBL is defined in the context of this study which; positions the importance of the research; introduces the study's context and purpose; poses the research questions; and describes the research design. Since this broad research into the phenomena of teaching practice has warranted a qualitative methodology, the choice of Grounded Theory Design is explained. The chapter concludes with an overview of the thesis and a chapter summary.

The researcher's position in this study as an experienced educator in the field of senior secondary science has added an essential perspective to this study. It has supported the selection of highly experienced educators as participants in the study and informed an interpretation of the findings.

1.2 The Researcher's Personal Orientation to the Research

With more than 25 years of classroom practice, in-service teacher education, pre-service teacher education, and work in education policy, the study began from the personal perspectives of both a practitioner and a researcher. The reasons for conducting this research are pragmatic: seeking to support teacher practice by investigating exemplary teacher practices and developing a pedagogical model that incorporates them. Personal practice in IBL has reflected a process of trial and error due to the paucity of research-informed models that could support the context of my teaching. It has since been discovered that other teachers have similarly trialled different approaches and developed their instructional practices in IBL over extended periods. This has caused a curiosity about whether the common elements of practice adopted by teachers in the NSW Australia context could be used as a basis for an instructional model.

Discussions with Australian science teachers prior to this study indicated that some imposed IBL research models that aimed to improve deficit practices did not have lasting effects after the researcher left the study. The teachers also expressed resentment about being told how to teach by someone they considered to be a non-expert in school classroom practice. The abundance of studies that position the researcher as the expert and give little recognition to the expertise of the participating teachers has been noted in Dobber et al.'s (2017) metanalysis of IBL teacher practice. Since then, very little research has attempted to fill this void. Rather than theorise yet another IBL model based on the literature, in this study I have sought to draw on the actual practices of classroom experts to develop a model of IBL practice.

Personal interactions with teachers have indicated that some teachers required support implementing IBL, and they often had minimal understanding of the tensions restricting their practices. It was also noted a reluctance of some teachers to engage in IBL in the senior years of schooling. Reasons given included the crowded senior science curriculum, the impacts of external testing, and the difficulties of managing the classroom. The perceptions of such educators have supported a perspective that has informed this study.

In contrast to reported deficits of teacher practice, prior to the study it was also noticed through my own work as an educator, many teachers were confident in their IBL practice in senior secondary science through the implementation of the 'Depth Study', a compulsory curriculum requirement in the senior science courses in the NSW Australia context (NESA, 2017 a,b,c,d).

The "Depth Study" requirement of the NSW Science curriculum is a mandatory curriculum requirement of at least 15 hours of class time for the Biology, Chemistry, Earth and Environmental Science and Physics NSW syllabuses. The Depth Study:

> *"…is any type of investigation/activity that a student completes individually or collaboratively that allows the further development of one or more concepts found within or inspired by the syllabus. It may be one investigation/activity or a series of investigations/activities." (NESA, 2017 a-d)*

Students must engage in the skill of questioning and predicting (NESA, 2017 a-d) which requires students to develop and evaluate research questions and hypotheses. Teachers may choose to spend the allocated time on practical investigations or a range of other science related activities.

Reasons for entering this research were for two reasons: (1) to contribute to IBL knowledge in senior secondary science education, and (2) to support and enhance teaching in this critical area by drawing on the findings from teacher experts. It is the intention that the findings will be applicable to the training of pre-service teachers, early career teachers and others with little experience of IBL.

1.3 Defining Inquiry-Based Learning

This section defines Inquiry-Based Learning (IBL) for the purposes of this study, recognising that it is a term used in a range of education disciplines (MacLaughlin & MacFadden, 2014). In science education, where the nature of *doing* science is a strong focus, IBL refers to the "skills, knowledge, and dispositions that are to be developed in students as a result of their engagement with classroom inquiry" (p. 929). The term "scientific inquiry" was considered as a focus for this study; however, this term does not reflect the nature of a broad range of inquiry activities that could be occurring in the science classroom in the study context.

The definitions of IBL used by researchers, teachers, and curriculum developers vary in the literature according to the nature of the learning activity and the philosophical perspective adopted. In science education, it is difficult to define IBL because it covers a broad range of approaches, for example, open and guided approaches to inquiry; scientific investigations; and inquiry activities that do not involve practical science work (Back & Byer, 2021). In addition, the emergence of inquiry activities that involve digital applications and virtual models have recently become a feature of IBL in the science classroom (de Jong et al., 2023; Liu et al., 2020). Any general definition of IBL in the NSW Australia context must recognise that IBL practices in school science education vary considerably (Levy et al., 2013; Tytler, 2007).

Considering the types of IBL that students can engage with in secondary science education, and the range of philosophies that underpin it, the well-referenced definition of IBL by Barron and Darling-Hammond (2008) is used in this study: IBL is "a student-centered, active learning approach focusing on questioning, critical thinking, and problem-solving" (p. 11). This broad definition of IBL considers a range of activities that feature in the secondary science context of this research, including practical scientific investigations; models; and digital and secondary source analyses.

1.4 Establishing the Importance of the Research

IBL in the NSW context of this research promotes aspects of the nature of science (NOS). The Depth Study curriculum requirement allows students to emulate scientific work and thus increase their motivation in science education (Duncan et al, 2021). According to McCormas and Clough (2020), NOS when applied to this research context includes developing an understanding of how scientists work, including an understanding of scientific inquiry. Learning about the nature of science is important to secondary science education for two reasons: the development of future scientists; and supporting the application of science in student's everyday lives (Tytler, in Lederman & Abell, 2014, p. 82). The importance of this research resides in the potential benefits of IBL in science education to learning and society.

The attraction of the brightest and the best students into science to tackle many of the worlds' problems has been recognised by the Organisation for Economic and Commercial Development (OECD), which organises the global testing of students' science skills and knowledge (OECD, 2019). OECD member countries place great importance on the testing regime of the OECD, and its highly regarded Programme for International Student Assessment (PISA) has heavily influenced Australian education policies (Commonwealth of Australia, 2024). PISA testing has had some positive benefits, although in recent times the apparent decline of science testing results globally has led to debate about the value of IBL (de Jong et al., 2023).

IBL requires students to be active learners who take responsibility for their own learning through self-regulated practices that can, however, present challenges to a classroom teacher's decisions about the purpose of their instruction. The reality of the IBL classroom is that learners might be working on different investigations and therefore require varying levels of differentiated support. In a differentiated classroom, teachers must adopt and adapt a range of pedagogical approaches as they act as facilitators, and this can be challenging for some teachers to enact without adequate support (Druhan et al., 2010; Haag & Megowan, 2015; Levy et al., 2013).

Teachers' perceptions of IBL also inform their pedagogical approaches and are thus relevant to this study. Some personal observations in science classrooms have indicated that teachers experience challenges in implementing IBL which support the findings of earlier Australian studies where both students and their teacher's expressed negativity toward longer forms of IBL activities (Goodrum et al., 2012; Whannell et al., 2018). In contrast, sound IBL practices have also been observed. The research gap relating to the status of IBL underpins the importance of this study.

A range of negative reports have attempted to use international testing results to diminish the advantages of IBL and position it as an ineffective pedagogical approach (Kirschner et al, 2006; Sweller, 2021). This debate appears to not recognise the range of IBL approaches available and may be misguided by an interpretation that IBL is synonymous with 'Discovery Learning'– an approach reported to have a negative impact on student learning (Adotimo & Klieme, 2020; Scott et al., 2018). Robust empirical studies are urgently required to inform this debate and ultimately to guide future science education practices. The paucity of empirical research on IBL in senior secondary science education adds little to a defensive argument for its merits.

Context-specific research is urgently required to arrive at a description of the specific roles that teacher play. Comparing historical IBL investigations is difficult due to their differing pedagogical approaches, levels of student guidance, participant age-groups, and research methodologies (Dobber et al., 2017). For example, should a teacher act as a "facilitator or coach" during the "exploration" inquiry phase (Bybee et al., 2006, p. 9) or adopt a role that combines direct instruction and different levels of guidance (de Jong et al., 2023)?

This research recognises the range of existing IBL instructional models and frameworks that support teachers in their planning and teaching. Among these, the popular phased models divide IBL instruction into manageable instructional chunks. Two well-referenced phased models, the 5E Biological Science Instructional Model (5E model) (Bybee et al., 2006) and the Pedaste et al. (2015) inquiry cycle, have proven effective in intervention studies. Both support planning for IBL by guiding students' activities but they only briefly mention the pedagogical role of the classroom teacher. The literature suggests that further development of these conceptual models might be warranted.

This section has emphasised the importance of IBL in senior secondary science education and its benefits for diverse learners. It supports the need to address the paucity of empirical studies on contemporary IBL pedagogies in Australia by investigating the perceptions and practices of science education leaders and expert teachers.

1.5 The Study Context

The context of this research is the NSW senior science curriculum requirement that 15 hours of class time be allocated to a Depth Study in each school year, while allowing a wide range of scientific activities. In their Depth Study, students actively pose and evaluate scientific questions and hypotheses, as well as communicate their findings (NESA 2017 a,b,c,d). They engage with the nature of science by learning to work as a scientist using a range of scientific skills (NESA 2017, a,b,c,d).

The Depth Study was included in the NSW curriculum and implemented without any explicitly recommended classroom strategies or an outline of the teacher's role. The researcher has observed how the implementation of the requirement has resulted in a range of instructional approaches, with teachers and their schools developing their individual interpretations of Depth Study as a form of IBL, even though the latter term is not used in the curriculum documents. Despite the provision of written resources to support the implementation of IBL, Nichols et al. (2017) noted teachers in Australian primary schools were not adequately supported to develop pedagogical approaches supportive of IBL.

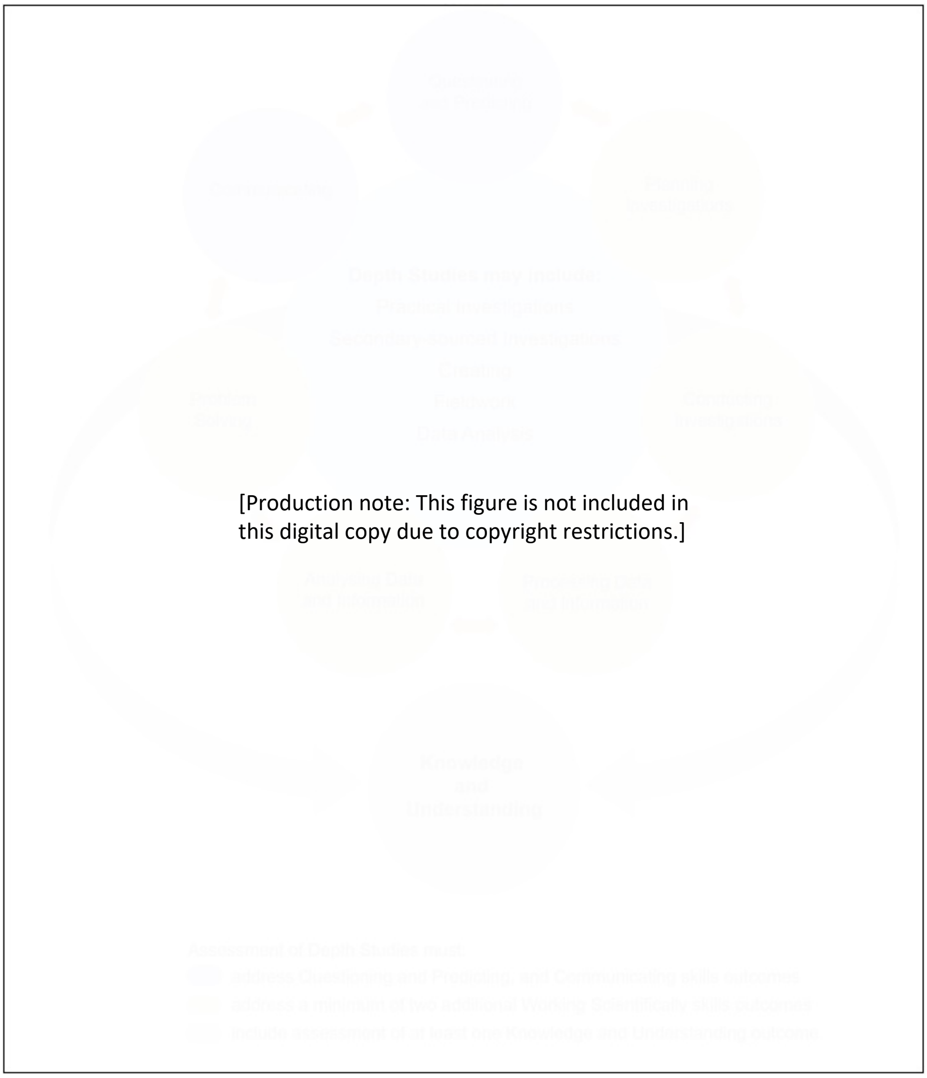
Historically, the shift toward IBL in Australia has been strongly encouraged through the introduction of the Australian Science Curriculum and the emphasis on learning about the nature of science (NOS) (ACARA, 2009; ACARA 2015). In NSW, little is known about secondary school educators' perceptions of IBL and how they might interpret and implement the Depth Study requirement from the curriculum documents following the implementation of the Depth Study curriculum requirement in 2017.

Figure 1. presents the Depth Study requirements along with the Working Scientifically skills, which are the common component of the Biology, Chemistry, Earth and Environmental Science, and Physics senior curricula. The NSW Science curriculum

documents do not use the term *inquiry-based learning*; however, the required component of developing questions for investigation under the outcome “Questioning and Predicting” has been interpreted in the study context as being the basis for IBL. The Depth Study is also intended to promote scientific inquiry through its emphasis on students’ investigative and analysis skills. Students can select from a range of activities, for example, laboratory investigations, fieldwork, data analysis, and secondary source analysis (NESA, 2017 a,b,c,d).

Figure 1

Depth Study Requirements



Note: Source: NESA, 2017a, p. 27

The Depth Study focuses on the practice of science and the requirement that students engage in the skills of questioning and predicting, requiring an IBL approach. The Depth Study complements conceptual understandings of science in the curriculum. The type of scientific inquiry is therefore guided by the content of the curriculum and the necessary components of the required assessment (NESA, 2017 a,b,c,d)

In this research, a pragmatic philosophy has been adopted. A pragmatic philosophy (Corbin & Strauss, 2015) focuses on knowledge creation through action, and seeks to make a practical difference through the findings by guiding action, which are the personal motivators for this research (Corbin & Strauss, 2015; Mertens, 2020). The important perceptions of secondary science educators and current good practices were sought to inform a model of teacher practice that recognises the significant expertise of teachers. Rather than impose a model of practice that has been developed by the researcher, I sought to understand the perceptions and existing practices of teachers who are experienced in IBL. This nuanced approach positioned the participating teachers as experts and provided strong evidence of exemplary pedagogical practices.

1.6 Study Purpose

The overall aim of the study was to deeply enquire into the perceptions and pedagogical practices of educators who have confidence in their pedagogical practice of the Depth Study requirement of the NSW Science curriculum. A small research sample was chosen to enable a detailed analysis of the research questions. It is the intention of this research to produce contemporary evidence supportive of a model of good teacher practice.

1.7 Research Questions

Two broad research questions were posed:

1. What are science education leaders' perceptions relating to inquiry-based learning in Depth Studies in senior secondary science?

2. What are expert teachers' practices relating to inquiry-based learning in senior secondary science?

The pragmatic philosophy adopted in this study and the nature of these broad research questions supported an inductive and interpretive study where the researcher would step back and draw on the expertise of the participants to answer the research questions, rather than impose an intervention.

1.8 Introducing the Research Design

An interpretative and qualitative research design has been chosen because the study sought to interpret the perceptions and practices of participants without imposing the researcher's own views as a researcher and experienced school educator. A systematic Grounded Theory Design (GTD) was adopted to derive nuanced insights relating to these phenomena and the ways the findings interact.

GTD methodology enables interpretation of qualitative data from a range of relevant data sources, including semi-structured interviews, focus groups, classroom observations, informal conversations, artefacts of student work, and teacher planning documents (Corbin & Strauss, 2015). By systematic coding and constant comparison of the data, dominant themes are developed that address the research questions. Finally, a review of the literature, which is conducted after data analysis, strengthens the findings and the proposed theory.

Recent developments of GTD have proposed systematic design as suitable for researchers who are new to GTD (Corbin & Strauss, 2015; Urquhart, 2013). Systematic GTD also provides a broad structure for the process of data collection and a system of thematic analysis that is considered suitable for a single researcher.

Systematic GTD also provides rigour by allowing honesty in data collection and coding, and credibility through systematic thematic interpretation. It deeply investigates phenomena that can only be gathered through a small sample size. Multiple data sources can be used to triangulate the data. In addition, the credibility and reliability of the findings are increased by strengthening the developed theory with existing literature. Table 1 gives an outline of systematic GTD.

Table 1

Systematic Grounded Theory Design

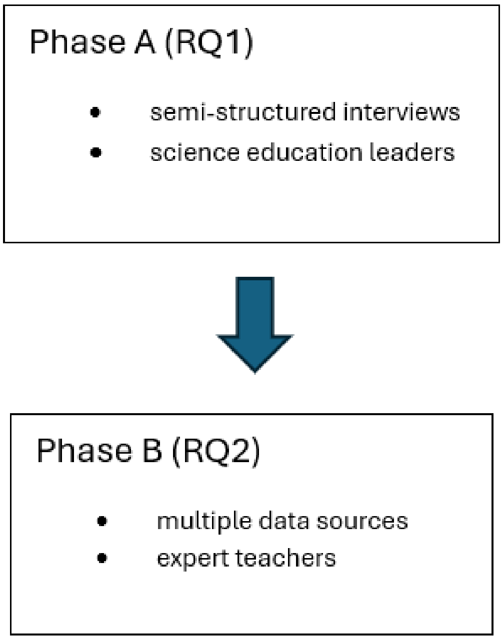
Elements of Grounded theory design	Systematic design
Procedures of research	Some flexibility within a prescribed procedure. The procedure is often set in study phases
Process of coding qualitative data	Use of open, axial, and selective coding processes
Development of categories/themes	Manual selection of dominant categories, use of memos, and diagrams during analysis
Focus of analysis	Rich descriptive analysis using connections between coded categories
Representation of the theory	Visual diagram and or explanation

Note: some elements of emerging design have been included in a systematic GTD. Source: Corbin & Strauss, 2015; Creswell & Guetterman, 2021.

The study had two research phases, each responding to a research question. Phase A informed Phase B (see Figure 2).

Figure 2

Study Phases



This research informs existing studies of contemporary perceptions and practices of educators in senior secondary science and adds to the body of research evidence. It should also inform the practices of pre-service and in-service teachers, given the difficulties that some of these teachers are reported to experience.

1.9 Overview of the Thesis

This thesis has seven chapters:

Chapter 1 introduces the study and positions the thesis as an important contribution to science teaching.

Chapter 2 is the literature review. It introduces socio-constructivist philosophy in science education, the significance of IBL in science education, teacher perceptions of IBL, levels of teacher guidance in IBL, pedagogical practices, and student perceptions of IBL. The literature review being conducted in two writing phases is consistent with the

GTD methodology adopted in this study. An integration of pedagogical practice is explored in the concluding section.

Chapter 3 is the methodology chapter. It argues for the suitability of GTD for addressing the research questions. It also describes the adoption of systematic GTD for the phased study sequence and for data coding and analysis (Corbin et al., 2015; Creswell & Guetterman, 2021).

Chapter 4 describes the research methods used in the two phases of the study. It also considers the ethics of research that involves human subjects and the importance of the anonymity of participants in the methods. The research participants are introduced in this chapter using pseudonyms.

Chapter 5 addresses RQ1 (phase A). It draws on the axial codes derived from the data to discuss the dominant themes relating to the perceptions of education leaders. This chapter develops a contemporary picture of the current education landscape and the role of IBL pedagogies, thus informing Chapter 6.

Chapter 6 addresses RQ2 (phase B). It draws on the axial codes derived from the data to discuss the dominant themes relating to expert teacher’s practices. It investigates the complexity of the phenomena and presents planning practices as being integral to classroom practices. It also deeply analyses instructional strategies using frameworks based on regulation practice and levels of inquiry.

Chapter 7 discusses the findings of the study and presents a suggested model of practice. Its final sections outline the implications of this research, recommendations for further research, and the limitations of the study.

1.10 Chapter Summary

This study investigated the perceptions of education leaders and the pedagogical practices of expert teachers of IBL in the context of senior secondary school science education in NSW Australia. IBL in science education is emphasised in global jurisdictions as being beneficial for student learning because students engage with the nature of science through an active process of inquiry where they learn to work with some independence. By building on the practices of the teacher experts, a model of good practice was developed.

This study supports a pragmatic philosophy through its use of qualitative research, and it positions educators and teachers as having expertise. As an experienced educator an unobtrusive inductive approach using the GTD methodology was chosen.

This thesis should both inform teaching practice and address gaps in the science education research literature.

Chapter 2

Literature Review

2.1 Chapter Overview

Inquiry-Based Learning (IBL) is reported to have a range of benefits in secondary science education including “increased motivation”, “deeper content learning”, “improved reasoning” (Duncan et al., 2021, p. 334), student “ownership”, and the “development of scientific skills” (Bevins & Price 2016, p. 17). IBL is beneficial to students by increasing academic achievement (Aktamis et al., 2016; Bevins & Price, 2016). IBL’s importance in the Australian science education context has been promoted by Rennie et al. (2001), Tytler (2007), and Goodrum et al., (2012). These authors have also recognised the benefits of IBL curricular and have urged teachers to move away from transmissive forms of instruction in the science classroom.

This chapter begins by positioning the origins of IBL in relation to constructivist philosophy and learning about the nature of science (NOS) in science education. The influence and impact of curriculum on IBL is discussed with a particular emphasis on the Australian context, before a review of the perceptions and practices of teachers of IBL, and the views of students of IBL. The concluding section focuses on the use of IBL conceptual modelling designed to support pedagogical planning and practice.

The noted paucity of studies in inquiry-based learning that include empirical data in the senior years of science schooling in a naturalistic classroom setting is highlighted as a research gap in this review and noted in an earlier work by Dobber et al. (2017) and Unsworth et al. (2020). Some insight from studies that focus on the earlier years of schooling are also included in this chapter to inform the context of this research.

The literature review has been completed in two stages due to the requirements of the doctoral candidature assessments. The preliminary literature review completed at the beginning of the study prior to data collection gave definition to IBL and painted a broad picture of existing teacher perceptions and practices to identify the gaps in contemporary research. The second review which completed the literature review chapter, occurred after data analysis, and supported the emerging and interpreted findings of this study of teacher perceptions and pedagogical practice.

2.2 Constructivism and Science Inquiry-Based Learning

This section highlights the influence of constructivist philosophies on IBL. The constructivist philosophy and the influence it has on IBL pedagogical practice in science education needs to be understood because it underpins a variety of IBL approaches. Constructivism is not presented as a single philosophy and the difference in philosophy also influences the differences in IBL pedagogical approaches (Bächtold, 2013).

There has been significant emphasis of teaching approaches that align with a constructivist philosophy in science education (Furtak, 2012; Tytler et al., 2019). These approaches prioritise students to actively engage in science by constructing their own knowledge, instead of being passive receivers of knowledge. The affordances of a constructivist approach in science education in the context of this research supports students to learn about the nature of science through practical scientific work, and develop the skills required to become informed citizens (Duncan et al., 2021).

The origins of IBL in science education are influenced by a constructivist philosophy and are further explored in the following section.

2.2.1 The Influence of Constructivism on Inquiry-Based Learning

This section explores the influence of constructivism on IBL and science teaching and learning, starting from John Dewey and a recognition of the constructivist perspectives of Piaget and Vygotsky. These are important influences on IBL in science education and underpin the enactment of pedagogical practice whilst noting that a shift toward socio-constructivist approaches have been noted in science education research, where students work collaboratively in science and co-construct knowledge together with their peers and with their teachers (Tytler et al., 2019).

John Dewey suggested a move away from transmissive teaching in the science classroom before constructivism was defined (Dewey, 1928). John Dewey observed that the process of scientific inquiry, which he felt was fundamental to the practice of science, was not used in the science classroom (Bächtold, 2013).

In a further development of Dewey's recommendation, Piaget's work in education psychology is often attributed to be the beginning of constructivist thinking (Hendry, 1996; Tytler et al., 2019). Jean Piaget (1936) proposed that "learning is a construction of personal meaning" where learners take responsibility for their own learning (Tytler et al., 2019, p. 40). The place of the teacher was thought of by Piaget as being one who provided appropriate materials to support students to construct their own knowledge using their past experiences (Dobbs in Besler et al., 2002).

The position of the teacher as a facilitator proposed by Piaget was later challenged by the developmental psychologist Jerome Bruner (1961) who proposed an approach to IBL that he named 'discovery learning'. In discovery learning Bruner proposed that students actively constructed meaning from the world around them and that the role of the teacher was further reduced. Bruner's theory is often cited by those who oppose IBL and refer to Bruner's discovery learning approach as the only IBL approach (Sweller, 2021).

In contrast to Bruner's theory, Lev Vygotsky proposed the theory of the "Zone of Proximal Development" (ZPD) which puts the teacher very much back into the picture when applied to IBL. This theory challenges theories that place the teacher as a passive participant in IBL to a position in the classroom that has an active role. Vygotsky describes ZPD as:

> What we call the Zone of Proximal Development is 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 (Vygotsky, 1978, p. 86).

The Vygotsky ZPD theory positions the teacher as having a prominent role in the classroom who is supportive of students constructing knowledge beyond a level that is otherwise limited by the students' previous knowledge.

The work of Lev Vygotsky and the development of his socio-cultural theory has an important influence by placing importance on the social interactions of students and their teachers in IBL. Vygotsky's focus on the importance of social interactions argued that discourse and language were fundamental to learning and very much a part of teacher practice in IBL (Tytler et al., 2019). Recent science teaching has reflected a socio-constructivist philosophy that "puts the teacher back into the picture" (Tytler et al 2019, p. 41) and recognises the social aspects of learning (Bresler et al., 2002; Vygotsky, 1986). Discourse and language were proposed as an important part of knowledge construction and highlighted the importance of collaborative learning in the science classroom (Vygotsky, 1962).

2.2.2 The Nature of Science in Science Education

The insights of the early constructivists have influenced the way science has been taught in conceptually in schools. A further shift in pedagogical practice in the 1970's placed importance on practical scientific work which was further influenced by the work of Joseph Schwab. Joseph Schwab identified the importance of students being able to formulate a scientific problem and carry out a scientific investigation in tandem with learning about subject matter (Deng, 2015).

The 'practice-turn' of science education in the 1970's placed value on students learning about the nature of science (NOS) and its importance was later recognised through curriculum in the US (Next Generation Science, 1996) and in Australia through the Australian Curriculum (ACARA, 2009). The Nature of Science (NOS) has been used with a variety of definitions. According to McComas (2020) In a classroom instructional sense, NOS includes students learning about the history of science, socio-scientific issues, argumentation, and the inquiry process (McComas et al., 2020). Relevant to this study is the emphasis on the "knowledge of how to (procedural knowledge)" do science (McComas, 2020, p. 32), and therefore the inquiry process is emphasised.

These origins are important since the epistemological position of constructivism and teaching about the nature of science and scientific practices, influences curriculum and pedagogical approaches in IBL (Bächtold, 2013).

2.3 Inquiry-Based Learning in Science Education

The inquiry process in learning about the NOS is important in this study and the term 'Inquiry-based learning' has been used. The definition of Inquiry-Based Learning (IBL) used by researchers, teachers, and curriculum writers varies according to the context and subject area and there are a range of definitions in the literature (Backa & Byker, 2021; Levy et al., 2013; Tytler, 2007; Zhang, 2016). The difficulty of defining IBL in science education is that the term broadly covers an extensive range of pedagogical approaches underpinned by a range of constructivist theories (Tytler, 2007; Tytler et al., 2019) including open, guided, and structured approaches to IBL learning in science which often involve practical work (Furtak et al., 2012) and the use of secondary sources including digital technologies and simulations (Akuma & Callaghan 2019; Liu et al., 2020).

This section defines Inquiry-based learning (IBL) in the context of this research and reviews the role of the teacher and the levels of guidance that they provide in IBL. Levels of teacher guidance are either referred to in the literature as being static levels of IBL where the level of teacher guidance is the same throughout IBL (Banchi & Bell, 2008), or flexible (Furtak et al., 2012) and are influenced by the adopted role of the teacher.

2.3.1 Defining Inquiry-Based Learning

In the literature, definitions of IBL relevant to the area of research are often used. Stender et al. (2018) cites the definition of IBL in the science classroom as "an approach in which students learn actively using scientific methods to answer research questions" (p. 1813). While this definition applies to IBL which is based on practical science investigations, it might not be possible to use this definition more broadly when students are working with secondary sources or digital models to answer an inquiry question. This section argues for a general definition which encompasses a range of IBL approaches that may be adopted during the enactment of the NSW Australia curriculum requirement of the Depth Study (NESA, 2017 a,b,c,d)

This research has adopted a broad definition of IBL to align to the flexible requirements of the Depth Study in the NSW Australia curricula. This study examines the teacher practices in the NSW, Australia curriculum requirement of the Depth Study (NSW Education Standards Authority (NESA), 2017 a,b,c,d) which does not promote any one IBL philosophy. At the time of this study teachers were not restricted to any one IBL approach over 15 hours of class time per year. They were able to choose laboratory, field, or secondary sourced investigations within that requirement. This study indicates how teachers have interpreted the requirement. The working scientifically skills curriculum requirements and the recommended time allocation of the Depth Study are the same for the Year 11 and 12 Biology, Chemistry, Earth and Environmental Science, and Physics courses. These science curricula were targeted as contexts for this study.

Depth studies for all NSW senior science courses can include the following science activities:

- a practical investigation or series of practical investigations and/or a secondary-sourced investigation or series of secondary-sourced investigations
- presentations, research assignments or fieldwork reports
- The extension of concepts found within the course, either qualitatively and/or quantitatively. (Depth Studies Year 11 and 12, NESA, 2017 a,b,c,d)

Considering the range of IBL that students can engage with while they are completing a Depth Study and for the purposes of this research, a broad definition of IBL by Barron & Darling-Hammond (2008) has been adopted and is:

"A student-centered, active learning approach focusing on questioning, critical thinking, and problem solving" (p. 11).

This definition considers the range of IBL activities including practical scientific investigations and secondary sourced investigations reported or observed in this study.

2.3.2 Guidance Levels in Inquiry-Based Learning

The literature often assigns levels of inquiry to define IBL activities. Definitions of IBL rely on interpretations of the level of teacher guidance and the level of student independence. Studies often describe a particular level of inquiry that is maintained throughout an entire sequence of lessons. A flexible level of guidance has been argued by Furtak et al. (2012) in a meta-analysis of studies of inquiry-based teaching, as being more appropriate. This section starts by exploring three levels of IBL which are often cited in the literature and used as definitions of IBL: structured, guided, and open IBL (Banchi & Bell, 2008). The chapter argues for a more fluid definition by recognising that teacher guidance does not adopt a single approach.

It could be argued that all school-based IBL is guided by the teacher in varying degrees (Furtak et al. 2012; Kuhlthau, 1993). In practical science where student safety is concerned there must be teacher guidance for safety reasons. Using the term Guided IBL as proposed by Furtak et al. (2012) describes the general reality of classroom practice however, it provides very little insight of specific teacher practices and actual levels of guidance that they use.

The Banchi and Bell (2008) levels of inquiry typology provides a description of IBL as a static teaching approach and level of guidance. Relevant to this study are the terms "guided Inquiry" and "open inquiry" which were defined by Banchi and Bell (2008) according to whether the teacher presented the students with an inquiry question (guided) or whether the students developed their own question (open). The same categories were used in a study by Sadeh and Zion (2012) to compare student preferences between the two approaches of whether the students were provided with a question or developed one on their own. This definition gives little attention to the range of student activities or teacher guidance in IBL apart from the formulation of a student question.

The difficulty in giving a single and definitive classification of the level of inquiry is that it does not recognise student differentiation, and that teacher guidance might change throughout an activity and between students (Furtak et al., 2012). While there have been attempts to define levels of inquiry that recognise a differentiated classroom and at each stage of the IBL in the middle years of schooling in the Australian context (Gordon et al., 2019; Lonergan et al., 2019), there is very little empirical evidence that focuses on the senior years of schooling that provide specific insight.

Of relevance to this study is whether the level of guidance provided by the teacher is static or whether it is based on a continuum as Furtak et al. (2012) suggests. Bybee et al. (2006) also suggest that the role of the teacher changes throughout the IBL. In senior secondary science, there is little known about the range of pedagogical approaches that teachers use in using suitable guidance levels.

Levels of IBL are proposed in research with varying description. The level of IBL is presented as a static category in the literature with application across a whole IBL activity. While some researchers have suggested that there is a change in the level of IBL across a single activity (Gordon et al., 2019), the definition by Furtak et al. (2012) which recognises a continuum of IBL guidance is often referred to. This fluid model is presented in Figure 3.

Figure 3

Continuum of Guidance in Inquiry-Based Learning

[Production note: This figure is not included in this digital copy due to copyright restrictions.]

Note. Source: Furtak et al. (2012) p. 306

The well cited Furtak et al. (2012) model is derived from a metanalysis which considered the amount of teacher guidance in each research paper cited. The researchers noted difficulty in being able to assign a static level of IBL to each study and arrived at the proposed continuum of guidance which included a sliding scale which recognises the variation of guidance provided by the teacher within each class and through a cycle or continuum of IBL. It recognises that teacher guidance is likely to be across a broad spectrum of guidance levels (Furtak et al., 2012).

2.3.3 Flexible Levels of Teacher Guidance

The reality of IBL in a differentiated classroom is that the level of inquiry can vary within a single class of students. Flexible levels of IBL have been proposed by Lazonder and Harmsen (2016), and Cornish et al. (2018) who have recognised that teaching and learning approaches and the guidance levels that teachers offer are not static within a dynamic teaching environment.

Contemporary research relating to the teachers' facilitation role is referenced in the literature by a significant metanalysis which proposes a range of levels of guidance (Lazonder & Harmsen, 2016). This meta-analysis is well-cited and offers some indication of the nature of the teacher facilitation role in IBL which involves an intentional level of guidance which is also cited in other IBL research (Rodriguez et al., 2020; Sharples et al., 2015). Lazonder and Harmsen (2016) reject the static assigning of inquiry levels to an IBL activity and recognise that differentiated instructional practices exist.

In describing the differences between guided and open IBL approaches the level of guidance provided by the teacher is significant since it varies considerably. Lazonder and Harmsen (2016) focused on the levels of teacher guidance in IBL across a range of school subject areas. The researchers define guidance as "…any form of assistance offered before and/or during the inquiry learning process that aims to simplify, provide a view on, elicit, supplant, or prescribe the scientific reasoning skills involved" (p. 687). The guidance typology proposed by Lazonder and Harmsen (2016) can be summarised as follows from the least to the most guided instructional practices:

- Process constraints: involve no direct instruction but divide the IBL into manageable "subtasks".

- Status overviews: “Make task progress or learning visible” (p. 689)
- Prompts: remind the learner of what they should do
- Heuristics: “Remind to perform an action and suggest how to perform that action” (p. 689)
- Scaffolds: “Explain or take over the more demanding parts of an action” (p. 689)
- Explanations: “Specify exactly how to perform an action” (p. 689)

Lazonder and Harmsen (2016) considered that the level of guidance might decrease with an increase in age of the learner and that certain types of guidance such as explanations and scaffolds were “more appropriate for younger learners” (p. 704). Surprisingly, these researchers found through a metanalysis of teacher practices of IBL that older learners were still supported by highly guided practices in a range of studies also noted by Dobber et al. (2017). The findings of this study also indicated that a range of guidance levels were included as part of the expert teacher practices.

The guidance typology by Lazonder and Harmsen (2016) has not been set as discrete limits and isolated practices, and different levels of inquiry are likely to emerge at different times and for different purposes in the classroom. For example, in a single class some students might require explanations and scaffolding, and other students might require prompts and heuristics to complete the same task. The Lazonder and Harmsen (2016) typology recognises the complexity and flexibility of teacher support in a single classroom. The fluidity of inquiry levels is consistent with other research (Gordon et al., 2019; Furtak et al., 2012; Lonergan et al., 2019) which also propose flexible guidance levels in the younger years of schooling.

In summary, some level of teacher guidance is always present in IBL in science education and the level of teacher guidance might be different between students and at different times in a sequence of lessons. The Lazonder and Harmsen (2016) typology provides further definition of the specific levels of guidance that teachers use within the classroom.

2.4 Inquiry-Based Learning in Science Education Curricula

Inquiry Based Learning has been promoted as a suitable teaching approach in science curriculum development across the globe and governments have intentionally included it in science curricular so that students can learn about the nature of science (NOS) (Duncan et al., 2021; Furtak et al, 2012). This section positions IBL in relation to the nature of science, and the influence of science curriculum on its enactment through curriculum reform activities. Curriculum implementation and the suggested pedagogical practices may be influenced by external factors such as political factors (Fensham, 2016), cultural influences (Kang & Keinonen, 2017), and social influences (Aditomo & Klieme, 2020; Ngaisah et al., 2018). These are important considerations and support conducting jurisdiction specific research.

2.4.1 Inquiry-Based Learning and the Nature of Science

Inquiry-based learning approaches in science education have traditionally centred on practical scientific inquiry and the scientific method (Duncan et al., 2021). More recently digital applications such as simulations (Lui et al,2020; Rodriguez et al, 2020), and science-based IBL activities such as making and interpreting scientific models are included in IBL science education supported by the curriculum (Akuma & Callaghan, 2019). The benefits of IBL are reported to increase student motivation, support the development of content knowledge, and improve critical thinking and reasoning (Duncan et al., 2021). Despite these benefits the systemic impact of curriculum on teachers in senior secondary science is reported to restrict innovative practice in the senior secondary science classroom (Unsworth et al., 2020).

The curriculum requirements for the study context of the Depth Study in senior science in the NSW Australia curriculum allows for a range of IBL approaches and recognises the nature of science which are included as skills outcomes. The curriculum does not promote a linear sequence of doing practical science and allows for a broad range of activities. The skills outcomes in the research context are as follows and reflect the skills and processes that scientists use:

- Questioning and predicting

- Planning investigations
- Conducting investigations
- Processing data and information
- Analysing data and information
- Problem solving
- Communicating

(NESA a,b,c,d, 2017)

Teachers and their students must engage in Questioning and Predicting, and Communication skills, and select at least two additional skills (NESA a,b,c,d, 2017). This flexible approach supports a range of IBL activities which include the common component of students developing investigable questions.

In secondary science education, learning about the nature of science (NOS) through IBL is important for students to learn about the work of practicing scientists (McCormas & Clough, 2020). According to Zion et al. (2020) the process of scientific investigation is not a linear step-by-step process which is often taught in science classrooms. Instead, Inquiry-based learning in science education is proposed as an iterative process to reflect the enacted NOS (Duncan et al., 2021; McLaughlan & MacFadden, 2014; Zion et al., 2020). According to Duncan et al. (2021) when IBL was introduced into the school curriculum as early as the 1950's processes tended to be over-simplified into a linear sequence which did not reflect the complexity and iterative nature of science.

The enactment of NOS requires scientists to constantly evaluate and iterate their work and therefore takes on a cyclic approach. In the NSW Australian curriculum, the required outcomes for a Depth Study, the context of this research, are presented as a range of skills and are not mandated by a sequential process (NESA, 2017 a,b,c,d). To support the learning about the nature of science, the chosen IBL definition for this research is flexible and supportive of a range of science activities.

In science education relevant to this research, IBL extends beyond students learning about and engaging in practical science work. The broad definition of IBL adopted in this study includes other IBL activities such as constructing and evaluating models and providing explanations about the surrounding world (Duncan et al., 2021). Models are described as “equations, taxonomies, computational models, causal models, and system models” (Duncan et al., 2021, p. 329). Students engage in asking questions and answering their question through scientific processes.

More recently, the use of digital technologies has offered affordances where access to scientific equipment and resources are limited (Akuma & Callaghan, 2019; Liu et al., 2020). Digital applications offer experiences that students might not be able to access including expensive scientific equipment and improved efficiency in time and reflect a contemporary approach to practical science. Mobile technologies also offer students the ability to store and process data collected from hands-on practical work (Liu et al., 2020). In Australian schools, mobile technologies are available and relevant to the study context.

With such a non-descriptive interpretation of science IBL, IBL can be interpreted in a variety of forms (de Jong et al., 2023) although its purpose in science education curriculum is to “…engage students in the same thinking processes and activities as practicing scientists” (Furtak, 2006, p. 454). Digital processes have expanded the nature of practical laboratory activities completed by students and broadened the range of activities that a student can complete.

In contemporary science education effective IBL implementation centres on the work of the teacher and can be summarised as involving:

- “Engagement in inquiry” (Duncan et al., p. 333)
- Supported by teacher guidance
- Fostering “Epistemic agency” (Duncan et al., p. 333)
- Developing “metacognitive understanding and regulation” (Duncan et al., p. 333)
- “Fostering social communities of inquiry” (Duncan et al., 2021, p. 333).

(Duncan et al., 2021; Lui et al., 2021)

2.4.2 Implementation of Inquiry-Based Learning in Science Education

Secondary science education reforms that have included constructivist approaches to teaching and learning in secondary science education have been promoted globally including the Australian Curriculum (ACARA 2009; Ministerial Council on Education, Employment, training and Youth Affairs, 2008), USA (Next Generation Science Standards Lead States, 2013), European Union through the "Ark of Inquiry" project (Pedaste et al., 2015), and global organisations such as the Organisation for Economic Co-operation and Development (OECD, 2019). Curriculum reforms have some influence on promoting pedagogical change at the classroom level, yet there is evidence that constructivist approaches in science education have had a slow uptake in some global jurisdictions and implementation might be inconsistent due to a range of factors (Haag & Megowan, 2015; Miller et al., 2018; McLaughlin & MacFadden, 2014; Scott et al., 2018; Zhang, 2016). This section examines reforms which have included IBL in the senior science school years. This research recognises the cultural, social, and political differences which can impact the quality and enactment of IBL.

Curriculum reforms throughout the world have influenced a shift in teaching and learning practices away from teacher-centred approaches (Haag et al., 2015; Akuma & Callaghan, 2019; Kang et al., 2017; Scott et al., 2018; Minner et al., 2010). Reforms have also included the promotion of inquiry-based learning in science education in recent years (ACARA, 2009; Akuma & Callaghan, 2019; Liu et al., 2010; O'Neill, 2023; Next Generation Science Standards Lead States, 2013., Scott et al., 2018; Wang et al., 2021). However, the shift towards practices with more learner agency, such as IBL, have been reported to be slow in some countries (Bevins & Price, 2015; O'Neill, 2023) and inconsistent in others (Haag & Megowan, 2015; Hume & Coll, 2010).

The intended IBL curriculum requirements are reported not to be the enacted curriculum in some studies (Hume & Coll, 2010; Rennie et al., 2001). If IBL is included in the curriculum, it has the potential to be eroded by extrinsic factors. Teachers in New Zealand were reported to be more heavily influenced by textbook publishers and professional learning providers, which have limited the practices of teachers to more traditional modes of teaching (Hume & Coll, 2010). In this empirical study, it was found that IBL was limited to fair testing and researchers saw very little evidence of open planning and investigating in Years 11 and 12 Science (Hume & Coll, 2010).

Actual IBL practices in a UK study were also inconsistent following curriculum implementation, and it was argued that the extrinsic impact of high-stakes assessment diminished the quality of IBL in the science classroom as it forced teachers into a more formulaic approach to scientific inquiry (Bevins & Price, 2015). While curriculum reforms in Hong Kong have included an investigative style IBL assessment in the senior years of High School, external testing has also been reported to erode the IBL curriculum requirement, and many teachers have chosen to devote more time in class to examination preparation (Yeung et al., 2012). The influence of high-stakes external testing at the end of schooling is a feature of education systems around the world (Yeung et al., 2012) and may impact IBL opportunities in the science classroom.

The lack of pedagogical guidance has been blamed in the literature for the slow implementation of IBL in the United States. The Next Generation Science Standards (NGSS) was introduced in 2013 (McLaughlin et al., 2014) Interestingly, the teacher guide that supported implementation of the standards was published in 2015 (National Research Council, 2015) which delayed implementation (Haag & Megowan, 2015; McLaughlin et al., 2014). A large-scale mixed methods study across US schools investigating the readiness of teachers to implement the NGSS revealed many teachers were unprepared for the IBL component of the new reforms and pointed out this time lag (Haag & Megowan, 2015). The identified challenges to teachers in implementing the NGSS were reported in this study to be time, resources, and teacher education (Haag & Megowan, 2015). This large-scale study surveyed teachers to determine their readiness and motivation to use the standards, and professional development required to support the implementation of the standards. The main findings of this study were that teachers sought more instructional time to achieve the standards, resources, and training (Haag & Megowan, 2015). The time lag between implementation and the availability of the teacher guide was highlighted as an impact on enactment.

The difficulty in comparing different education jurisdictions is highlighted in comparative studies and metanalyses due to cultural and social differences. Comparing teacher practices of IBL is highlighted by a study of science teaching in both Finland and Korea who ranked highly in international PISA testing (Kang & Keinonen, 2017). In a comparative literature review of the challenges to IBL in secondary science between Finland and Korea, the challenges to teachers in implementing science curriculum reforms were shown to be different. The challenge of large class sizes in Finland did not have the same impact in Korea. In Finland, the effect of more qualified teachers in teaching science had a significantly positive effect and yet it showed a negative correlation in Korea (Kang & Keinonen, 2017). The authors of this study suggest cultural reasons for this finding due to the rapid change in education in South Korea from a traditional transmissive approach to pedagogy, which was more common with experienced and highly trained teachers who had difficulty in implementing IBL. Whereas in Finland, an inquiry approach which was implemented by newly trained teachers compared to highly trained teachers was challenging (Kang & Keinonen, 2017).

In contrast to the findings of Kang & Keinonen (2017) in Finland and South Korea, US research found that teacher experience had no significant difference on positive IBL practices (Liu, 2010). Also, in a US context, it was found that novice teachers gravitated to more traditional teaching approaches than expert teachers in a qualitative study that compared the observed practices of novice with more experienced teachers (McNew-Birren & van den Kieboom, 2017). These studies highlight the need for localised, jurisdiction-specific research to focus on teacher perceptions and practices of IBL such as this study. Furthermore, the cultural, social, and political differences between countries and different education contexts make it difficult to apply research from one study to a different context.

The transition from traditional transmissive learning in science to IBL approaches has been reported to be slow in curriculum reform in Taiwan and China which both have a long history of teacher-centred pedagogical approaches. Both studies reported that the operational curriculum was slow to move towards more student-centred approaches to learning (Fang, 2021; Yao & Guo, 2018). In the Chinese study a survey of teachers reported that only 10.7% of teachers were conducting scientific investigations in the classroom and very little IBL was reported which was in stark contrast to the aims of the intended curriculum (Yao & Guo, 2018). Transmissive approaches to teaching have also been reported to dominate actual practice in a qualitative case study in Taiwan (Fang, 2021).

These examples indicate a mismatch between the intention of curriculum reform and actual pedagogical practice. They also highlight that cultural, social, and political differences can impact the quality and enactment of IBL and signal the importance of localised research. It is noted that very few studies that focus on quality IBL practices influenced by curriculum reform or how the intended curriculum might positively impact the enacted curriculum. The paucity of IBL research in senior science education in the Australian context also noted by Unsworth et al (2020), has done little to help us understand tensions despite a long history of IBL in science education.

2.4.3 The Influence of Curriculum Change in the Australian Context

The intended curriculum has influence over IBL enactment in NSW Australia. The intended curriculum provides the curriculum direction. In the Australian context the Australian Curriculum provides the direction that promotes science IBL (ACARA, 2012). NSW has adopted the skills requirements of the Australian curriculum and included mandated a Depth Study that is formally assessable (NESA a,b,c,d, 2017). This has mandated that all students in NSW engage with IBL; however, it does not ensure consistent and effective instructional practice. Little is known how teachers interpret this curriculum requirement.

Australia has a long history of constructivist teaching approaches in science education since a 'practice turn' in the 1970's which saw a re-thinking of teaching approaches in science education (Aubusson, 2011). It could be assumed that Australia would learn from past curriculum implementation mistakes (Aubusson, 2011). Earlier research prior to the enactment of the Australian curriculum, suggested that the intended curricular was not actualised following IBL implementation in Australia (Rennie et al.,

2001) and teachers were often reverting to recipe-like investigations despite a curriculum requirement of open-ended scientific investigations (Goodrum et al, 2012). Like the US, IBL has been included in the Australian curricular with very little teacher support in the form of professional learning at the time of curriculum enactment and this is also the experience of the Depth Study requirement in the NSW curriculum (NESA, 2017 a,b,c,d).

At the time of writing, the NSW Government proposed a move to return to explicit teaching strategies. This sudden turn which has been highlighted through new curricula has the potential to reduce the emphasis on IBL and the nature of science with a return to earlier traditional teaching approaches (Commonwealth of Australia, 2024). Empirical evidence that champions IBL is essential at this current time to promote the learning advantages.

2.5 Teacher Perceptions of Inquiry-Based Learning

This section explores teacher perceptions of how IBL is understood, regarded, and interpreted by the educators who enact the Depth Study curriculum requirement. The inter-relationship between a teacher's philosophy of constructivism and enacted classroom practice has been presented in Section 2.2.1. Further impacts of curriculum requirements have also been established as impacting a teacher's perception of IBL in Section 2.4. The importance of determining teacher perceptions of IBL in this study is that teacher perceptions might change over time and influence the confidence of teachers to enact IBL.

There is a body of evidence that suggests that a teacher's perceptions of IBL including a positive set of attitudes, beliefs, and values of IBL have shown to have a profound impact on teacher confidence in IBL in the classroom and can improve pedagogy in secondary science (DiBase & McDonald, 2015; Aktamiş et al., 2016; Engeln et al., 2013; Khalaf & Zin, 2018; Miller, 2016). This is important in the context of this research because teacher perceptions of IBL can also be related to a teacher's knowledge of constructivism and how this is interpreted in practice (Bächtold, 2013). This is important because teachers' views of constructivist philosophy can influence their pedagogical approach (Bächtold, 2013).

2.5.1 Teacher Understanding of Inquiry-Based Learning

IBL is underpinned by a constructivist philosophy and in this research context social constructivism has had great influence on the enactment of IBL (Tytler et al., 2019). Constructivist philosophy, which was discussed in Section 2.2, informs a range of pedagogical approaches in IBL which include a range of levels of guidance (Bächtold, 2013; Furtak et al., 2012; Hendry, 1996). How this translates into teacher practices is reported to be misunderstood by some teachers (de Jong et al., 2023; Furtak et al., 2012). Teachers are also reported to not understand that a constructivist philosophy does not provide a direct formular for teaching (Bächtold, 2013; Dobber et al., 2017; Hendry, 1996; Levy et al., 2013; O'Connor et al., 2016). IBL is recognised in this study to be enacted using a range of interpretations relating to constructivist philosophy.

Teachers' beliefs relating to constructivist pedagogies and the teacher role in the classroom can have a significant impact on the enactment and understanding of IBL. In the global context, studies have indicated that teacher beliefs and the pedagogical positions they choose to adopt in the classroom are related. Using a case study methodology of two UK teachers, Correia and Harrison (2020) proposed that teachers who held a belief that the teacher role in IBL was to act as a facilitator, tended to promote open forms of inquiry. Those who adopted what the researchers termed a "shepherd" approach indicated a preference for strong teacher guidance (Correia & Harrison, 2020). Liu and Wang (2022) also noted that teachers adopted a mediator or mentor role in the classroom.

The misinterpretation of the specific the role of the teacher in supporting the students in IBL have led to reductionist debates which undermine the value of IBL. Often the definition of 'Discovery Learning' is used to criticise IBL approaches (Sweller, 2021; Hattie, 2018) which requires that teacher provide minimal guidance to students. Explicit instruction is also highlighted as an essential missing precursor to problem solving activities (Ashman et al., 2020). Recent studies of IBL highlight the importance of explicit forms of teaching in IBL alongside lower levels of teacher guidance (de Jong et al., 2023).

Specific to science education and according to Zion et al. (2020) there is a reported lack of understanding about the nature of science when IBL methods are used by teachers. This lack of knowledge might be because the epistemology of science is complex and iterative and there is no one scientific method that guides teaching and learning practices (Zion et al., 2020). Lack of exposure of teachers to the realities of scientific research practices have also been suggested as contributing to this lack of knowledge (Zion et al., 2020).

2.5.2 Teacher Regard of Inquiry-Based Learning

In Australian schools, IBL is not new to science education, and it might be expected that it is now well embedded. Yet, before the introduction of the Years 11 and 12 Australian science curricula in 2015, a report commissioned by the Australian Academy of Science revealed that many students were experiencing recipe-like practical investigations and teacher demonstrations in the Year 11 and 12 science classrooms (Goodrum et al., 2012). Teachers reported a negative attitude toward open-ended scientific investigations, compared to shorter inquiry activities which were favoured (Goodrum et al., 2012). This same hesitancy about longer IBL science activities is also reported in the middle years of Australian schools by Whannell et al. (2018). Since 2012, there has been very little research evidence to determine whether these teacher impressions have changed in the senior years of Australian schooling.

In jurisdictions where IBL has been required through the curriculum, teachers have expressed a positive regard of IBL, yet many were not confident of their ability to implement it (Akuma & Callaghan, 2019; DiBase & McDonald, 2015; Haag & Megowan, 2015). A teacher's understanding of the nature of IBL and its perceived impact on learning was highlighted in a US study which utilised a large-scale survey of 275 middle school and senior secondary school teachers to determine their attitudes, beliefs, and values of IBL. Teachers in this study highlighted "time, assessment, teacher knowledge, and student and external limitations" as impacting their practice. In this survey 58% of respondents felt that planning for inquiry: takes too much time" and 75% felt that it took too much time away from regular classwork (DiBase & McDonald, 2015). Both responses indicate that teachers in this study might not value IBL and their belief on what is required to facilitate IBL might affect enactment. The value and regard of IBL as can have a positive impact on the enactment of IBL and are explored in the following section.

Science IBL pedagogical practice was earlier reported by Hubber et al (2010) who examined school, student and teacher practice whilst engaging with national science competitions in Australia. This small-scale study concluded that schools that had established a strong research culture and where teachers and their students strongly believed in the value of open-ended investigations produced higher outcomes. The researchers argued that a high regard of IBL in the wider school community, was essential for developing a research culture of inquiry in a school.

A commissioned Australian study examined teacher practices prior to a major curriculum reform by asking the research question "What does science in Year 11 and 12 look like in our schools?" (Goodrum et al, 2012, p. 21). At that time, teachers criticised a crowded curriculum and the demands of assessment on the teaching program. They expressed concern over "…the requirement to conduct open or extended investigations in every senior science subject in some jurisdictions" (Goodrum et al., 2012, p. 21). This survey indicated that at that time, teachers might not have had a high regard for IBL and that teachers also reported that there were impacts that hindered implementation. The reported study in this section by Goodrum et al. (2012) is significant because it was commissioned to support the development of the current Australian Curriculum and since that time there are minimal cited studies that indicate that these findings have changed.

According to the survey findings of two Australian studies, there was limited use of what the researchers described as being "longer scientific investigations" which involved IBL (Goodrum et al., 2012; Whannell et al., 2018). A negative attitude of teachers implementing longer inquiry-based investigations in the earlier years of secondary science was also reported (Whannell et al., 2018). There is very little

Australian data to indicate current perceptions and practices of teachers in the high-stakes senior years of secondary science, and this warrants further exploration.

2.5.3 Teacher Confidence in Inquiry-Based Learning

Teacher confidence of facilitating an IBL classroom in secondary science has been shown to be supported by their perceptions of IBL, their knowledge of IBL, and an understanding of the nature of science. Reports of varying levels of confidence may be influenced by cultural and societal influences which makes teacher confidence difficult to compare findings between different research contexts. Studies cited report a range of impacts on teacher confidence which need to be managed.

Teacher confidence for facilitating IBL varies in the literature between different countries. Levels of confidence are reported to be influenced by cultural and societal influences (Kang & Keinonen, 2017; Ngaisah et al., 2018). Studies drawn from world regions where IBL has been introduced more recently in China and Indonesia compared to Australia (Zhu & Geelan, 2013; Ngaisah et al., 2018; Effendi-Hasibuan & Mukminin, 2019) show differences in teacher confidence and self-efficacy in relation to their IBL practices compared to regions where IBL has had a long history in schools such as the US (DiBase & McDonald, 2015; Haag & Megowan, 2015). Low teacher confidence can result in teacher reluctance to engage in IBL (Zhu & Geelan, 2013).

In a study of US science teachers' attitudes, values, and beliefs of the use of inquiry in middle school and high school, more than 60% of those surveyed reported that they were concerned about their ability to adopt an IBL pedagogical approach in science (DiBase & McDonald, 2015) which reflected low teacher confidence. In a study which investigated a teacher's readiness to engage in IBL in The Next Generation Science Standards in the US, teachers reported anxiety about their ability to facilitate the IBL and 84.9% of teachers surveyed in this study were willing to undergo professional learning which indicated a general willingness to engage in IBL if they received appropriate training (Haag & Megowan, 2015).

Teacher confidence of IBL approaches is also reported to be inconsistent between teachers within jurisdictions. For example, teachers were reported to have polarised perceptions and confidence in IBL. In the United States, researchers found that when a mandatory requirement of implementing IBL through ‘Science Fairs’ was introduced, it provoked both strong positive and negative views amongst teachers (Miller, 2016). Earlier Australian evidence also suggests that this difference of teacher confidence and the views that they hold might also be varied (Goodrum et al, 2012; Whannell et al., 2018). These differences also suggest that some teachers who are confident in their approach might also be able to demonstrate good practices. Empirical studies which examine teachers who have confidence in IBL is under-explored research area in Australian research in senior secondary science.

A meta-analysis of 33 studies reported that a teacher’s confidence in relation to their IBL practices was highly related to a teacher’s set of beliefs of the inquiry process and could also be related to a teacher being more willing to adapt their practices (Chichekien et al., 2016). Teachers in this study reported that a lack of support, negative student feedback, and a lack of understanding of teaching inquiry impacted their confidence.

Confidence in IBL can be affected by a lack of knowledge of IBL and the nature of science and the scientific method (Chichekien et al., 2016). Findings of studies in a range of jurisdictions where IBL was recently introduced are suggestive of a lack of IBL knowledge amongst teachers in China and in Indonesia (Zhu & Geelan, 2013; Ngaisah et al., 2018; Effendi-Hasibuan & Mukminin, 2019). In the US and Australia, IBL is not a new introduction to the curriculum and yet knowledge of IBL has also been highlighted as being as a determiner of teacher confidence and readiness in the classroom in US schools (DiBase & McDonald, 2015; Zion et al., 2020).

Managing the inquiry classroom requires teachers to adapt their management strategies and some teachers are reported to have difficulty in re-establishing classroom norms and routines in this changed environment. These impacts can affect teacher confidence resulting in teachers fear “losing control - control of instruction, control of students, control of the class.” (Quigley et al., 2011, p. 55). If teachers have always taught using an authoritarian approach in the classroom, a resetting of classroom management strategies might prove to be challenging.

A focus on improving the confidence of teachers in the IBL science classroom has resulted in a range of studies which have focused on professional learning programmes to address teacher understanding of IBL (Zion et al., 2020), and the nature of science (Pedaste et al., 2015; Zion et al., 2020).

2.6 Pedagogical Practices in Inquiry-Based Learning

Pedagogical practice in IBL is complex and multifaceted and involves a range of teacher practices which correlate to positive student outcomes (Mostafa, 2018). This section starts by describing the role of the teacher in IBL, teacher facilitative practices, questioning and discussion practices, and integrated pedagogical practices. Student perceptions of their teachers' practices are included in this section as a significant interpretation. Meta-analyses are highlighted in this section as being important literature sources since they attempt to explore the interactions between the different elements of pedagogical practice. Very few empirical studies have attempted to research the complexity of pedagogical practice in a naturalistic setting using a single study (Dobber et al., 2017).

Relevant empirical studies that include the earlier years of science education have been included in this section due to the paucity of research in the senior years of schooling.

2.6.1 The Role of the Teacher in IBL

The constructivist philosophy draws its foundation from epistemology and cognitive psychology (Duncan et al., 2021; Hyslop-Margison & Strobel, 2007; Tytler et al., 2019). IBL incorporates different pedagogical approaches, reflecting the varied constructivist underpinnings described in Section 2.2.1. This section considers the influence of constructivism on the role that the teacher plays in the IBL classroom. This is important because it influences the nature of IBL enactment and the pedagogical choices that teachers make in IBL.

In IBL teachers consider their position in the classroom which could include passive facilitators (Bruner, 1962), facilitators (Bybee et al., 2006), and active participants in a social group (Vygotsky, 1962). There are a reported range of constructivist approaches and interpretations which tend to be influenced by philosophy of personal constructivism which match the Piaget philosophy (Bächtold, 2013), and socio-constructivism where students construct meaning in a social setting such as with their teacher or other students as co-constructors of knowledge (Vygotsky, 1978). It is also possible that a mixture of constructivist philosophies is more suitably applied to a longer IBL activity (Bächtold, 2013).

Of the major theorists, Dewey (1928), and Vygotsky (1978), agree that students approach their learning through a range of experiences based on their prior knowledge. In addition, Dewey and Vygotsky, in contrast to Piaget, agree that the teacher's role is essential to promote engagement, create a conflict in student understanding, and support students to develop a new understanding (Vygotsky, 1978). These challenges to student learning can include factual challenges, evidence challenges, pragmatic perspectives, and social challenges (Hyslop-Margison & Strobel, 2007) as necessary ingredients in learners' knowledge construction and place the teacher as being a co-constructor of learning rather than a passive participant.

The move toward collaborative work in science education compared to individual work strongly feature a socio-constructivist philosophy in the pedagogical approaches that teachers adopt (Tytler, 2002). Many of the well-cited IBL conceptual frameworks that have been developed to support IBL teaching in a range of educational contexts consider a socio-constructivist philosophy (Bybee et al., 2006; Bybee, 2014; Kuhlthau et al., 2012; Pedaste et al., 2015) and recognise the integral role of the teacher and peer interactions. In these frameworks and models, the role of the teacher has been promoted as an active participant and students and their teacher co-construct knowledge within a guided approach to IBL.

The teacher's role and the position that they adopt in the classroom are crucial elements of IBL instructional practice. In the previous section the teacher role was identified as being influenced by intrinsic factors, and in Section 2.4 extrinsic factors such as curriculum, were also suggested as having an impact on IBL. The term ‘facilitator’ is often used to describe the role of the teacher in IBL. According to Bybee et al. (2006), the role of the facilitator in a practical setting is as “facilitator or coach…if called upon, the teacher might coach or guide students…” (Bybee et al., 2006, p. 9). The definition of facilitator has been challenged in the literature as being an unsuitable approach with recent reports of teachers adopting explicit teaching approaches balanced with supporting students to regulate their own learning (de Jong et al., 2023).

The literature is inconclusive about the specific nature of the facilitation role of the teacher and no one approach is recommended. In an analysis of PISA results Mostafa (2018) concluded that a range of teacher practices were used in science education and any one approach was not considered to be superior to another. This variation of teaching approaches has also been noted by other researchers (Dobber et al., 2017; Erodgan & Campbell, 2008; Fensham, 2022). Varied levels of guidance that a teacher might provide received some attention through intervention studies where the researcher has implemented a model or program of teaching prior to conducting an empirical study (Dobber et al., 2017; Lazonder & Harmsen, 2016; McLaughlin & MacFadden, 2014). Dobber et al. (2017) noted that very few studies examined existing teacher practice define the reality of the teacher’s role with any clarity.

Descriptions of teacher facilitation in the context of IBL often cite the role of the teacher as a facilitator without specifically providing advice on the recommended range of support that might be implemented (Bybee et al., 2006). The facilitation role might change depending on the level of IBL chosen and the philosophical position of the teacher. In very few studies cited were there attempts to explore the complexity of facilitation and how the teacher role might evolve (Dobber et al., 2017).

Bugingo et al. (2024) proposed an explicit and reflective instructional approach in teaching and learning about the Nature of Science (NOS) which included scientific inquiry. According to Bugingo et al. (2024), using an explicit approach enabled all aspects of NOS to be addressed through a series of guided activities. Yet a balance between guidance and a reflective approach where students were provided with “the opportunity to draw their own interpretations and conclusions and not being passive only” (p.57) was required to learn about NOS and the reality of how scientists work.

Other science education research proposed that a balance between explicit forms of instruction and implicit approaches are the reality of IBL in the science classroom (de Jong et al., 2023).

Empirical studies where teachers have been observed in the classroom, suggest that there are many variations of the role of the teacher when IBL is enacted in school lessons (van Uum et al., 2017; McLaughlin & MacFadden, 2014; Scott et al., 2018). The position of the teacher and their use of a range of guided instructional practices vary in the literature. This is an important point because each research study is contextually different and suggests that some IBL research may not be able to be applied across a broad range of IBL approaches.

A static and passive teaching role is proposed by Bruner (1962) in promoting the 'Discovery Learning' model suggested that the teacher role should be minimal. This passive role is often interpreted by other researchers to be the current approach of teachers implementing all forms of IBL (Hattie, 2008; Sweller, 2021). The current education commentary surrounding explicit instruction often heralds the merits of explicit instruction over misinterpreted constructivist methods (Sweller, 2021). Explicit instructional practices in IBL appear to run counter to a constructivist perspective of IBL according to some researchers (Zhang, 2016), and very much a part of IBL by others (Bugingo et al., 2024; de Jong et al., 2023). However, the two arguments do not have to be understood as diametrically opposed because teachers use a range of strategies in IBL which can include explicit teaching (de Jong et al., 2023).

A constructivist view of instructional explanations as an explicit instructional strategy, is reported to support students to develop an understanding of scientific concepts and involves dialogic discussion between the student and the teacher to support students in constructing knowledge and scientific skills (Kulgemeyer & Geelan, 2024). Explicit instruction which requires students to learn about procedural knowledge particularly in relation to safe practices in the practical sciences is reported to be less interactive and more authoritative (Fang, 2021). de Jong et al. (2023) proposed combining direct and inquiry-based instruction and argued against the reductionist debate that pits IBL and direct instructional methods in opposition to each other.

The integration of different teacher practices in IBL including explicit and implicit teaching approaches was explored in an analysis of the 2015 Programme for Internation Student Assessment survey science data. Researchers sought to define the role of the teacher in IBL and proposed a model of mentor and mediator (Liu & Wang, 2022). The findings from the data analysis suggest that a teacher might change their role in response to learners from one of intervention (mediator) where the teacher role might be authoritarian and directive, to one of a mentor where they guide and support students in a collaborative and shared role (Liu & Wang, 2022). While these definitions of mediator and mentor are broad, differences within each category are likely, which warrant further exploration.

Researchers have analysed the complexities of teacher practice through meta-analyses of empirical research which provide a broad picture of the complexities of instructional practice (Dobber et al., 2017; Furtak et al., 2012; Lazonder & Harmsen, 2016). Researchers of these significant meta-analyses have noted the difficulty of comparing qualitative studies which are often used in education research and propose that quantitative data support rigorous data analysis (Dobber et al., 2017). The difficulty of including quantitative data when closely examining teacher practice through survey data has been noted to be less reliable because teachers are not consistently able to report on their actual practice with accuracy (Capps et al., 2016).

Being able to describe a definitive role of the teacher in IBL also was noted as being problematic by Lazonder and Harmsen (2016) because of the range of practices that a teacher must adopt. In their meta-analysis, the varying levels of guidance that a teacher used in IBL were analysed. Lazonder and Harmsen (2016) noted that IBL research did not focus on the interactions of different levels of guidance and recommended that future research should focus on where "multiple types of guidance are best combined" (p. 705) and therefore recognised that teacher instruction could not be reduced to a simple model.

The difficulty of defining and comparing IBL teacher facilitation approaches in the literature can be complicated by the context of the IBL, and cultural and political influences in each education jurisdiction as previously noted in Section 2.4.2. The differences in teaching were highlighted in a previously cited study where traditions of teaching were different in South Korea and Finland (Kang & Keinonen, 2017). An authoritarian role in South Korea was preferred and similar in a Chinese study (You & Guo, 2018). Different interpretations of IBL in a Chinese study following curriculum reform resulted in IBL being interpreted differently and not as intended due to this cultural teaching preferences (Yao & Guo, 2018). These examples highlight the need for jurisdiction specific research due to cultural and historical differences.

The lack of practical definition and advice on the role of the teacher has been argued to result in a lack of quality practice. 149 teachers who participated in a Years K-12 US study held “naïve views” about IBL and the researchers considered how to conduct professional development to address this issue: “One answer may be that these approaches are not defined in a user-friendly way” (Capps, et al., 2016. p. 956). The difficulty of being able to support teachers with definitive advice about their facilitative role in IBL due to the varied reports of a teacher role has been highlighted in both in Australia and the US (Capps et al., 2016; Fensham, 2022).

Reports of static levels of guidance where little support is provided (Bruner, 1962; Yao & Guo, 2018), contrast to models of flexible and varying guidance that have been reported (Dobber et al., 2017; Lazonder & Harmsen, 2016; Liu & Wang, 2022; McLaughlin & MacFadden, 2014; Scott et al., 2018; van Uum et al., 2017). The accompanying teaching strategies that support a flexible pedagogical approach are of interest in this study since they align strongly to the research findings. Significant meta-analyses highlight a range of instructional practices using the typologies of regulation practices (Dobber et al., 2017; Furtak et al., 2012) and guidance levels (Lazonder & Harmsen, 2016) which are discussed in the following sections. Empirical IBL studies which focus on how those strategies interact is under-researched in the senior secondary science context (Dobber et al., 2017).

By adopting a socio-constructivist approach in IBL, the role of the teacher must move away from being the prime source of knowledge to a less authoritarian role. The teacher enables students to think and construct skills and knowledge in a learning community. The teacher role must also be flexible and differentiated to recognise the different needs of each learner.

2.6.2 Teacher Regulation Practice Typology

The purpose of teacher practices in IBL is significant, and the typology of regulation practices is useful to highlight the differences between regulation practices. Regulation practices that teachers adopt are important since these teaching strategies support students to become self-regulated learners. Two significant meta-analyses define a regulation practice framework which are Furtak et al. (2012) who make a plausible argument for the benefits of IBL, and Dobber et al. (2017) which focuses on teaching practices in IBL. Both meta-analyses are significant to this study because they enable description of the purpose and level of guidance in IBL as regulation practice.

Teacher regulation practices are a typology of teacher practice adopted by Furtak (2012) to categorise the purposes of instructional practices in a significant meta-analysis. The regulation practices of “Procedural”, “Epistemic”, “Conceptual” and “Social” were used to examine inquiry learning domains with a focus on the student (Furtak et al., 2012. p. 309). These were further adapted in a later meta-analysis relating to teacher practice (Dobber et al., 2017). In this analysis, a distinction is made between the teacher practices of meta-cognitive regulation, social regulation, and conceptual regulation and the researchers categorised research studies based on these purposes of teaching instructional practice (Table 2).

Table 2 is supplied as a summary of the regulation practice typology developed for both review studies.

Table 2

Regulation Practice Typology

	Furtak et al., 2012 (inquiry domains)	Dobber et al., 2017 (p. 205) (Teacher regulation practices)	Teacher role examples (Dobber et al., 2017)
Metacognitive		"Focus is on learning to act and think as a scientist".	The teacher encourages student questioning and discussion
Procedural	Students ask questions and engaging with the investigation procedure		
Epistemic	Students draw on the nature of science		
Conceptual	Students build knowledge	"Focus is on subject specific knowledge and rules"	The teacher uses explicit teaching to draw on previously learned work and link it with new information
Social	Students actively participate in a group and in class.	"Focus is on guiding the social processes of learning"	The teacher supports groupwork.

Notes: The table adapts the typology by Dobber et al., 2017; Furtak et al., 2012

Both Furtak et al. (2012) and Dobber et al. (2017) noted the difficulty of using a typology to analyse the research studies and assign teacher practices to distinct categories since regulation practices often overlap. It was recognised that more than one typology could be present in a single research study (Dobber et al., 2017) and noted that social regulation was often integrated with conceptual and metacognitive regulation practices.

Each of the regulation practices described in the literature have a distinct pedagogical purpose and three regulation practices are identified using the Dobber et al. (2017) typology. The first regulation practice is metacognitive regulation which incorporates teaching strategies that enable students to think critically about their planning and practice. It involves a range of different verbal utterances and non-verbal cues by the teacher and has been identified in IBL instruction in other research studies (Furtak et al., 2012; Dobber et al., 2017). In the science classroom, metacognitive strategies promote students to think actively and work in an equivalent way as a scientist might in practice. Metacognitive approaches used by the teachers include the verbal approaches of questioning and discussion. Questioning and discussion practices are often enhanced through non-verbal gestures (Tytler & Aranda, 2015).

Metacognitive regulation is a feature of how teachers support their students to pose and investigate inquiry questions. The difficulty that teachers have in supporting their students' questioning is noted in the literature alongside a lack of global research in this area (Herannen & Aksela, 2019). It might be expected that teacher talk practices would support student questioning and, Herannen and Aksela (2019) developed a conceptual model of student questioning to support teachers using the information derived from a systematic review. The research noted that students were typically not left alone to develop and investigate research questions, and the role of the teacher was identified to be highly significant. Only one study quoted in the Herannen and Aksela (2019) review of the literature was of an open IBL activity in senior secondary science and lacked detail on the teaching approaches adopted. The findings of the Herannen and Aksela (2019) study is also supported with the findings of Minner et al. (2010) who noted that guided support was commonly used by teachers to support students to develop investigable questions. The lack of evidence in both reviews in the senior secondary years of schooling is a noted research gap.

Social regulation is emphasised as a process that guides the social aspects of IBL (Dobber et al., 2017). Bardone et al. (2017) also emphasised the importance of teachers providing a "pattern of inclusion" (p. 301) and the importance of student participation in a social group during an empirical study in Turkish schools. Social regulation practices were identified as having three purposes: to "bridge the gap" between different learners, to provide a focus on collaboration strategies within the class, and teacher practices that involve the organisation and management of student learning groups (Dobber et al. (2017). These practices are often reported to be integrated with teacher practices that relate to the cognitive and metacognitive dimensions of learning.

In an analysis of PISA data which focused on the Finland dataset, Kang (2022) concluded that students benefited by the student-teacher relationship with increased levels of scientific literacy enhanced by the social aspects of learning from their teacher. In this study the benefit of social regulation was an important consideration when students were working in collaborative groups.

Regulation practices categorise the purpose of the pedagogical practice that support students to become self-regulated learners. By using a typology, features of teacher regulation practice can be distinguished.

2.6.3 Discussion and Questioning Practices in IBL

The verbal interactions between teachers and their students reflect a socio-constructivist perspective in IBL, where the teachers and students are co-contributors. Verbal interactions are not presented as isolated discourse practices in this section since they involve a range of other actions and resources used to support and enable the development of conceptual, metacognitive and social regulation in students (Dobber et al., 2017). The verbal utterances of teachers are practices that are accompanied by other actions "to elicit and acknowledge student responses, to clarify and to extend student ideas" (Tytler & Aranda, 2015, p. 425). Verbal interactions in IBL are presented as an active practice that involves a co-contribution between the teacher and the student.

The term "discursive moves" has been referred to in the literature to closely examine the talk practices of teachers by recognising that visual cues and voice changes are also key to the way teachers orchestrate their classroom practice (Bansal, 2018; Tytler & Aranda, 2015). Observations of teachers in empirical studies, have emphasised that teachers often changed their discursive moves from one of authority to dialogic discussion (Bansal, 2018; Tytler & Aranda, 2015), indicating a wide range of verbal practice and a balance of teacher authority and student independence in the classroom in the younger years of schooling (de Jong et al., 2023; Tytler & Aranda, 2015).

Providing scientific explanations was highlighted as significant in IBL as a dynamic teacher practice by Kulgemeyer and Geeland (2024) in a meta-analysis of constructivist discussion practices. Scientific explanations were regarded as dynamic in nature and not a monologic presentation of information where the students were passive receivers. Active student participation, including role play, was discussed as an interactive strategy that could be used in scientific explanations to build scientific understanding (Kulgemeyer & Geeland, 2024).

In contrast to discussion practices, which require the active participation of students, it is also recognised that direct instructional practices also have their place in the science classroom to convey essential conceptual information (de Jong et al., 2022). Orienting the learner at the start of an IBL activity and using direct instructional methods can have an essential place in IBL learning (Pedaste et al., 2015; Tytler et al., 2023). The literature does not agree on the positioning of direct instructional methods and how much information teachers should provide is not agreed upon in the literature (de Jong et al., 2022); however, the significance of direct instructional methods is generally reduced in IBL to support students to regulate their own learning.

McNew-Birren and van den Kieboom (2017) proposed that teacher questioning was a core teaching practice in constructivist teaching and advocated for teachers to use "high press questions" in the classroom and involve students in active participation. Questioning practices and methods of with-holding answers to student questions (Furtak, 2019) are two practices that invite students to think and participate in discussion practices (McNew-Birren & van den Kieboom, 2017). Effective questions were described as 'open questions', which required students to think critically (McNew-Birren & van den Kieboom, 2017). To accompany this approach, researchers proposed that teachers adopt "robust lesson goals" and support "activities that support students in making sense of scientific concepts" (McNew-Birren & van den Kieboom, 2017, p. 85). The researchers concluded that high press questions must characterise genuine IBL instruction and that low press questions were more typical of traditional forms of instruction where students were asked to recall information. The importance of effective questioning practices is also emphasised by Duncan et al. (2021) as part of IBL instructional approaches supportive of student self-regulation.

Studies of teacher-to-student questioning practices are often unique to each study context and influenced by the cultural setting. In a study of Chinese schools, low press questions or no questions were typical of 17 Physics teachers (Jin et al., 2016), and Bansal (2018) noted the mostly authoritative discussion practices in science classrooms in Indian schools. The difficulty in adapting jurisdiction-specific research into the Australian context where IBL has a more extended history presents an argument for using contextually relevant research.

Teacher-to-student questioning is strongly featured in US research, which, like Australia, has a history of socio-constructivist teaching methods. Furtak et al. (2019) investigated how teachers withheld answers from their students in IBL and found that teachers needed to follow the advice provided by the US curriculum, not directly to answer student questions. van Uum et al., (2017) also noted that the teachers in their study "… explained that they facilitated self-directed learning by not answering pupils' questions directly" (p.2477). The teachers in the Furtak et al. (2019) study reported the need to be better equipped to respond to the challenges of students who could not progress their work due to a lack of required information. The researchers recommended a balance of responding directly to student questions and not providing the answers (Furtak, 2019).

Providing scientific explanations (Kulgemeyer & Geeland, 2024) and using teacher questioning practices (Jin et al., 2016; McNew-Birren & van den Kieboom, 2017) are highlighted as essential strategies that encourage student participation. It is agreed that the complexity of the role of the teacher and their pedagogical practices "cannot easily be reduced to a few variables" (Dobber et al., 2017, p. 210) and discussion and questioning practices are integrated with a range of pedagogical practices and actions (Bansal, 2018; Dobber et al., 2017; Tytler & Aranda, 2015).

2.6.4 Supportive Pedagogical Practices

Very few empirical studies explore the interactions between a range of teacher practices that support student learning in IBL. Two areas of integrated pedagogical practice identified in the literature that have strong relevance to this research are the use of the use of scaffolding as a strategy to accommodate different learners within a single class (Dobber et al., 2017; Lazonder & Harmsen, 2016; van Uum et al., 2017), and integrated practices that support student questioning development (Herranen & Aksela, 2019). These teaching strategies orchestrate a range of pedagogical approaches rather than a single approach including verbal interactions and a range of teaching resources.

Scaffolding is described as a level of teacher guidance which “assist learners in performing demanding activities by explaining what to do and how to do it, and provide designated means to carry out, structure, or simplify the learner’s actions” (Lazonder & Harmsen. 2016, p. 689)”. Scaffolding practices often includes a range of accompanying materials, and practices including verbal interactions (Dobber et al., 2017; Lazonder & Harmsen, 2016; van Uum et al., 2017).

van Uum et al., (2017) categorised the use of scaffolds into “soft” and “hard” scaffolds as supportive teaching strategies in an empirical study of four classes of primary students in self-directed learning in IBL. Hard scaffolds included written templates and resources, and soft scaffolds included the teacher to student interactions which provided scaffolding. While the researchers supported an integration of both soft and hard scaffolds, they sought to focus on the how teachers were enacting scaffolding. The researchers found that there was strong teacher support for the hard scaffolds, and that the soft scaffolds that supported teacher instructional practice while students were using the hard scaffolds were often not included. Of interest in this study was that the researchers saw very little promotion of self-directed learning in practice and teachers were not commonly using “soft scaffolds” as integrated practice. The tendency for teachers to rely on the use of hard scaffolds to support their students without including a range of responsive verbal interactions was suggested to be a less effective teaching strategy and an integration of soft and hard scaffolds was recommended.

Teacher practices that support student questioning including a range of guidance levels also involves integrating a range of teaching strategies. In a content analysis of 30 papers which sought to develop a model to support student questioning, Herranen and Aksela (2019) investigated the range of teacher practices that supported and accompanied student questioning in differentiated classrooms during open IBL including the use of scaffolds. The researchers stated that the “Teacher’s role in student-question-based inquiry is often considered a supporter or a facilitator of inquiry (p. 21)”; however, they also elaborated on this point to argue for the value of a range of teacher practices that support student questioning. The range of practices used to support student questioning practices included direct instructional practices by providing essential information, the use of teacher questioning, learning inside and outside of the classroom, co-planning of IBL, group discussion, management of student groups, and monitoring student progress. This research acknowledged the complexity, integration and range of teaching strategies that supported student questioning in IBL.

The paucity of empirical research where a range of different teaching strategies were used in IBL in the senior years of schooling is a research gap (Dobber et al., 2017). These insights, in the primary learning context, provide an indication of a range of pedagogical practices that co-exist in the classroom in IBL in the senior science context.

2.6.5 Student Perceptions of Pedagogical Practice

The student voice relating to IBL pedagogical practice is not a dominant theme in the literature and therefore student views of pedagogical practices are not well understood. Student voices are of interest in the current study due to the age of the senior secondary student participants and the ability of older students to inform the interpreted findings.

Common research methods that have been used to determine student perceptions of their teachers’ practice in IBL research in the science classroom include focus student group discussions (Goodrum et al., 2012), student surveys and questionnaires (Concannon et al., 2020; Whannell et al., 2018), and observation (Bunterm et al., 2014; Hume et al., 2010).

In the Australian context, studies of student perceptions of longer IBL activities in science have shown some negativity of both students and their teachers compared to shorter activities in the senior years of schooling (Goodrum et al., 2012) and the middle years of schooling (Whannell et al., 2018). Of most relevance to this study is

Goodrum et al. (2012) whose earlier commissioned study influenced the structure of the Australian Science Curriculum. Of concern at that time, was that practical work was described by most student participants as being “recipe-based” and 79% of students reported transmissive teaching (p. 52). From this study and other earlier work, it was recommended that the teaching of science should centre on inquiry (Goodrum 2001; Goodrum 2012) and the Australian curriculum reflected that recommendation by promoting the nature of science and IBL. A Malaysian literature review also reported a lack of student motivation, student frustration and confusion in completing longer inquiry activities (Khalaf & Zin, 2018).

In the US where science fairs have had a long history there are surprisingly few studies which report directly on student perceptions of science fairs which reflect an IBL approach (Schmidt & Kelter, 2017). In a study of student’s attitudes to science after participating in a science fair and completing an extended research project, a negative effect on some students has been reported who found that the length and complexity of science fair projects were too extensive (Schmidt & Kelter, 2017).

Studies where students report on their teacher facilitation practice in IBL are scarce. In Australia, student perceptions of their teacher’s IBL facilitation practices of Year 11 science students arrived at no association between motivation levels and their teacher practices as a facilitator (Carvalho et al., 2011). Students in this study who completed a survey were more motivated by their independence and “perceived themselves as playing a central role” (p. 37) rather than being able to reflect on their teacher’s practices. This is a surprising finding since it might be expected that students in this age group might be able to evaluate more objectively outside of their own experience.

A significant US study of 127 high school students reported that very few older students held informed views of IBL of their teachers practice despite the teachers having informed views of IBL in this study (Concannon et al., 2020). These findings are important because it suggests that older students may not be able to reflect on the accompanying pedagogical practice in IBL.

Overall, student perceptions of IBL and their teacher’s practices indicate that student views are important and can be triangulated with other data sources to provide additional interpretation in qualitative and mixed methods studies. Earlier perceptions of students that have reported a negativity toward longer IBL activities in science warrant revisiting.

2.7 The Use of Conceptual Frameworks and Models to Support Planning

The literature indicates that planning practices of teachers are often influenced by supportive conceptual frameworks and models. A range of conceptual frameworks and models have been used to support teacher planning in IBL by guiding a process or a structure for both teaching and learning. The sequential and often cited 5E Biological Science Instructional Model (5E model) (Bybee et al., 2006) proposed five instructional phases to guide the planning of an IBL sequence of work. Bevins and Price (2015) argued against sequential models which they felt limited the iterative nature of science. Other often cited frameworks and models consider the iterative nature of science suited to senior secondary science by building in the ability to iterate and cycle through science IBL (Lubiano and Magpantay, 2021; Pedaste et al., 2015; van Rens et al., 2010). This section examines the planning support that conceptual frameworks and models provide.

Process driven conceptual models promote a guided IBL approach which are recommended by a range of researchers (Bybee et al., 2006; Dobber et al., 2017; Scott et al., 2018). Typically, guided IBL is reported to be planned in discrete manageable inquiry phases which are promoted through these IBL models. The sequential 5E model is an often-cited conceptual model, and the phases were proposed to be used in a strict order (Bybee, 2009). Other less cited models focus on the cognitive dimension of the learner using phases of inquiry include the 7E and the OE3R models (Eisenkraft, 2003; Lubiano and Magpantay, 2021; Rahmadhani et al., 2021). Each are situated in the cognitive dimension of learning and support teacher planning.

The seminal work of Bybee et al. (2006) provides a suggested sequence to support planning units of work through the 5E Biological Sciences Instructional Model (5E model) and is developed for the earlier years of schooling. The role of the teacher for each of the inquiry phases is summarised in Table 3 in sequence.

Table 3

The Role of the Teacher: 5E Model

Inquiry Phase	Role of the teacher
Engagement	The teacher presents 'the situation and identify the instructional task' and sets guidelines for the activity.
Exploration	The 'teacher initiates the activity' and acts as 'facilitator or coach' (Bybee et al., 2006)
Explanation	The teacher 'presents concepts, processes, or skills…' (Bybee et al., 2006)
Elaboration	The teacher facilitates group discussion and cooperative learning opportunities.
Evaluation	The teacher assesses the students.

(Bybee et al., 2006)

The highly valued 5E model guides the process of IBL by focusing on student practices and provides some brief information on the teachers' role. A teacher's role is presented as a set of goals, yet the pedagogies required to achieve those goals are not indicated and the facilitative role is ill-defined. This argument does not criticise this model; however, it might provide some impetus for consideration of an enhancement to this model by providing further guidance for pedagogical practice.

A further iteration of the 5E model by Pedaste et al. (2015) was developed as a framework in conjunction with a meta-analysis for the secondary years of schooling and as a fit-for-purpose model to guide teacher planning in the middle years of schooling. It too, is situated in the cognitive dimension of the learner and the advice to teachers about their role as facilitator is also limited. In constructing the framework for inquiry phases, the researchers in this study noted 109 terms for the description of inquiry phases in the literature (Pedaste et al., 2015) and drew on previous works including the Bybee 5E instructional model to formulate a suitable conceptual model.

While phased conceptual models and frameworks provide a supportive planning tool, sequential models like 5E model may not be supportive of the messiness of science when students start to develop independence and evaluate and repeat processes (Bevins and Price, 2015). In contrast to pedagogical models that are often procedural or formulaic and focus on student learning, Bevins and Price (2015) proposed a three-dimensional and iterative model of IBL which supported instructional practice and the nature of science. The Bevins et al. (2015) model moved away from process driven models and focused on the conceptual, procedural, and personal dimensions of IBL favouring an open approach to IBL supported by self-determination theory. The shift away from an emphasis on the teacher's role and the establishment of class 'routines' was encouraged.

Design-based research underpinned the development of the van Rens et al. (2010) framework for upper secondary science IBL. The developed conceptual model centred on three dimensions of student learning described as: "willingness", "ability" and "knowing" and rejects a phased and systematic approach to science IBL to mirror the iterative work of the scientist and the development of students towards working independently. The model included the instructional phases of: "…orientation on, information about, acquisition of, application of and reflection on all aspects of a cyclic and iterative inquiry process" (p. 802) and the three dimensions of learning were situated within each teaching phase supporting a cyclic and iterative approach to IBL. The framework focus was situated in the cognitive dimensions of learning although the phased planning approach provides some planning support to the teachers.

Pedagogical models are useful as they can simplify a planning process and can be easily adapted in the classroom. According to Bevins and Price (2015) phased models might risk oversimplifying a set of complex processes particularly when the nature of science is considered, by restricting the level of IBL to a less open model. The IBL models cited are situated in the cognitive aspects of learning and often sequential and the balance between providing no structure and a highly rigid set of phases is acknowledged in some of the cited phased models (Pedaste et al. 2015; van Rens et al., 2010).

Very few models that support teacher practice recognise the constant monitoring of student work and the formative assessment practices which accompany monitoring.

The Interdisciplinary Mathematics and Science (IMS) teaching model shows promise in the early years of schooling. It recognises the importance of the role of the teacher in IBL (Tytler & Prain, 2021). IMS places importance on orienting students, balancing direct and indirect instructional methods, and continuous monitoring of student work in a guided activity are all consistent with the practices of expert teachers in the current study. While the context of the IMS model has a different application to practical science in the senior years of schooling, this iterative model is supportive of teacher practice.

As a further extension to the constant monitoring of student work in IBL that are indicated in the IMS model, are formative assessment practices which require teachers to evaluate student work. In a Swedish study, formative assessment practices which were either pre-planned, or spontaneous and flexible were investigated as classroom practice. Formative assessment was reported to be challenging for teachers and the researchers proposed this as an area for further teacher professional development in IBL (Grob et al., 2017). This finding of teachers being challenged by formative assessment approaches was also supported with similar findings in an earlier study (Jaquith et al., 2011). Formative assessment is important because the constant monitoring of students needs to be accompanied by teacher feedback practices that support student work in IBL.

Conceptual models are supportive of planning processes; however, the balance between a restrictive and sequential phased model, and an iterative model need to be considered according to the context of the IBL and the age and ability of the students. The reported decrease in students engaging in IBL has been further impetus to support the formation of conceptual planning models that are fit-for-purpose (Libiano et al., 2021), iterative, and supportive of the nature of science.

2.8 Chapter Summary

Inquiry-Based Learning is influenced by a constructivist philosophy which represents a wide variety of interpreted approaches when applied to IBL teaching and learning. In science education IBL considers the nature of science and the work of practicing scientists and therefore the movement toward socio-constructivist approaches where students work collaboratively in practical science has become common practice (Tytler, 2019). There is some evidence that suggests that implementation of IBL might not be consistent despite implemented IBL curriculum requirements (Goodrum et al., 2012; Scott et al., 2018). Therefore, robust contemporary empirical studies which identify contemporary IBL pedagogical practices are urgently required to support teachers.

This research adds to a body of knowledge of IBL in the senior secondary science classroom and relies on making the following assumptions based on the literature:

1. The perceptions of teachers, their adopted philosophies, and pedagogical practices impact IBL implementation and practice
2. The contemporary IBL science classroom reflects a dominance of socio-constructivist approaches that reflect the nature of science
3. The intentions of IBL in implemented and intended science curricular are not consistently enacted
4. Pedagogical approaches can be impacted by intrinsic and extrinsic factors
5. Pedagogical approaches are flexible and not static
6. Students offer an authentic voice through their perceptions of pedagogical practice triangulated with other evidence.

Chapter 3

The Researcher and Methodology

3.1 Chapter Overview

This chapter explores the personal ontology of the researcher, theoretical underpinnings of the research, and the chosen research methodology. The chapter makes a case in favour of Grounded Theory Design (GTD), as a suitable methodology for this research.

The strong foundations for this research were influenced by pragmatism and being able to choose a methodology which could support research that had a practical application. It has been the researcher's experience that teachers of senior secondary science have reported that existing models of pedagogical practice have not been fit for purpose, and therefore the purpose of this research is to support IBL teaching. It is also the researcher's experience that there are some good IBL practices which could be drawn upon to develop a model of pedagogical practice to support teaching. The pragmatic paradigm that underpins this research is coupled with interactionism by recognising that there could be multiple interpreted realities that occur in a social setting.

In this chapter GTD is argued as a suitable methodology supportive of a deep investigation of the phenomena in a natural classroom setting. GTD is underpinned by the theoretical perspectives of pragmatism and interactionism which align with the researcher's perspectives. To deeply investigate the research questions a small sample size which included multiple qualitative data sources was considered suitable in an inductive study to allow theory to develop from the data.

3.2 Theoretical Underpinnings

The philosophical stance for this research is pragmatism and interactionism (Corbin & Strauss, 2015; Lincoln & Guba, 2013; Urquhart, 2013). In developing a personal ontological stance, consideration was given to the researcher's position in the world, how the world is viewed, and the position of the researcher in this study. It also recognised the important contributions made by the participants of this study. This section explores the researcher's philosophy and the associated theoretical underpinnings of this study.

3.2.1 Personal Ontology and Research Paradigm

The ontology or worldview of the researcher was influenced by lived experience and a desire to improve IBL pedagogy by contributing to knowledge in this research context. In Section 1.2 the researcher's extensive experience in science education and IBL was outlined. Influenced by more than 25 years of lived experience working in secondary science education, it is believed that teaching is an interactive pursuit that involves the teacher, the students, and the external community as a highly interactive social system. The science IBL classrooms in the context of this study in IBL are viewed as being a socio-constructivist classroom environment where students work with each other and their teachers to answer investigable questions related to science.

The importance of the complex interactions of teachers with their students in the secondary science IBL classroom, the routines, and processes that they follow represent important world views. It is from this stance that the research is situated. It is also believed that multiple realities might exist and definite answers to the research questions might not be a realistic outcome of research.

The importance of conducting this research in a natural setting and being able to learn from the educator experts was influenced by a range of theorists including Lincoln and Guba (1985) who advocated for research conducted in a natural setting. The work of Lincoln and Guba (1985) was an important consideration, who proposed a naturalistic paradigm for research that involved social interactions. The philosophy adopted by Guba and Lincoln recognised that there could be multiple interconnecting realities to develop some understanding of the phenomena being investigated. However, the constructivist paradigm that they advocated for resisted a clear focus on a purpose. In the current study, the intended goal for the outcomes of the research is for the pragmatic reasons of supporting teachers.

This research was strongly influenced by the research paradigm of pragmatism and a strong desire to improve IBL teaching in senior secondary science. Other theorists have proposed pragmatism as a paradigm and of most interest to this research is when pragmatism is combined with interactionism in a social setting. Pragmatism uncovers useful knowledge that can be applied (Corbin & Strauss, 2015; Lincoln & Guba, 2013) and originates from the work of John Dewey and George Herbert Mead (Corbin and Strauss, 2015). The foundation of pragmatist philosophy is that "knowledge is useful for practice or practical affairs" (Corbin & Strauss, 2015, p. 21). From this perspective, knowledge is gained from those who practice IBL and can be utilised to inform theory. This paradigm is supportive of the researcher's purpose in conducting this research.

Pragmatists recognise that "truth is equivalent to what we know but eventually, it may be judged partly or even wholly wrong" (Corbin & Strauss, 2015, p. 20). The perspective of Corbin and Strauss (2015) is agreed by the researcher who has recognised that seminal works in IBL may be challenged or enhanced through further research. It is the experience of the researcher from a perspective of pragmatism that existing conceptual models and IBL approaches may not be fit for purpose in the senior secondary science context of this research. It is also recognised that existing theories might also include some elements that are useful to the senior secondary science context.

A second paradigm of interactionism is also applied to this research. The research recognised the complex actions and interactions that occurred in a social setting (Corbin & Strauss, 2015). Teacher perceptions and practices were valued in the researcher's own professional experience, and of interest, was how different pedagogical perceptions and practices interconnect. Teaching is regarded as being a complex play of different pedagogical practices and the interactions between them and the patterns that emerge were sought in this study. In a social setting the interactions between participants and the researcher supported an interpretation of reality (Creswell & Guetterman, 2021). Interactionism recognises that there is the possibility of multiple realities by drawing on the interactions between the researcher and the participants (Corbin & Strauss, 2015; Creswell & Guetterman, 2021). The complexity of the interactions between teachers and their students are important in this study which are recognised as being foundational to teacher practice.

In arriving at a paradigm for this research both pragmatism and interactionism were suitable paradigms that underpinned the theoretical foundations of this research. The interpreted knowledge derived from the social interactions in a social setting have a practical purpose for educators.

3.2.2 Considerations in Selecting a Methodology

This section argues for an inductive qualitative approach to research in a naturalistic setting. The chosen methodology of Grounded Theory Design (GTD) considered the research paradigms of pragmatism and interpretivism and the broad research questions.

It is important to restate the research questions for reference since they influence further discussion relating to methodology and epistemology:

1. What are science education leader perceptions relating to inquiry-based learning in Depth Studies in senior secondary science in the NSW Australia context?

2. What are expert teacher practices relating to inquiry-based learning in senior secondary science?

Broad research questions have been chosen because the researcher recognised that the perceptions of study participants could not be predicted, and that classroom pedagogy is multi-faceted and involved interacting practices. The classroom environment in this study was highly interactive, and the researcher desired to gain fresh insight into teacher practice and develop an understanding of the pedagogical approaches that teachers already used.

The context for this research was IBL in the NSW Australia secondary senior science curriculum which often involves a socio-constructivist approach to learning where students enquire about, investigate scientific phenomena, and construct scientific knowledge (Hand et al, 1997). The socio-constructivist science classroom environment includes both interactions and actions between the teacher and the students which both have meaning. To deeply investigate the actions and interactions of teachers together, fresh insights could emerge from the data that might not be known by the researcher. Therefore, an inductive method was chosen for research to enables emerging data sources to be interconnected.

In arguing for an inductive research method in a naturalistic setting, Dewey (1929) insightfully stated the following using a pragmatic paradigm:

> Insofar, we have the earnest possibility of human experience, in all its phases, in which ideas and meanings will be prized and will be continuously generated and used. But they will be integral with the course of the experience itself, not imported from the external source of a reality beyond. (Dewey, 1929, p.138 in Corbin & Strauss, 2015, p.20).

Dewey saw the benefit of deriving meaning from the human experience in a natural setting in contrast to forming a theoretical viewpoint external to the reality of the human experience. His comment also recognised that the human experience could change and may continue to change. This stance is supportive of seeking contemporary insight into the human experience in this research context.

The research paradigms of pragmatism and interactionism are supported by GTD methodology and the arguments that supported the selection GTD for this research are included in the following section.

3.3 The Argument for Grounded Theory Design Methodology

The importance of this chapter is to argue for the use inductive research including Grounded Theory Design (GTD) methodology as being suitable for this study. In senior secondary science education research, inductive studies in IBL are scarce (Dobber et al., 2017; Hasni et al, 2016). In this research, an inductive approach which allowed for the phenomena to emerge from the data was the desired approach. This section argues for the use of GTD through its suitability, being able to address broad research questions, the use of multiple data sources and a discussion of the credibility of GTD research.

3.3.1 Suitability of Grounded Theory Design

In choosing a methodology, a deep investigation rather than a broad investigation was preferred to uncover findings that were potentially not expected by the researcher. It considered the researcher's world view, and the selected paradigms previously stated. In this study, broad questions were posed and GTD methodology was considered to be an appropriate methodology (Corbin et al., 2015; Creswell & Guetterman, 2021). GTD can answer the broad research questions because it relies on the triangulation of multiple forms of data through data analysis. The methodology seeks to form theory through the connections between multiple forms of data.

Grounded Theory Design (GTD) was also chosen as a methodology because the study sought to develop theory from empirical and qualitative data (Creswell & Guetterman, 2021). GTD is also situated within a pragmatic and interactionist paradigm (Corbin & Strauss, 2015) consistent with the researcher's views. Several permeations of GTD involve an unstructured interpretation of data to a semi-structured collection and analysis of data. The different approaches originate from three different camps of GTD methodology: Glaser, Corbin and Strauss, and Charmaz (Creswell & Guetterman, 2021) and despite purist perspectives of GTD, the approaches are often combined (Creswell & Guetterman, 2021).

GTD methodology is not without apparent controversy and the original developers, Glaser and Strauss held some different views after the initial development of GTD. According to Corbin & Strauss (2015), the two researchers diverged and formed differing views of GTD. This is important because their differences account for the different approaches to GTD which have emerged since its original development.

According to Creswell (2012), Glaser trained in quantitative data methods and the controversy between the two researchers was initiated by Glaser in 1992 who criticised Strauss for using for guiding GTD with a structure that did not allow theory to emerge. There are a range of different perspectives of GTD and according to Creswell (2012), there are three broad designs. These are a Systematic Design which is championed by Glaser and Strauss (Glaser & Strauss, 1967), the Emerging Design by Glaser (Creswell, 2012) and the Constructivist Design by Charmaz (Creswell, 2012) (Table 4). In choosing among the three approaches to GTD both the central idea and the feasibility of the study have been considered.

Table 4

Grounded Theory Method Approaches

	Systematic Design	Emergent Design	Constructivist Design
	Corbin and Strauss	Glaser	Charmaz
Procedures	Structured	Flexible	Flexible
Development of categories	Pre-set broad categories are explored	Categories emerge from the findings	Emerging categories derived from the study participants
Coding and analysis	Open, axial and selective coding	Comparison of emerging data	Researcher determined codes based on participant experiences

Note. Adapted from Creswell, 2012; Creswell and Guetterman (2021)

GTD was initially developed using a pragmatic and interactionist theoretical perspective by Strauss and Glaser, yet there are variations in theoretical perspectives throughout the literature (Creswell & Guetterman, 2021). Charmaz has been reported to criticise the structured approach to GTD adopted by Glaser and Strauss and has promoted a much more fluid constructivist design approach (Creswell & Guetterman, 2021). Whereas, Urquhart, (2013) has noted the difficulty that early researchers have with the constructivist design and unstructured GTD research and is supportive of a systematic approach. These are important considerations for a doctoral researcher and the advice given by Urquhart (2013) has been considered for this research.

It is not uncommon for researchers to adopt elements of systematic, emergent and constructivist design in GTD research (Creswell & Guetterman, 2021). Six characteristics of GTD were proposed by Creswell and Guetterman (2021) which could include elements of each of the three different approaches depending on the research context:

- Process approach
- Theoretical sampling
- Constant comparative data analysis
- Core category development
- Theory generation
- Memos (Creswell & Guetterman, 2021, p. 486).

In this research each of these features were present and included in the methods in Chapter 4 which adopted a systematic GTD approach to the research along with some elements of an emergent design during the later stages of data analysis. According to Creswell and Guetterman (2021) systematic design is commonly used in education research. However, GTD approaches often include elements of each of the three approaches (Creswell & Guetterman, 2021).

In a systematic approach a semi-structured procedure was used, and the coding of data was through a process of open, axial and selective coding which provided for further study rigor (Creswell & Guetterman, 2021). The core categories were pre-set to address the research questions and involved an interpretation of perception and practice. A two-phased approach which provided structure to the study was also adopted to provide structure and increase the rigor of the study. A systematic approach also more clearly supported the requirements for university ethics approval which is discussed in Chapter 4.

GTD develops theory from the data, and it is important to understand the definition of theory in this context. According to Corbin & Strauss (2015) a theory in GTD is:

> …a set of well-developed categories (themes, concepts) that are systematically developed in terms of their properties and dimensions and interrelated through statements of relationship to form a theoretical framework that explains something about the phenomenon. (Corbin & Strauss, 2015, p. 62).

In developing theory, elements of an emerging design approach have been implemented at the selective coding phase of data analysis. The strict coding process inherent with systematic design was overly restrictive for this study and not open to emerging new phenomena and on-going peer review. It was necessary for some flexibility in the coding process to be included to support the requirements for a doctoral thesis by contributing new knowledge. Therefore, a comparison of emerging ideas through active discussion, engagement with memos and diagrams, with academic experts in this research field, and critical reading of the literature support the emerging model in this research during the final analysis.

To strengthen theory development, Corbin and Strauss (2015) advocated for not completing a substantive literature review prior to data analysis. Due to the University requirements for a doctoral thesis an initial literature review was conducted to define and frame the phenomena being explored and a second literature review that enhanced the emerging findings was conducted after data analysis in keeping with GTD methodology. The strengthening and validation of theory using existing literature is also supported by other researchers (Creswell & Guetterman, 2021; Urquhart, 2013).

3.3.2 Developing Research Questions for Grounded Theory Design Research

Broad research questions, like those posed in this study are well-suited to inductive and interpretive research such as GTD because they place less restriction on allowing phenomena to emerge from the data (Corbin & Strauss, 2015).

The broadness of the research questions that were posed in this study were exploratory and unsuitable for hypothesis testing in a deductive study. From the outset, the research questions were designed to provide flexibility and allow a theory to emerge from the data using qualitative data collection techniques and analysis and impose very little pre-knowledge of the phenomena on the study.

In posing broad research questions, the sample size was reduced since the amount of data generated from each participant was large. The advantage was that a small sample size enabled deep analysis by deeply investigating the phenomena. GTD involves a limited number of participants to enable a deep investigation (Creswell & Poth, 2018). Due to the time taken to deeply investigate a series of cases, GTD studies tend to include a small number of cases using a wide range of data sources (Corbin & Strauss, 2015; Urquhart, 2013). In this study, it was feasible in the time taken to complete a doctorate to include ten semi-structured interviews and investigate the practices of four expert teachers in a natural setting using multiple data sources. The triangulation of multiple forms of data also limited the number of participants.

3.3.3 Multiple Data Sources in Grounded Theory Design

The GTD methodology adopted in this study was also considered to be appropriate for this study since it relied on the systematic collection of a range of qualitative data within a naturalistic setting (Glaser & Strauss, 1967; Creswell, 2012). GTD does not limit the type of qualitative data collected and allows some flexibility by collecting data from informal conversations with the research participants and constantly considering, reflecting, and comparing data during the data collection process to develop the theory.

In a systematic GTD, multiple study phases are often used (Creswell, 2012; Urquhart, 2013) and in this study two study phases were selected with the first phase informing the second study phase. The thematic analysis of an initial phase allowed for phenomena to emerge that could be further deeply investigated in the second study phase. The phased approach also allowed the researcher to cycle back to emerging phenomena in the first study phase to provide emphasis and derive further meaning (Creswell, 2012; Urquhart, 2013).

According to Corbin and Strauss (2015), there is no limit to the number of different sources of data used in a GTD study and this is dependent on the nature of the research and the sources of data available. In this study, interviews, documents, artifacts, and observation field notes were all included in the data collection during the second phase of the study to address RQ2. A detailed account of the methods used in this study are presented in Chapter 4.

The large volume of data collected that requires analysis in GTD is reported to be overwhelming for researchers if it is not constantly managed and analysed (Corbin & Strauss, 2015) and for practical reasons, data management structures needed to occur throughout this study. By implementing two phases of the study, the researcher could stop collecting data after one study phase and resume after initial analysis and coding to manage the volume of data. According to Urquhart (2013), a phased approach to GTD research is recommended to those who are new to GTD research, to the manage high volume of data and the analysis.

Memoing is an essential feature of GTD and assists in theory development throughout the study (Corbin & Strauss, 2015; Urquhart, 2013). Memoing was an important process because it provided an additional data source which included the interpretations of the researcher whilst collecting data. Processes included ongoing researcher's notes, diagrams, and coding, and may not form a part of a dissertation but ensures rigor in the study and the development of ideas. For example, drawing diagrams to show the process during observation and iterating the diagrams during analysis and writing has challenged ideas and supported the development of the GIST framework which has been developed in this study.

3.3.4 Credibility of Grounded Theory Design

The credibility of the theoretical findings of GTD research depend on being able to present truthful and useful knowledge. Truthfulness can be enhanced by ensuring validity, reliability, credibility and truthfulness, and rigor in the chosen procedures (Corbin & Strauss, 2015). Like any qualitative research, researcher bias was a further consideration that required management through a process of self-reflection and robust research processes.

In this study, GTD was selected to support the validity of the study which philosophers have referred to as 'truth' (Corbin & Strauss, 2015). Truth is equivalent to what we know and can be built upon to allow for the evolution of phenomena (Corbin &

Strauss, 2015). The findings of a GTD study, such as this study, are grounded in the knowledge of the 'knower' and their interpretations. The researcher sought to develop an integrated process or theory which had strong validity to the research questions and the pragmatic reasons for engaging in this study (Creswell & Guetterman, 2021).

The methods selected in a GTD study are not fixed or formulaic and the researcher is able to choose the methods that best serve the research questions. Guba and Lincoln (1985) described a series of steps that increase the trustworthiness of qualitative research conducted in a naturalistic setting during implementation. These processes, also relevant to GTD research, need to be considered from the outset and built into the research design. These processes include: "Maintaining field journals" (p. 282), "Maintaining safeguards that limited distorted interpretations, organising on-site discussions, triangulating data, gathering additional materials, debriefing," and "maintaining an audit trail" (p. 283). Processes for these steps can be enhanced by digital processes that enable management of the large volumes of data and allow a digital audit trail to be established. Safeguards include ethical considerations relating to the confidentiality of sensitive data and working with child participants discussed in Chapter 4 which were ethics approved.

According to Prior (2009) (in Corbin & Strauss, 2015, p. 344) the rigor of GTD is enhanced both during data collection and during the analysis of the data. Rigorous GTD research included a literature review, theoretical sampling, prolonged and persistent engagement, constant data comparison, peer review and member checks during a process of active engagement. The rigor of GTD was strengthened by the researcher who sought to have observations clarified through in-member checks and peer review, thus increasing the truthfulness of the study (Corbin & Strauss. 2015). The findings were also recommended to be further compared in the literature to scale-up the theory, thus adding further rigor.

An audit trail was necessary to review previous thinking, increase the credibility of the research, and support iterations of the emerging theory (Corbin & Strauss, 2015; Guba & Lincoln, 1985). Digital processes were recommended to store all data, codes, theoretical diagrams, and memos so that they could be reviewed and compared along the way (Urquhart, 2013).

GTD researchers recognise that the knower will have their own perspectives which cannot be completely divorced from the research (Creswell & Guetterman, 2021). Through a process of reflective thinking and rigorous processes research bias can be limited. Reflective thinking can be enhanced by a constant reviewing of the data, journal writing and constructing memos to support on-going thinking. Added interpretations by participants provided further support of reflective processes.

GTD is a credible methodology which includes strong validity, reliability, credibility and truthfulness, and rigor.

3.4 Chapter Summary

From a philosophical viewpoint, pragmatism and interactionism provide the paradigms for this study. An interpretive epistemological stance argued for a qualitative and inductive approach to this study to deeply investigate the phenomena. This approach is argued to uncover new knowledge and recognise that knowledge is not static.

GTD is an appropriate methodology for this study since the study seeks to develop a theory from new and existing knowledge (Creswell & Guetterman, 2021). GTD positions the participants as having expertise in the study area and involves the researcher adopting an unobtrusive approach to data collection. GTD is a credible methodology which can include a range of qualitative methods and data sources which can be triangulated and coded to develop dominant themes and build theory.

Chapter 4 outlines the approved research methods and the ethical considerations for this research which includes GTD methodology.

Chapter 4

Research Design and Procedures

4.1 Chapter Overview

A systematic Grounded Theory Design (GTD) methodology has been selected for this study, which sought to deeply investigate the research phenomena of teacher perceptions and practices. The broad research questions selected for this study required a method that supported the flexibility required for a deep investigation by allowing themes to emerge from theoretical sampling.

This chapter presents the research design which had ethics approval by the University of Technology (UTS) Human Ethics Research (HREC) (ETH194039) (Appendix I). This chapter presents the research design principles, the selected methods, study phases and participants, theoretical sampling processes, data analysis, theory generation and study credibility.

The significance of this study is emphasised by the highly experienced education leaders and expert teachers selected as participants. They were chosen according to strict selection criteria and provided deep insight into the phenomena. Multiple data sources were selected in Phase B of this study to deeply understand interacting teacher practices.

4.2 Research Design Principles

The design principles adopted reflected Grounded Theory Design (GTD) methodology, and a systematic design (Corbin & Strauss, 2015). The guiding principles of GTD for this study are introduced in this section.

4.2.1 Adopted Grounded Theory Design Principles

GTD was the chosen methodology in this research because the perceptions and practices of education leaders and expert teachers had not been thoroughly researched in the context of this research. Furthermore, the interactions of teacher practices in a natural classroom setting in IBL were sought which were discussed in

Chapter 3. GTD had the potential to deeply analyse and draw together a range of practices into a broad theory by examining the interactions of teacher practice in a social setting.

A systematic GTD approach was chosen for the method and analysis, consistent with the work of Strauss and Corbin (Corbin & Strauss, 2015; Creswell & Guetterman, 2021), which advocated for some pre-determined structures. The systematic approach adopted was rigorous and employed a systematic method of coding using open, axial, and selective coding structures (Corbin et al., 2015; Creswell & Guetterman, 2021). The study was conducted in two research phases, Phase A and Phase B, provided a broad process and supported a flexible structure.

According to Creswell and Guetterman (2021), three main processes presented as principles are inherent in GTD:

- Theoretical sampling
- Constant data comparison
- Theory Generation.

By using theoretical sampling, those forms of data considered beneficial, by adding insight into the phenomena, were selected (Creswell & Guetterman, 2021). Multiple data sources were included and are described in Section 4.3.

The inductive nature of GTD research required constant data comparison to increase the rigour of the analysis. Within each study phase, a constant process of memoing and asking questions about the data provided this comparison. The process of data analysis and the constant comparing of data, is outlined in Section 4.3. Methods of thematic analysis of the data and developing a core category prior to theory generation were inherent with GTD research (Corbin & Strauss, 2015). During analysis some known typologies were also used to categorise and further analyse the data where consistencies emerged between the data and the literature. According to (Creswell & Guetterman, 2022) it is not uncommon for additional data analysis methods to be used in GTD research.

The third principle of GTD research is theory generation, which was a pragmatic reason for choosing GTD as a methodology and methods for theory generation are discussed in Section 4.5. A selective core category was closely examined after coding and constant comparison of data, and the Guided Inquiry Science Teaching (GIST) framework was proposed as a theory in Chapter 7.

4.3 Study Phases and Participant Selection

This section discusses the methods used in the selection of study participants within two phases of study, which were ethics-approved by the University of Technology Sydney HREC (ETH194039). Selection of study participants recognised the design principles of theoretical sampling described in Section 4.2 when working with human participants. All requirements of ethics approval were adhered to throughout the study period.

4.3.1 Position of the Researcher and the Study Participants

The educators and teachers in this study had pedagogical expertise through their experience in science education. This stance placed value on their perceptions and pedagogical approaches to build theory. This section explores the positions of the researcher and the study participants to enable a deep analysis of the research phenomena.

A researcher can decide on their research position in a naturalistic setting in this research context as being one of authority, a co-contributor, or as an observer. In this study the researcher took on an unobtrusive stance as an observer and recognised the expertise of the education leader and expert teacher study participants. By limiting the influence of the researcher on the study, it was also recognised that researcher influence could not be eliminated in qualitative research, and a process of constant self-reflection and data checking was built into the methods to reduce the impact of researcher bias (Lincoln & Guba, 2013).

IBL studies which position the researcher as an expert by imposing an intervention and observing the enacted programme, were a dominant feature of IBL empirical research according to a significant meta-analysis of pedagogical practice by Dobber et al. (2017). Cited empirical studies which observed IBL interventions, positioned the researcher as the expert at the commencement of the study, and reduced their influence during observation (Bunterm et al., 2014; Nichols et al., 2017; Zion & Mendelovici, 2012). Three significant meta-analyses indicated a gap in empirical research in IBL pedagogical practice and recommended a recognition of the expertise of teacher and educator study participants in future research (Dobber et al., 2017; Furtak et al., 2012; Hasni et al., 2016). In this research context, which sought to learn from the observed experts, positioning the researcher as an authority was not considered to be appropriate to answer the research questions and support the validity of the study. The intention of the research was to uncover the truth from the educator and teacher experts rather than the researcher exerting influence on the study participants.

Deficit teacher practice in IBL was often cited in the literature which often included the effects of imposed interventions in empirical IBL studies (Dobber et al., 2017). Three meta-analyses recommended empirical studies that focus on the role of the teacher in the classroom and a consideration of positioning the teacher as being of equal importance to the researcher (Dobber et al., 2017; Furtak et al., 2012; Hasni et al., 2016). Co-construction of lesson design (Bevins & Price, 2015), and co-construction of an IBL model (Rens et al., 2015) were noted references which recognised the importance of the teacher by the researcher who adopted design-based research by working together. During the time of this research the potential impact of the researcher on the workload of the participants was a strong consideration in gaining approval for research in schools, and design-based research was unsuitable since it required considerable time and commitment by the study participants.

According to Skamp (2022), in a review of Research in Science Education Articles (1994–2018) only four papers since 2010 were published which included action research where the researcher and participants were co-contributors in science education research and were of equal importance. The author noted that the complexity of this kind of research and noted the difficulty that researchers had to locate willing study participants. In gaining approval for this research the willingness of the participants to participate was influenced by the potential impacts on their work.

A researcher approach that recognised the expertise of educators and teacher participants was warranted in this study to deeply address the research questions. This recognition of expertise positioned the researcher as an unobtrusive observer in the classroom and an expert in interpreting and analysing the data (Creswell & Guetterman, 2021; Corbin & Strauss, 2015). The usefulness of the findings including data drawn from educators and teachers who were experts in their field supported the development of a framework of pedagogical practice as an outcome of GTD research.

4.3.2 Dual-Phased GTD Research

Two study phases are often used in IBL research, and are consistent with GTD methodology (Urquhart, 2013; Creswell, 2012). There were very few examples of dual-phased IBL GTD methodology research in the literature in the study context. In this context, Correia and Harrison (2020) and McLaughlin and MacFadden (2014) were two research studies that used a dual-phased GTD study where the first study phase informed the second.

Conducting one study phase, analysing the data, and reflecting on the preliminary findings before the second phase, enabled the gradual building of the theory. In this study, an academic paper was written (de Ridder, 2021), and a conference presentation (ASERA, 2021), was delivered to gain peer-reviewed feedback before the commencement of the second study phase. Gaining early feedback was a valuable approach for a beginning researcher and an opportunity to engage with the academic community early in the research to inform the remainder of the study. Using the feedback gained prior to conducting the second phase of the study, the definition of 'expert teacher' was reconsidered, further reading of recommended additional literature sources was recommended, and the potential application of the research for early career teachers was considered after conversations with academics and experts in the field.

The data gained from the first phase strongly suggested features of IBL adopted by teachers described by the education leaders. These features influenced the selection of participants for the second phase of the study who also adopted similar IBL approaches. The approaches described included the use of teacher developed topics, guided classroom support, and practical science.

4.3.3 Ethics Considerations and Approvals

Study design principles adhered to the University of Technology Human Ethics Research (HREC) approval number ETH194039 and considered the risks of working with children and adult participants. Ethics approval necessitated informed consent of the child and adult participants, consideration of the researcher's conduct during data collection, and data confidentiality and data storage. Revisions to the initial approval were granted during a public health pandemic during Phase B of the study to include additional health and safety considerations which were adhered to throughout the sampling period. A schedule of ethics approvals is included in Appendix I.

It was recognised that there was a potential risk between the researcher and the study participants in qualitative research (Creswell & Guetterman, 2021) because of the in-person interactions and working with human subjects. Risks working directly with children were reduced by establishing procedures to ensure child protection requirements, to address potential sensitivities including embarrassment, by ensuring that the student participants were treated with equal respect, ensuring that the researcher was not left alone with students, and maintaining anonymity and the anonymisation of the collected data. Carer consent was required in addition to student-informed consent for student study participants (Appendix E).

Adult participants were also a risk which required management. All adult participants were treated respectfully and were told that the researcher was not seeking out any negative practice. The researcher told students that their teacher was recognised as being an expert and that the researcher was there to learn from their practice. The data generated retained the anonymity of the teacher participants and their schools as required by ethics approval unless the teacher and the school principal provided consent.

All participants were provided with a participant information sheet (PIS) (Appendix A-F) to enable transparency between the participants and the researcher's work by providing informed consent to participate. The PIS sheets informed each participant about the nature of the study, how data was to be collected, and how data was to be stored and used. Informed consent by the University of Technology Responsible Conduct of Research Committee (HREC) was required for this study, with consideration of children and adult participants and the potential for sensitive data that could be collected. The selection of participants was approved by HREC and is included in Sections 4.3.4 and 4.3.5.

The qualitative methods used in this study generated a large volume of potentially sensitive data, including scripted data, audio, documents, artefacts, and photographic images. The design principles were situated in the assurance of confidentiality and anonymity (Corbin & Strauss, 2015), which required deidentifying and coding all data and securing digital data storage as required by ethics approval. The removal of actual names of persons and locations were replaced by pseudonyms and student names were redacted before data storage in secure University digital storage as required by ethics approval. Audio data recordings in both study phases were deleted immediately after transcription and not retained. Digital data, including images of student work and documents, were stored securely and password-protected on the University server as required by ethics approval and password-protected files. Hand-written field notes were stored in a lockable cupboard and deidentified with pseudonyms. All deidentified and hand-written content and copied artefacts were digitised before analysis.

Good teacher practices were sought in this study, and an unobtrusive research stance required by GTD and ethics approvals supported the teacher participants not to be interrupted frequently during their work and not to feel threatened or embarrassed by any interactions with the researcher. All participants were invited to review transcribed data if they wished before storage. Study participants could also withdraw any collected data before the data was deidentified, view the data, or opt out of the study at any time without judgment.

4.3.4 Selection of Adult Study Participants

Study participants were selected according to set criteria and endorsed by other science educators and their peers in the NSW Australia jurisdiction. Phase A of the study included science education leaders sought through the Science Teachers Association NSW and the researchers' professional contacts. The selection criteria are represented in Table 6, and each science education leader selected for this study met these criteria.

Table 5

Selection Criteria for Phase A Science Education Leader Participants

Selection Criteria
1. Holds a leadership position in secondary science education as a Head of Department, an education advisor or a consultant who works across a range of schools in the area of secondary science education
2. Science Teachers Association NSW council or a committee member who is actively involved in professional learning (past or current)
3. Experienced teacher with a minimum of ten years of teaching experience

Adult participants in Phase B of the study were ‘expert teachers’ which did not imply that the teacher participants had reached perfection or were the best teachers. Selection recognised their standing in the science education community and their experience in secondary school education. Tytler and Aranda (2015) also used expert science teacher participants in an earlier study where the researchers “sought out teachers with reputations as expert teachers of primary science, both through recommendations of peers and/or experience of teacher educators in working with the teachers in other contexts” (Tytler & Aranda. 2015, p. 428) It has not been the goal to locate participants who might exhibit perfect practice or have perfect knowledge, but to draw on their expertise as highly experienced educators in this study.

In Phase B, three expert teachers from three different schools were initially selected for the case study using the criteria represented in Table 7, This was expanded to four teachers with HREC permission at three different schools who fit the criteria since two teachers who worked together at one school (Cockatoo High School) were recommended by another science education leader in Phase A of the study and both met the criteria. All expert teachers were from the Sydney, NSW region due to the travel access requirements of the researcher and the feasibility of one researcher conducting the research. Furthermore, in a GTD study, a small number of cases is recommended as it allowed for a deeper investigation into multiple data sets over a period (Corbin & Strauss, 2015). Additional classes at each case school were also permitted to be observed subject to informed consent.

The selection criteria for Expert Teachers for Phase B are represented in Table 7.

Table 6

Selection Criteria Phase B Expert Teacher Participants

Selection Criteria
1. Recommended by leaders in Phase A of the study as being experts in Inquiry-Based Learning in senior secondary science
2. Teachers who have received recognition for teaching or are involved in significant science education leadership (e.g. NSW Premiers award, ACE awards, Teachers Guild of NSW, textbook writing awards, school-based awards in recognition of their teaching in secondary science, elected members of external professional learning organisations)
3. Experienced teachers with a minimum of ten years of teaching experience who are currently or have held science education leadership positions
4. Teachers who are involved in leading external professional learning activities in the area of interest (e.g. Science teacher association, education sector professional development, conference presentations)

Phase B expert teachers committed to lesson observations, a semi-structured interview, short informal interviews, and organised student focus group discussions. They made documents and student artefacts available to the researcher as required over the entire course of the Depth Study, which was proposed as 7-14 hours of classroom observation. The schools supported the different facets of the case study, which were approved by the principal of each school. One of the schools also requested that four additional teachers be observed as a part of the study since they worked closely with the expert teacher and were a part of her practice. This arrangement was also approved by the principal of this school and supported by ethics approval.

4.3.5 Student Participants

A student voice was important consideration in this study to enable an additional interpretation to the researcher's own observations. The student voice in IBL research is not a regular feature of the methods used in IBL research, which is surprising, considering the importance of the students in this setting. Studies where students' voice are included in the form of interviews and surveys often centre on students' views of IBL levels (Sadeh & Zion, 2012) and students' views on their learning achievement (Yıldız-Feyzioğlu & Demirci, 2021). There is a paucity of research that invites students to reflect on their teachers' practices using inductive research methods and even though it could be argued that they don't have expertise in teaching, their perceptions were an important interpretation.

The researchers position in the classroom as an observer warranted an unobtrusive approach in observing and interviewing students and not exerting influence on their practice by adopting the role of a teacher. Since the students in this study were senior secondary students, an unobtrusive approach that made minimal interruptions to their work was also recognised to support the schools' requirements for minimal interruptions to the school programme.

Australian research that investigated student perceptions in the study context are scarce and often rely on self-reported surveys (Dobber et al., 2017). An earlier paper by Hand et al. (1997) examined student perceptions of constructivist teaching approaches in an Australian study using a questionnaire. At that time a paucity of research, which included the student perceptions of IBL and their teachers' practices, was noted and this conclusion does not appear to have changed in the time since this study due to the paucity of literature in this area. In the Australian context, Goodrum et al. (2010) and Whannell et al. (2018) sought students' perspectives on IBL teaching through questionnaires and focus groups which reported on deficit practices and the students' reluctance to engage in longer projects. These surveys were not able to provide insight into specific helpful teacher strategies which is the intent of this research.

Students were a part of this study to observe their interactions with their teachers and to provide further interpretation of their teachers' practices. Students were self-selected to participate in the study, invited through their teacher, and granted permission by their caregivers. No student was coerced into the study. Student data was collected as written field notes during observation, and artefacts of student work were collected and audio-recorded during focus groups at the end of the observation period with the consent of each student and their carers. Treating all student participants with respect in the classroom, whether they were participants or not, and not making anyone feel embarrassed was maintained throughout the study.

Student data was deidentified prior to storage. A specific request made by one of the schools that no students' visual images be collected, was adhered to for all schools in the study since visual images of the students were not required to answer the research questions. All identifiers indicated on student works were removed prior to secure storage. Photographed student work involved seeking permission from the student before taking the photo and not including the student's own image in the photo.

Consenting students self-selected to be a part of the student focus groups. Where there were more than six interested students a second focus group was conducted. Focus groups were conducted indoors and a staff member who wasn't a teacher supervised the students during the interview. Audio recordings of the student conversations were transcribed, deidentified and the recordings were deleted promptly.

4.3.6 Research Invitations and Consent

This section outlines the processes of inviting participants and informing them of the study. Transparency of the intention of the research and how data was to be collected, managed, and used were communicated to all participants using a Participant Information Sheet (PIS) (Appendices A, D, E). Study participants provided written consent, and student participants were also required to provide their caregiver's consent to support their being included. Verbal consent was permitted for the Phase A interviews if preferred by the participant and as approved by the University HREC.

Some of the selected adult participants were known to the researcher through her professional contacts, and to avoid coercion in the study, the invitations to participate were sent from the researchers' University academic supervisor. Criteria for selection into the study (Table 6) were maintained, and participants were selected through the NSW Science Teachers Association and the researcher's own contacts.

Invitations for Phase A of the study were sent directly from the academic supervisor to the participants after being selected by the researcher. Invitations included a Participant Information Sheet (PIS) and a consent form, which was completed and returned to the academic supervisor (Appendix A). One reminder was sent by the supervisor if there was no response. The researcher did not coerce anyone into the study. Participants were also able to provide verbal consent prior to the semi-structured interview if they chose to, and the verbal consent script is included in Appendix B. Verbal consent was recorded and transcribed for some participants at the start of the interview. All participants consented to the semi-structured interviews, which were conducted via videoconference.

Invitations to participate in the study For Phase B were sent to school principals along with a PIS and consent form (Appendix F), which were returned to the academic supervisor before the participants were invited. Signed consent forms were returned to the researcher and stored securely before contacting the participants.

The selection of Expert Teachers for Phase B of the study was based on recommendations from the educators in Phase A and according to the selection criteria for Phase B, represented in Table 7. The University of Technology HREC approved each case study school before being invited into the study. Phase B case studies also involved students under 18, and anonymity and child protection considerations were considered in ethics approval according to the NSW government's required approval including ‘Working with Children’.

Invitations to participate in Phase B were initially sent to each independent school principal, who approved participation pending acceptance by the teacher/s (Appendix F). Email invitations to school principals, including a Participant Information Sheet (PIS) and consent form requesting the participation of at least one of their expert teachers, were sent from my university academic supervisor. Principals returned the signed consent and included their requests of the researcher as a condition of approval.

Once the School Principal approved the case study to be conducted (Appendix F), the researcher was permitted to speak to the expert teacher to arrange a meeting and send the participant information sheet and consent form for the teachers to complete and return (Appendix D). Informal conversations occurred over videoconference to introduce the study and clarify the requirements of the study, and the information contained in the PIS sheet and consent form.

After this conversation, the teacher distributed the student consent forms and PIS (Appendix E), and these were returned to the teacher after their caregiver provided consent. The researcher signed the copies, which were returned to the students and teachers. Teachers retained a list of students who consented to be a part of the study, and the list was made available to the researcher for the duration of the study.

The teachers and students were told they should not feel coerced into the study and could withdraw at any time. It was optional for students in the class to be observed as a part of the study, and they were not coerced or made embarrassed if they had chosen not to be a part of the study. Students who were a part of the study wore stickers during the observation sessions, and those students who were not participating were treated with the same respect as those who participated.

4.3.7 Introduction to the Study Participants

There was a willingness of invited education leaders and expert teachers to participate in the study and they engaged in the study with great interest. This section introduces each of the invited study participants who fit the selection criteria.

Phase A Participant Profiles

Pseudonyms are applied to each of the participants during transcription of the recorded data. A short description of each participant is as follows:

Sasha was a middle career science teacher who was acting as Head of Department at a large independent girls' school at the time of the interview. She was actively involved in various science education network groups and had significant experience in jurisdiction marking and professional learning.

Megan was an experienced educator who was a Head of Department at a large Sydney-based coeducational independent school. She led an external network group and actively delivered and coordinated professional learning programs. Her work in supporting early career teachers was well known in secondary science education. She also participated in Phase B of the study.

Elle was a middle career teacher who recently won an external award for her leadership and teaching. She worked at a large coeducational independent school. At the time of the interview, she was acting as Head of Department and represented her school in external science teachers' networks. She also participated in Phase B of the study.

Tom was a mid-career teacher who held the position of head of department at a coeducational school. He was actively involved in delivering conference workshops in the Year 11 and 12 Depth Studies at the national and State level.

Ali was an experienced educator and has achieved various awards and recognition for her teaching and leadership in science education. She was Head of Department at a large coeducational school and was actively involved in delivering workshops and conference presentations external to her school. She is also well known for mentoring other teachers at her school.

Greta was a teacher educator and worked with a range of schools in the Sydney region at the time of the interview. She was also actively involved in the Science Teachers Association of NSW and contributed to teacher professional learning and teacher conferences at State and National level.

Nadia was an experienced teacher who chaired a large science teacher network and has supported many teachers both within and external to her school. At the time of the interview, she was an Assistant Head of Department at a large Sydney boys' school and actively engaged with the Science Teachers Association of NSW.

Peta was an experienced secondary science educator and was an education consultant who was actively involved in the Science Teachers Association of NSW. She regularly worked with schools and conducted a range of professional learning workshops throughout NSW Australia.

Ann was an active member of the Science Teachers Association of NSW and held a senior leadership position at a coeducational Government School. She actively engaged in delivering workshops and organising large conferences and teacher events external to her school. She also worked in regional centres as an active member of the Science Teachers Association of NSW.

Matt was a younger teacher with ten years of teaching experience who worked at a coeducational Government school and was an active member of the Science Teachers Association of NSW. He had engaged in science education conference management, delivering professional learning workshop sessions external to his school. His sphere of influence with younger teachers in the profession was broad.

Phase B Participant profiles

Teachers and their schools are identified by pseudonyms. Four expert teachers at three Sydney Schools are introduced in this section.

Elle and Robin: Elle and Robin worked at Cockatoo High School and were experienced Chemistry teachers. They often taught together and worked closely together to develop Chemistry programmes for senior classes. Elle also participated in Phase A of the study.

Both teachers were reported to be outstanding and were well-known educators who also engaged in external science networks and have both been involved in delivering professional learning activities external to their school. Both teachers are suitable for the study due to their experience and achievements in science education. These teachers were both middle-career teachers and both also held middle management positions within the school. Elle was awarded with a leadership award through a teacher organisation just prior to the study and Robin had previously received a significant Government award for her teaching. Both teachers have been reported to incorporate IBL in their classes for an extended period and Robin was able to show minutes of a meeting dating back to 2018 where teachers were working on incorporating an IBL component into their senior science teaching.

Megan: Megan led a science faculty at Lorikeet High School at a large Sydney Coeducational School. She also taught Biology in Years 11 and 12. Megan was also a participant in Phase A of this study.

Megan has led integrated STEM initiatives in her school and was experienced in implementing IBL in science in the senior years of school. Megan was highly recognised in the science teaching community and had been elected to be the chairperson of an external teacher network and has extensive experience in delivering teacher professional learning activities that focus on student-centred pedagogies. She regularly supported her younger staff in delivering external science and was well recognised in her school.

Erin: Erin led a large science faculty at Currawong High School which is a large Sydney boys' independent school. She had extensive teaching and leadership experience in the NSW curriculum area. She was confident in using IBL in her classroom and her science faculty have developed a range of IBL courses and units of work within her faculty. Her school actively promoted IBL pedagogies through transdisciplinary teaching. She was well-known for her capacity to mentor and support teachers in a range of pedagogies and for her work external to the school including textbook authoring. She also requested that four additional teachers be included in the observations of the same Depth Study at this school as they were collaborating in the planning of the Depth Study and working with Erin. These teachers, who provided consent to be observed included four mid-career teachers (Amanda, Brad, Christine, and Kate).

Study participants were selected based on set criteria (Tables 7 and 8). The University of Technology Human Research Ethics Committee (HREC) was advised of the teacher participants, and the case study schools for both study phases. Invitations to participation from education leaders and expert teachers were sent from the researcher's academic supervisor to reduce participant coercion in the study. Expert teachers invited additional teachers and students to each case study school who participated with informed consent.

4.4 Theoretical Sampling Processes

Qualitative data sources were collected in two discrete study phases during 2020 and 2021. Qualitative data sources included transcribed interviews, field notes of lesson observations, artefacts of student work, and school curriculum documents relevant to the study. Data in this study was considered potentially sensitive because it involved human participants including children and secure storage of deidentified data was implemented as required by university ethics approval.

Epistemology centres on determining how a researcher develops knowledge and how they make claims about knowledge (Scott & Usher, 2011). The ability to make justifiable claims involved the selection of research methods that were consistent with GTD methodology and could inform the research questions. GTD can include a range of qualitative research methods (Creswell, 2012; Creswell & Guetterman, 2021; Corbin & Strauss, 2015) and this section explores and justifies the chosen approved research methods for this research, the two study phases, analysis of the data, and theory development.

4.4.1 Methods of Researching Broad Research Questions

According to Corbin and Strauss (2015) and Creswell and Guetterman (2021) the selection of sampling methods is not restricted to a simple formula in GTD. Qualitative methodologies can include a single form of data or multiple forms of data that can be triangulated during analysis. In this study, multiple data sources have been selected to deeply investigate the broad research questions. The use of observations, interviews, documents and artifacts provided rich data and were recognised as being appropriate to address the research questions in this current study. Documents included teacher materials, student materials which the teacher provided for the students and artifacts included student submitted work, and photographs of samples of teacher and student work.

In the practical senior secondary science education context, the actions of the participants and the physical environment were integrated together. The actions of the participants occurred in a learning environment which included resources, laboratory equipment, the classroom arrangement, and the virtual learning environment. Therefore, a range of data sources was required to research the interactions between teacher talk practices and the classroom environment.

Interviews of Participants

In selecting survey methods of participants in this study, consideration was given to the feasibility of conducting in-person interviews for a single researcher and having the ability to deeply explore emerging data. Interview methods include semi-structured interviews of education leaders and expert teachers, informal discussions with expert teachers, informal discussions with the students and student focus-groups. These methods were chosen because of the benefit of allowing the participants to talk freely and to collect a broad range of data.

In Phase A of the study the teacher perceptions of IBL in secondary science education addressed RQ1 and semi-structured interviews were the chosen method. Studies that have utilised semi-structured interviews have sought to give priority to hearing the voice of the participants which is also a priority in this research (Correia & Harrison, 2020; McLaughlin & MacFadden, 2014). Semi-structured interviews guided the discussion by aligning to the research questions and allowing new themes to emerge through open conversation (Creswell, 2012). Interviews of teacher participants resulted in descriptive data which was thematically analysed using GTD methodology. Correia and Harrison (2020) used both field notes and recorded conversations to investigate teacher beliefs of IBL and McLaughlan and MacFadden (2014) recorded interviews of teachers in a GTD study. Both studies included rich descriptions of the participants' responses consistent with GTD research.

The use of semi-structured interviews was chosen over structured surveys or interviews in this study as it as this enabled the participants to provide opinion about IBL and provide examples of practice. It enabled probing questions to be asked if the researcher wanted further clarification (Corbin & Strauss, 2015). In an Australian study of Primary school teachers who were enacting IBL, researchers also saw the benefit of conducting semi-structured interviews of the teachers to find out their "philosophies, experiences and ideas about teaching science" (Tytler & Aranda, 2015, p. 429). While semi-structured interviews tend to be small-scale, they provide rich insight and provide some direction for the interview without deviating from the central theme (Opie, 2004).

The problem of teachers reporting on their own practice, is that reported teacher practice might not be consistent with enacted practice (Capps et al., 2016). The deficiencies of predicting actual teacher practice using a survey is highlighted in a study where teachers reported a high level of IBL enactment and in practice and during observation, they were using minimal IBL (Capps et al., 2016). Other studies also report this inconsistency, for example, evaluating emotions of study participants in a naturalistic science classroom (Ritchie et al., 2016) and Feldman & Özalp (2019) who highlighted the low calibration between a teachers self-reported practice and actual practice in research studies. The advantage of using additional data sources and triangulating the data during analysis added rigor to the investigation methods.

To gain a broader perspective of interpreted pedagogical practices, student focus group discussions were chosen as an effective method. In an earlier study prior to the development of the Australian curriculum, prior to the introduction of the Depth Study in the NSW, Science curriculum, student focus groups were used-to determine student views on IBL projects in Year 11 and 12 science classrooms (Goodrum et al., 2012). The rich scripted participant feedback enabled deep insight into some of the issues of students and teachers who were working on science IBL projects and is adopted in this study as a suitable method for the student participants.

Written surveys are more frequently cited in the literature as being a preferred option of gaining student views of IBL due to their statistical significance (Dobber et al., 2017); however, it was considered unlikely that a survey could be used to evaluate pedagogical practices with the required depth. The senior students in this study had the ability to articulate the teacher practices that were important to them and a focus group which allowed open discussion without directing their responses toward one answer was deemed appropriate in this research context.

Lesson Observation

In addressing research RQ2 it was recognised that pedagogical practice was highly interactive and included a range of impacts in a social setting. To deeply investigate those interactions an important aspect is teacher talk. However, it is also recognised that in science teaching there are a range of other actions and resources that might be included as teachers interact with their students in a practical classroom.

Unobtrusive classroom observation was selected for this study over a period of consecutive lessons to reduce the 'Hawthorn Effect'. The Hawthorn effect exerts pressure on research participants to perform at a level that is not typical (Ary et al., 2014). In this study, observations occurred during multiple lessons to enable the researcher to observe what was normal practice in the classroom once participants became accustomed to the researcher's presence. Audio-visual recording is not used in this study as it is thought that it might promote the ‘Hawthorn Effect’ for both the student and teacher participants. Interpretations of the findings were enhanced by the students’ views of their teachers’ practices addressing RQ2.

Classroom observation is recognised to be complex and the subjectivity of interpreting pedagogical practice in a social setting gives recognition that observations cannot be broken down into distinct phenomena such as verbal utterances (Scott & Usher, 2011). Teacher talk is central to the practice of teaching and capturing speech and the actions of teachers in the classroom in this research context often involve audio-visual technologies or field notes (Corbin & Strauss, 2015). The decision on how to collect observational data including teacher talk was determined in this study by which method provided the greatest value, and which method was manageable over a series of consecutive lessons.

Some studies have recognised that teacher talk in IBL is often accompanied by gestures and other practices including the teachers’ movements around the classroom. Data are often collected through audio-video technologies (Bansal, 2018; Jin et al., 2016; Tytler & Aranda, 2015). Compared to these studies a longer observation period was warranted in the current study to examine the processes during a sequence of consecutive lessons. The volume of video data generated through audio-visual data collection methods was unmanageable for a single researcher to analyse thoroughly if all verbal utterances were to be recorded. Digital recording deeply investigates the cycle of the teacher talk practices over a short observation period and was not considered to be a practical method over a longer IBL sequence of several lessons in this study due to the large volume of data generated.

The interactions between the researcher and the participants were important. Researchers utilised unobtrusive observation, semi-structured interviews, and document analysis in an interpretive New Zealand Study that sought to "investigate the reality of classroom science learning" (Hume & Coll, 2010, p.47). Of interest and as part of the lesson observation, tools used to capture the range of teacher and student interactions, audio transcripts of the classroom, were reported to be difficult to decipher due to the large amount of background noise. This was a consideration in the current study which could be managed by using field notes.

In practical terms, in a noisy and interactive IBL classroom the audio recording of the interactions between teachers and their students would be difficult to manage for a single researcher whilst maintaining an unobtrusive position in the classroom (Opie, 2004). However, it was also recognised that verbal interactions were important and of interest in this current study. The method chosen retained the unobtrusive stance of the researcher in the classroom was recording using field notes. Field notes captured samples of teacher utterances and allowed additional practices to be recorded. The added advantage was that the recording could be digitised and thematically analysed along with accompanying journal notes.

In this study the anonymity of the students who participated in the study was a risk that was controlled. Audio-recording the classroom was not agreed by one of the consenting schools which also influenced the decision to use journalling and the recording of field notes to record the interactions between the teachers and the students. Recording field notes also managed the ethical issues of recording interactions with students who did not consent to be a part of the study. The use of recording field notes is described in GTD research as being unobtrusive and enabled interacting approaches to be examined concurrently (Corbin & Strauss, 2015).

Although the researcher adopted an unobtrusive approach, the researcher was free to interact with participants to gain clarification of the observations. According to Corbin & Strauss (2015): “Non-verbal behaviours can be misinterpreted…” (p. 41), and in-member checks were helpful to gain additional interpretation of the observations. These interactions, such as informal conversations between the researcher and the adult participants to gain those clarifications, were also recorded in a research journal.

Multiple Data Sources

Multiple forms of data interact in a social setting provide a comprehensive picture of teacher practices. Further data sources were considered for this research and included teacher documents, student written resources including assessment information, artefacts of student work, and journaled recorded observations of the classroom environment. These were selected as being reflective of a teacher's planning practices and classroom practices in this research context and reflected sources of data that were discussed in Phase A of the study by the education leaders.

In GTD research, data sources can also include memos, diagrams, and notes, which were developed by the researcher during and after the observation period (Corbin & Strauss, 2015), which have also been used as sources of data. These reflective data sources interacted with the dynamics of teaching and provided evidence of the planning and evaluative practices of the study participants.

This section argued for using multiple forms of qualitative data to answer the research questions consistent with GTD research.

4.4.2 Study Phases and Processes

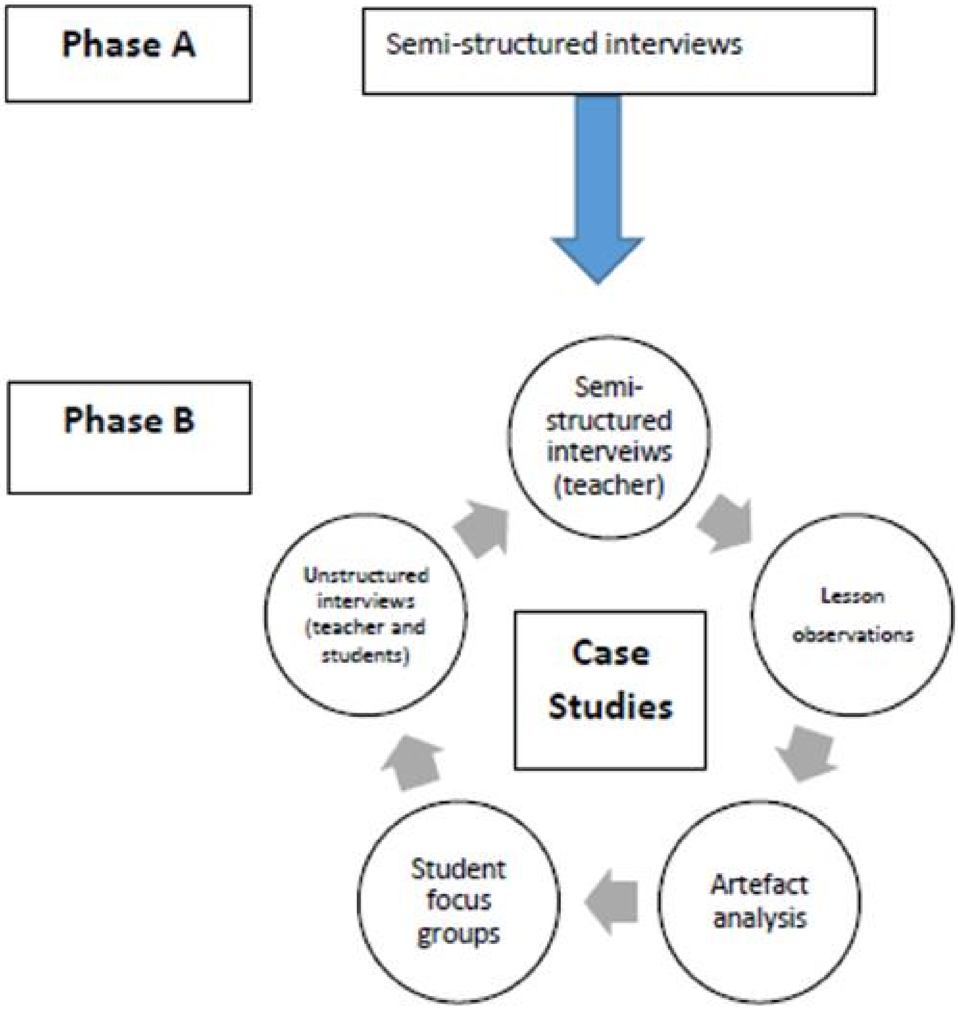
Phase A of this study was conducted in 2020 before Phase B in 2021. While each Phase was conducted in sequence, the data from Phase A was coded prior to the commencement of Phase B and supported participant selection for Phase B. The study phases and the sequence of coding and analysis are represented in Figure 4.

Research question 1 (RQ1) was addressed in Phase A of the study and RQ 2 is addressed in Phase B. A two-phased approach is consistent with the GTD design of Corbin and Strauss (2015) where the first phase informs the second. This was important for two reasons:

- Phase A supports the selection of expert teachers for Phase B
- Analysis of Phase A considered broad descriptions of teacher perceptions of IBL that could be highlighted for a deeper understanding in Phase B.

Figure 4

Study Phases and Data Sources



The selection of procedures used in this study and the justification of each selected procedure are summarised in Table 5.

Table 7

Study Procedures and Justifications

Study Phase/participants	Procedure and product	Justification
Phase A: Ten science education leaders	Semi-structured interviews of approximately 30 minutes in duration and conversational in approach. Interviews are audio-recorded and transcribed into text.	To determine a range of perceptions of IBL to inform RQ 1. The findings provide direction for Phase B of the study.
Phase B: Four expert teachers and four additional teachers	Classroom observation of full IBL instructional sequence (7-14 hours). Hand-written field notes and digitally transcribed.	To address RQ 2 to observe actual classroom practices of the teacher and their interactions with students.
	Document analysis: curriculum documents. Copied and deidentified.	To determine process, information supplied to the students and hard scaffolds supplied to the students to address RQ 2.
	Informal discussion: Hand-written in a journal and digitally transcribed.	To provide evidence of planning practices and gain further insight into the practices of the expert teacher (RQ2).
Phase B: Student participants	Student artefacts: copied student work stored as digital and deidentified copy.	To inform interpretation of RQ 2 by including a student perspective relating to their teachers' practice.
	Student focus groups: audio recorded and transcribed.	To inform RQ 2.

A range of qualitative data sources were chosen to deeply investigate the research questions.

4.4.3 Phase A Data Sources

Participants in Phase A of the study were from NSW Australia and worked in both regional and city locations. Each of the ten participants participated in semi-structured interviews of approximately 30 minutes which were conducted by videoconference. Science education leaders spoke of their perceptions of IBL by addressing five broad interview questions.

A semi-structured interview was preferred over a written survey or a structured interview because it allowed theory development without the influence of a narrow range of questions or the researcher's views (Corbin & Strauss, 2015). According to the literature, using broad questions provided consistency over the concepts discussed (DiBase & McDonald, 2015; Creswell & Poth, 2018) and in this study it enabled the participants to discuss each concept freely and without restriction.

Of the interviews conducted, Ali, Ann, Elle, Greta, Matt, and Peta spoke freely about the topic, yet the other participants required further question prompts to elicit descriptive answers. Five broad questions were selected for the interview, and sub-questions were added to investigate emerging phenomena further. These questions are included in Table 8.

The sample size of ten participants enabled a deep investigation and was further influenced by the feasibility of conducting the interviews by a single researcher and analysing large volumes of qualitative data. To gain a broad perspective during the interviews, educational leaders who had a broad and direct knowledge of the practices and perceptions of a range of other teachers were selected.

Written consent forms or recorded verbal consent forms were collected by ethics approvals at the start of the interview. The dates and length of the interviews are included in Appendix C. Some participants opted to provide verbal consent at the start of the interview and the script used as approved, is included in Appendix B which was read, agreed to and recorded at the start of the interview.

The semi-structured interviews were conducted using five broad questions (Table 8) to allow some direction for the conversation, to provide consistency, and to allow comparisons between participants while allowing participants to direct the conversation. Interviews were conducted via videoconference in a quiet and private location and outside of work hours and the participants were told that the interview was to be for approximately 30 minutes. Participants were asked to leave their cameras on and not blur their background. After 30 minutes the participants were given the option of continuing the interview.

Audio-recorded data was transcribed soon after the interview as a de-identified written transcript and digitally stored securely as required by ethics approval.

Table 8

Semi-Structured Interview Questions

1. Do you believe that Depth Studies promote inquiry-based learning and a depth of learning that is appropriate for each science course? Why/why not?
2. What are some of the more successful teacher approaches to the programming and design of the Depth Studies?
3. What are some of the successful ways that teachers facilitate a Depth Study in the classroom that have proven to be successful?
4. What challenges are teachers facing in designing and implementing the Depth Study?
5. What are some of the successes and challenges that Year 11 and 12 students experience in completing a Depth Study?

Prior to the start of the interview, participants were provided with a definition of IBL. They were reminded that the conversation about the Depth Study only applied to the NSW Australia Senior Biology, Chemistry and Physics courses to ensure a common basis for discussion. During the interview, each question was probed with sub-questions and was conversational.

Digital audio recordings were transcribed immediately after the interview, and the audio recordings were deleted soon after. Participants could read and approve the written transcript before they were finalised if requested. All references to names, schools, educational sector, or places of employment were redacted from the transcript, and the original recordings were deleted immediately after transcription and before secure storage. Pseudonyms were used for all participants prior to data storage as written text and subsequent coding.

4.4.4 Phase B Data Sources

Phase B sampling occurred at three case schools in 2021. These were coded with the pseudonyms of Cockatoo High School, Currawong High School, and Lorikeet High School. Multiple qualitative data sources were collected at each case school. Charmaz

(2014) argued that GTD researchers should adopt a view of research that does not restrict the outcomes. However, for a beginning researcher working independently, a process was required to manage theoretical sampling, the collected data and maintain ethical work practices. Furthermore, schools required advice on the activities of the researcher and the collection data before the school observations. A systematic GTD approach was considered suitable, as Corbin and Strauss (2015) recommended. Each sampling technique was pre-planned, communicated to each study participant, and ethics approved.

School observations occurred one school at a time with an unavoidable short cross-over of time between Cockatoo High School and Lorikeet High School due to a change in program dates by Cockatoo High School. The observation period for each school was the full duration of class-time for the Depth Study programme. The researcher was also invited to stay and visit the staffrooms outside of the class time of the participating teachers, where informal conversations took place. By conducting observations consecutively, it allowed progressive digitisation of field notes to occur efficiently and adequate reflection time during the observation period.

Semi-Structured Interviews

Semi-structured interviews were conducted as a 30-minute videoconference for each of the four expert teachers before the observation period. Two education leaders completed this interview during Phase A of the study (Elle and Megan). The interview used the same methods as the Phase A semi-structured interviews. All four participating expert teachers participated in the semi-structured interviews before the observation period.

Unstructured Interviews

Unstructured interviews with the expert teachers were recorded as hand-written field notes in a journal or audio recorded with permission of each expert teacher. According to Corbin and Strauss, unstructured interviews, which do not include pre-structured methods, provide rich data that aids theory-building (Corbin & Strauss, 2015). The interviews aimed to clarify observations and gain perspective on the perceptions of the expert teacher relating to their pedagogical approaches. Online conversations were audio-recorded and transcribed prior to deleting the recording. Unstructured interviews occurred in the classroom and the teacher staffroom between classes. These were later digitised and included in the data analysis.

Lesson Observations

Lesson observations were conducted in person and focused on the teacher's practices and their interactions with the students. Classroom observation is commonly used in education research (Scott & Usher, 2011), and a range of approaches exist. Lesson observations were deemed to be important in this research because reported practice is not always the reality of what is occurring in the classroom (Corbin & Strauss, 2015). Lesson observation runs the risk of the researcher misinterpreting meaning, and therefore, member checks with the study participants were also essential to clarify the meaning of observed phenomena. Phase B lesson observations were conducted unobtrusively in keeping with GTD methodology, and data recording was hand-written using a journal. Photographs of documents and student work were also included in the data collection.

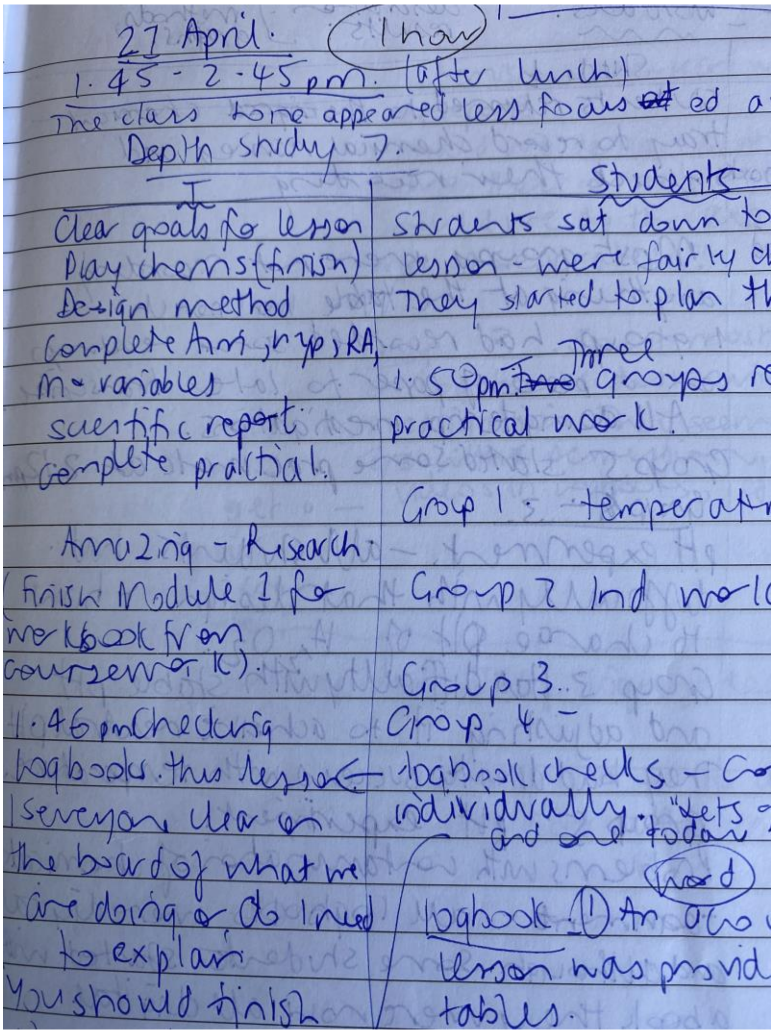
At Cockatoo High School, 11 hours of lesson observation occurred over one week for two expert teachers. At Lorikeet High School, 13 hours of lesson observation took place over three weeks with one expert teacher. At Currawong High School, 9 hours of lesson observation took place over one week with one expert teacher and four additional science teachers working with the expert teacher. The time variation between schools depended on school timetabling and arrangement of the IBL activity.

Due to public health concerns at the time of the observations the researcher sat at the back of the class during periods of explicit instruction and limited movement around the class during practical work. Each observation was between one hour and three hours in duration which reflected the timing of each lesson. Photographed images of student work and teacher notes which were displayed in the classroom were also collected as data sources.

Field notes were hand-written in a journal and were structured as the teacher's actions/interactions and student responses. A sample journal entry is included in Figure 5.

Figure 5

Field Notes Cockatoo High School



The field notes were digitally transcribed immediately after each observation, allowing for thorough data coding during analysis. Rapid transcription also meant that in-member checks could be made with the expert teachers during the observation period. The field notes also included records of conversations with the teacher and handwritten memos. These notes included dates, times, teacher and student practices and communications. Field notes and artefacts were stored securely in a locked cupboard between use and converted to digital copies for later analysis.

During classroom observation, the researcher was not left alone with the students, and this was told to the teacher at the start of the observation period. The researcher provided each school with her Working with Children Check number as required by the Working with Children Act, 2012, before the observation period and adhered to the principles of working ethically with children.

During observation, all students wore a sticky name tag so the researcher could identify the students who were a part of the study. Only students who were a part of the study could be approached by the researcher only briefly to avoid interruptions to their work. Due to health restrictions, the researcher needed to maintain a safe distance from the students, which limited the number of unstructured conversations between the researcher and the students while they were working. This restriction was not considered a limitation since the study focused on the teacher and the interactions between them and their students, which could be heard. The researcher implemented hygiene procedures as required by the University and each school and minimised movement around the school site and within the classroom whilst on-site as required by the University of Technology Sydney (UTS) COVID-19 risk assessment for that time.

Information about teacher practices was not discussed or evaluated with any senior school managers at the case study schools. Information collected via student focus groups was kept confidential and not discussed with the teacher. During the student focus group sessions, a school staff member who was not the class teacher was also present to supervise the students privately.

Potentially, schools could be identified after the research period, and this could be negotiated with all stakeholders if it was seen to be beneficial to all involved in the study. Identifying the school and the expert teacher required the Head of School and the expert teacher to provide consent as required by ethics approval. This might be considered if an academic paper were to be published, or a conference presentation or workshop were to be delivered which named the expert teacher or school.

4.3.2.4 Documents and Student Artefacts

De-identified programming documents, notes from meetings, resources provided to the students, and student artefacts were provided to the researcher both digitally and in hard copy for analysis. Some student works were also photographed during the observation period. Any de-identified copied materials were stored in a locked cupboard, and digital copies were saved on the secure University e-storage for up to five years after the study. The purpose of the artefacts was to inform the practices of the teacher and were not judged on any quality criteria since this was outside of the research questions.

The analysis of teacher planning documents, materials provided to the students, and student artefacts enabled a rich interpretation of teacher practices, which reflected planning and evaluative practices. Teacher materials collected and used in the classroom included booklets produced for the students, including assessment information, background information on the teacher-selected topic, hard scaffolds, and practical methods. Teachers in this study did not use a detailed work programme, and this was not provided.

The impact of observation on the work of the expert teachers and their students was considered, and the researcher sought to be unobtrusive during observation and in their interactions outside of the classroom.

Student Focus Groups

Focus groups rely on the interactions between the researcher and the group and small group size of up to six students enabled all students to participate in conversation. University ethics approval required a list of the survey questions prior to the interviews for approval. An approved introductory script which was read before the start of each focus group is included as Appendix H. The survey questions were broad to enable open discussion and listed in Table 9. Probing questions were also used to elicit further responses where required for some of the questions.

Table 9

Student Focus Group Questions

1.	Do you believe that *Depth Studies* enhance your learning in this subject?
2.	What aspects of the Depth Study did you enjoy?
3.	How did your teacher help you during the Depth Study?
4.	Were you happy with your own achievement?
5.	What did you find challenging?

The researcher randomly selected the student focus groups from the list of students who had provided consent to be included as study participants. It was recognised that four to six students are an ideal size for a focus group (Creswell, 2012) to allow all participants to be involved in the discussion and reach a consensus (Yin, 2014). A second focus group was held at a case study school if more than six consenting students were willing to participate. The student focus groups included two focus groups at Cockatoo High School, one focus group at Lorikeet High School and one focus group at Currawong High School. The conversations were audio-recorded using a portable audio recorder to assist with transcription and deleted once transcribed. Students were permitted to express their opinions, and no students were embarrassed by the process. Focus group interviews were conducted outside of class time, and students were permitted to eat during the focus group while on a lunch break. A school staff member who was not the classroom teacher also supervised each session, and the interviews were conducted away from other students.

The focus group at Currawong High School was conducted via video conference due to government health restrictions and school closures during this portion of the study. This change was approved by UTS HREC and did not impact the ability to collect this data (Appendix I). The focus group was supervised by a school staff member who was not the class teacher and had joined the online meeting before the students. The discussion was video and audio-recorded, and the audio recording was saved securely, deidentified, and transcribed. All recordings were deleted soon after transcription.

All ethics approved processes were adhered to during data collection.

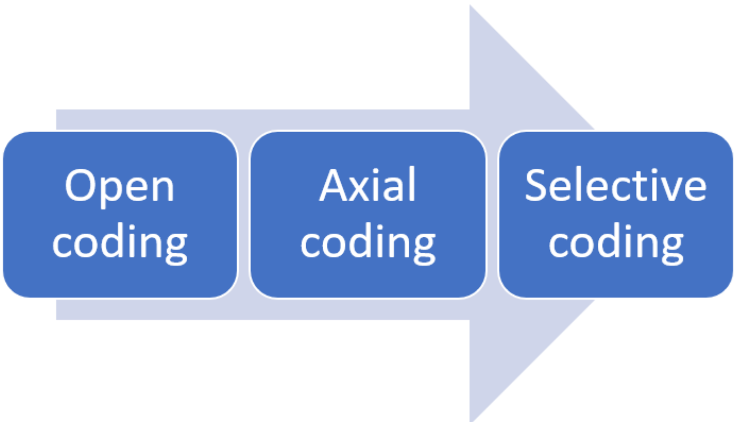
4.5 Data Analysis

This section reports on the analysis of data informed by GTD methodology using a process of thematic analysis. Data analysis involved processing the data and data coding including open, axial, and selective coding. Data analysis also included a process of making constant comparisons of the data throughout the coding process. The comparative process sought differences and similarities, raised questions, made suggestions for further exploration, and recalibrated assumptions about the data (Corbin & Strauss, 2015).

The coding process is shown in the Figure 6 and follows the recommended coding process by Corbin & Strauss (2015) and Urquhart (2013).

Figure 6

Coding Sequence



Open codes were redeveloped into a smaller group of axial codes to address RQ1. A second coding phase of all data occurred after Phase B data collection to answer RQ2 to build theory and included relevant raw data from the previous study phase.

During analysis, the security of data was a risk which required management due to the potential of exposing study participants and sensitive data. This risk might involve sensitive comments being recorded; and images of the students who wished to be anonymised being retained and used without consent. The large volume of different types of data necessitated a systematic approach to ensure all data were considered and compared and software was used to manage and store the high volume of deidentified data. Ethics approval required deidentification of data and secure digital data storage which was adhered to throughout data collection and analysis.

This section presents the data analysis processes adopted in this study as open coding, axial coding, constant data comparison, and selective coding and core concept development.

4.5.1 Grounded Theory Methodology Data Analysis

Data analysis in GTD involved a rigorous process of coding and memoing, which compared categories and sought to locate the connections between data that support a central phenomenon (Corbin & Strauss, 2015; Urquhart, 2013). The processes of data analysis used in this study are consistent with a systematic approach and adopt some elements of emerging design because the data is later compared. Memoing sits alongside the coding process as emerging ideas evolve.

Raw data was processed before open coding by deidentifying all identifiers including names of individuals, schools and locations, deleting original digital recordings post transcription, removing data outside of the scope of the research questions, and storing the data securely. Data that were collected that was outside of the research questions were removed from analysis prior to coding. Removed data included student work submissions after the observation period, and interview data which was outside of the scope of the context of the study such as discussions relating to other courses or year levels.

Data coding is essential to GTD, and NVIVO digital software was used in this study to code and store data systematically and securely. Emerging categories were analysed using a constant process of transcribing and coding data throughout all study phases (Creswell & Poth, 2018; Urquhart, 2013). The building of the theory, and in this study, the GIST conceptual framework, occurred concurrently with data collection, processing, and analysis (Glaser & Strauss, 1967).

4.5.2 Open Coding of Descriptive Data

Open coding relied on exact phrases and terms that emerge from the data (Urquhart, 2013; Creswell & Poth, 2018). The open codes were interpreted as being the dominant themes by the researcher. In GTD research the researcher needs to distance themself from the data and not impose their own authority on the research (Corbin & Strauss, 2015). By taking a less authoritative approach the categories used for coding emerge from the words used by the participants during an open coding process. Although the researcher is not confined to a particular order of data analysis (Corbin & Strauss, 2015), systematic GTD researchers are recommended to follow a system of thematic coding (Urquhart, 2013). Thematic and open coding was the first step in the data analysis in this research to develop the themes that emerged from a naturalistic setting.

The first open coding process occurred followed Phase A sampling and included transcripts of ten semi-structured interviews. All transcribed data was read and sorted into open codes. Thorough assigning of data to each code was enabled using digital software. The open codes developed for Phase A are included in Appendix J which were named according to the terms used by the study participants.

Open coding of Phase B data included the transcripts of semi-structured interviews of expert teachers, field notes, transcripts of student focus groups, transcripts of lesson observations, consenting students' artefacts, information sources provided to the class, digital resources provided to the students and teacher planning documents. As in Phase A, the data was read, and the codes were manually developed using the phrases and words used by the study participants. Digital software supported the thorough coding of all raw processed data including images, scripted data, and copied teacher and student materials.

4.5.3 Axial Coding of Descriptive Data

Axial coding as a second coding step was determined manually based on grouping open codes which were developed into broader themes. The process adopted in this study recognised Strauss and Corbin's (2015) recommendations of theoretical sampling and coding, where axial coding is described as “relating categories to subcategories along the lines of their properties and dimensions” (Strauss & Corbin 1998, in Urquhart, 2013, p. 124). Memoing and comparing data supported the determination of the axial codes, which was further enhanced using the functionality of the digital software to show connections between data sources and the volume of data collected under each coded theme.

Axial coding occurred after the open coding processes of study Phases A and B to address the research questions. Axial codes developed after the first study Phase are discussed in Chapter 5 and were:

1. The role of the teacher
2. Curriculum impacts.

Axial coding was supported by regular memoing and drawing flowchart diagrams. Corbin & Strauss (2015) also recommend that axial coding occur after reviewing memos and diagrams developed throughout the study. The memos and diagrams informed the constant data comparisons during the axial coding phase and supported the later development of the selective codes.

The axial codes developed from the Phase B data represented a large volume of scripted data, including observations, interviews and conversations which were entered into NVivo digital software by placing sections of text as paragraphs and sentences under each code for the deidentified participants. Digital software enabled a thorough and systematic data coverage in the analysis which readily identified the coded source of information. Using digital software also enabled word searches and visualisations of data to be developed, which assisted data analysis to determine data relationships and dominant coded themes. The developed themes for axial coding are represented in Appendix J.

4.5.4 Constant Data Comparison

From the outset, constant comparisons using memos and diagrams have been a feature of analysis that informed the axial and selective coding processes. Data comparisons were used to ask questions about the data and determine possible interactions and relationships (Corbin & Strauss, 2015). Three methods were used to compare the data: memoing, constructing diagrams, and comparing the data to the literature. These sources of data allowed for an audit trail to be developed throughout the study period.

Memoing included scripted notes, including the researcher's reflections during and after data collection. Examples of scripted memos are in Figure 7.

Figure 7

Memo September 2020

Generally, there was consensus of those interviewed all felt that the Depth Studies were generally a positive step to promote inquiry in the Stage 6 courses and are a welcome addition to the syllabus in NSW. Stated that they felt that many teachers were not confidently facilitating inquiry in the classroom and that some of the Depth Studies might be more prescriptive than others with students accessing closed inquiry rather than guided or open inquiry approaches. There was doubt about the depth of learning that was occurring in classrooms around NSW. It was noted that Depth of Learning in Chemistry and Physics was considered to be not well accessed, yet in Biology and Earth and Environmental Science this was not the case. Why? Some teachers felt that there was not enough structure provided to the Depth Studies to adequately guide teachers into appropriate pedagogical practices.

Memo Excerpt. Phase B. 16 April 2021

Post observation conversation reflection excerpt (16 April 2021): (Megan) felt that the time taken to complete a full inquiry study would not allow enough time to complete the Year 12 course. She admitted that it wasn't ideal and was a product of

the final examination that determines the ranking of students and being able to prepare them for that.

For both the Year 11 and 12 Depth Studies she had clear timelines and expectations divided into short time periods to keep the students on-track.

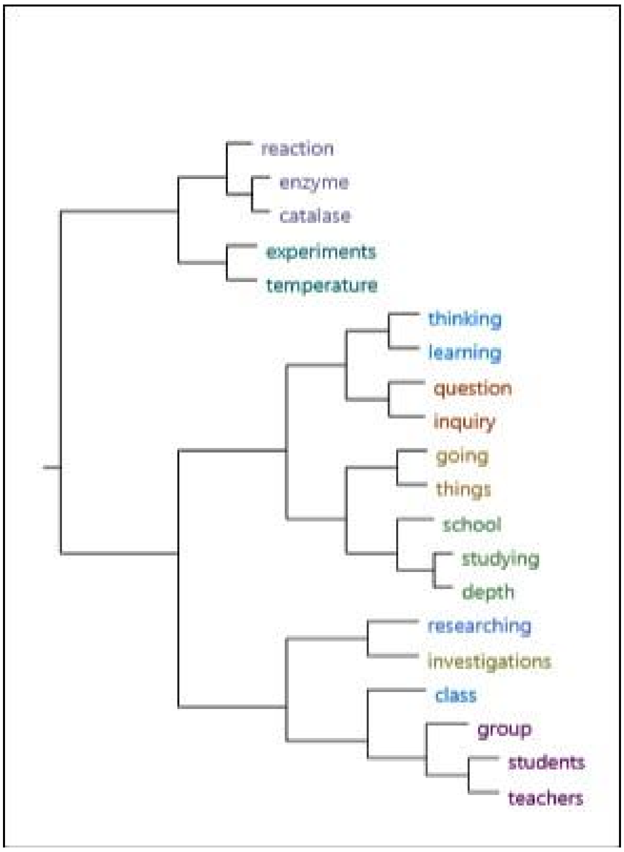
The first excerpt were notes recorded by the researcher following the Phase A semi-structured interviews, and the second example followed a lesson observation of an expert teacher. After the collection of data from Phase A, it was useful to journal overall impressions of the semi-structured interviews and develop questions about the data, such as questions about the difficulty that education leaders raised with Physics Depth Studies, and the type of structures that they felt might be appropriate to facilitate the Depth Study.

Writing memos was a valuable process to record ongoing thinking about what was being observed during Phase B of the study and to record overall impressions of observations and initial interpretations. In Figure 7, the notes about the expert teacher, Megan, captured points that she raised in open conversation after a lesson, which enabled further interpretation of the observations.

Memos in the form of visualisations of data supported by the digital software assisted the interpretation of data and developed the connections between the coding themes. Figure 8 is a dendrogram that drew on the most common word usage to show the relationships between the most used words after the scripted data had been entered into the digital software. This diagram assisted in the axial coding of the themes during the coding process by examining the connections between commonly used terms.

Figure 8

Dendogram of Data



Note. Source: Horizontal dendogram produced from Phase A data using NVivo software

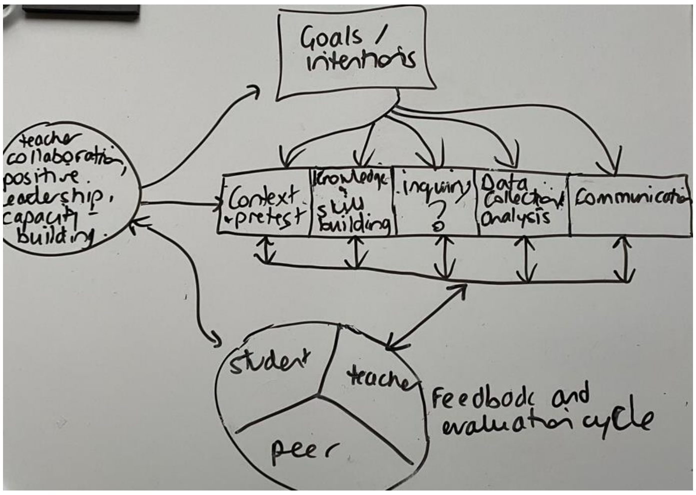
The horizontal dendogram in Figure 8, illustrated the nature of IBL as described by the education leaders, using the most used words during their interviews. Words on the same branch have a relationship and the colours indicate the data sources. Teacher and student interactions while students were working in a group were featured as being highly connected, reflective of a socio-constructivist view of IBL in this research and were most often discussed together during the interviews. The importance of language through questioning and discussion practices and the development of student collaboration were highlighted in this research and required careful analysis. Digital software was instrumental in drawing relationships between open-coded data and connecting the findings of Phase A to Phase B prior to axial coding.

Memoing included the drawing of flow diagrams, and Figure 9 illustrates this process which focused on the process, that expert teachers took in Phase B of the study to facilitate IBL. Figure 9a was constructed following lesson observation and before open coding to think about the processes that the expert teachers were using. Another iteration of the process is represented in Figure 9b after selective coding and with consideration of an existing theoretical framework of regulation practices (Dobber et al., 2017).

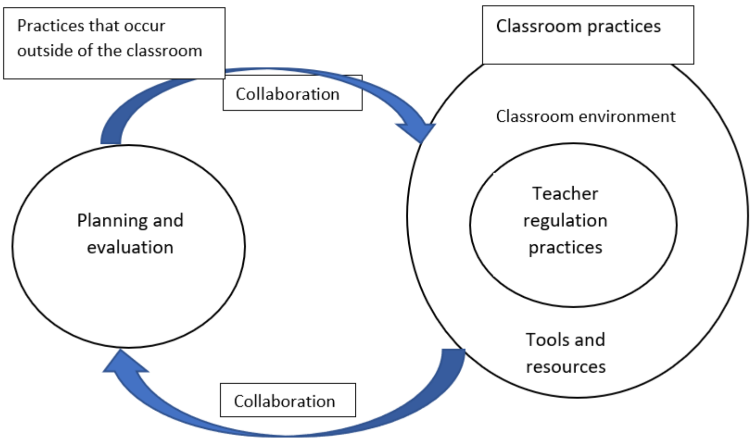
Figure 9

Memo Instructional Processes

a. Early hand drawn memo of teacher practice (7 November 2021)



b. Memo of the instructional process (22 May 2023)

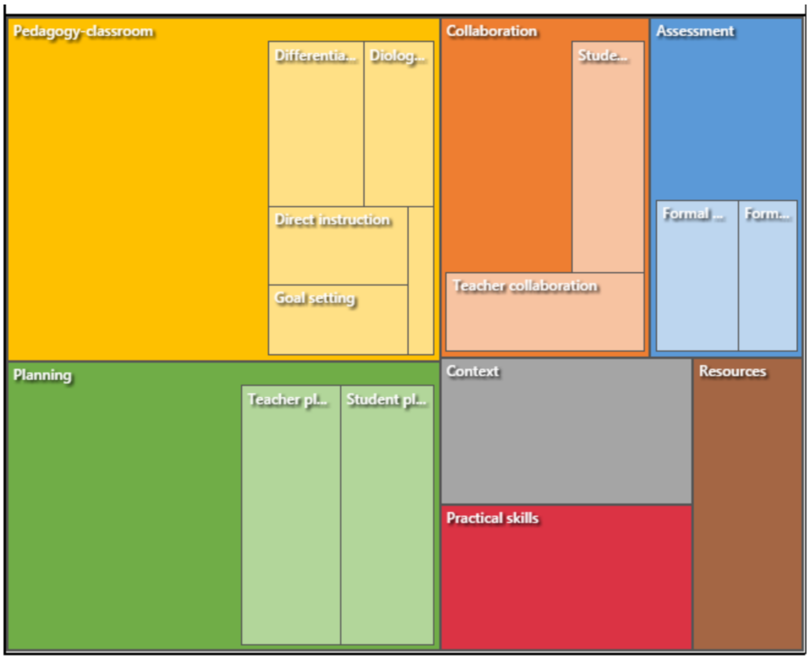


The memos in Figure 9. were instrumental in considering the connections between pedagogical practices. These ideas were challenged and iterated through peer review and discussion with the university academic supervisors, and later, they were enhanced through the literature and existing conceptual frameworks to develop theory.

Digital software enhanced the development of axial and selective codes by comparing data. In developing the selective codes for the study, digital software was useful to support the development of dominant themes alongside memoing and the literature. (Figure 10).

Figure 10

Data Representation



Note. Source: Diagram produced by NVivo 10

Figure 10 shows the relative proportions of the collected data under the dominant open codes, which assisted in developing the dominant themes of the study and the selected codes. Classroom pedagogical practices were a dominant theme of the collected data, supported by collaborative planning practices. An added advantage was that the visualisations of the diagrams supported the communication of thinking and valuable peer feedback through the visualised data.

Visualisations of data were compared and discussed with academic supervisors at the University of Technology Sydney and at three academic international conference presentations during the study period. The academic peer feedback clarified the connections between data sources and provided some insight into the interpreted themes and selective codes.

4.5.5 Selective Coding and Core Concept Development

All data was considered for the development of the selective codes which categorised the data around one or more core variables (Urquhart, 2013). During this process, a small number of core themes were established, and in this study, the selective coding process was enhanced through discussions and feedback with the academic community, member feedback during data collection, and the literature. At this point, elements of emerging GTD were used during an iterative process of selective coding.

The selective coding process drew data together from both phases of the study. The core concept of instructional practice emerged as highly connected to most data sources. The selective codes were further analysed against existing research and with existing frameworks to determine similarities and differences. Developing selective codes also required a review of open and axial codes, memos, and diagrams to compare the findings to the literature. The selective codes are represented in Table 10.

Table 10

Selective Codes

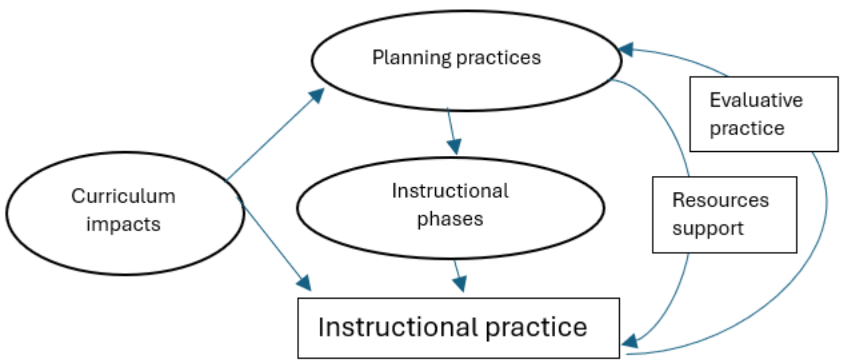
Selective codes	Justification
The role of the teacher in IBL	Emerged from Phase A as being a problem for some teachers and in Phase B the importance of the role of the teacher was emphasised by the expert teachers (Section 5.1)
Curriculum impacts	Informed the study context and pedagogical practice and strongly emphasised in Phase B (Section 5.2)
Expert teacher planning practices	Highlighted in both study phases and supportive of classroom practices (Section 6.1)

Selective codes	Justification
Instructional phases	Emerged as significant practice in Phase A (Section 6.2) and in the literature
Instructional practice	The central concept of selected teaching strategies informed by the selective codes (Section 6.3)

The connection between the selective codes and the core concept of instructional practice is illustrated in Figure 11. The core concept in GTD studies must be central and connected to the data sources. According to Corbin and Strauss (2015), the core concept must be "sufficiently broad" (p.187) and must tie all categories together and must appear frequently in the data.

Figure 11

Selective Codes and Core Concepts



The selective codes and the core concept were iterated further through the literature, peer and teacher feedback at conference presentations, and discussions with academic supervisors.

The selective coding process deviated from the traditional systematic coding approach for GTD proposed by Corbin and Strauss (2015) since the core concept of instructional practice was further analysed as a significant finding. A closer examination of instructional practices was warranted as a contribution to knowledge. The core concept of instructional practice was scaled up in this study to enhance the generated theory, and this analysis process is included in the following section.

4.6 Theory Generation

Theory generation is a significant reason for selecting GTD, supporting the practical application of the findings that are grounded in the collected data. The phenomenon in this study was the core concept of teacher instructional practice. The central concept of teacher instructional practice was chosen because it emerged frequently in the data and was broad enough to allow other categories to be related to it (Corbin & Strauss, 2015). The central theme had added dimensions, and these interactions were also explored through further analysis and scaled up using the literature. The generated theory addressed the research questions and added to the literature base to address the requirements of a doctoral thesis.

The development of the theory required additional analysis to scale-up the findings and this section outlines the processes used in this analysis. These processes included the use of constantly comparing the data, consideration of feedback, and developing memos, a further literature review, and a process of deep analysis of the core concept are presented in the following sections.

4.6.1 Scaling-Up Theory

Theories produced from GTD research are developed through deep analysis of a small sample size (Urquhart, 2013). In this study the developed theory was further scaled up through constant data comparison through journalling, constructing diagrams, and memos (Corbin & Strauss, 2015; Urquhart, 2013), and with a second literature review (Glaser & Strauss, 1967). In this study, the core concept of instructional practice was further analysed within five instructional phases and closely analysed using two typologies which were consistent with the findings: regulation practices (Dobber et al., 2017) and guidance levels (Lazonder & Harmsen, 2016). By scaling up the findings, a deep analysis of the characteristics of the practices of the expert teachers emerged.

The usefulness of memos, a field journal, and diagrams constructed throughout the study assisted in the final integration and scaling-up of categories through constant data comparison. Constant data comparisons were a feature of the coding process discussed in Section 4.6.3 and recommended by Corbin and Strauss (2015). Diagrams were a useful method of comparing data through memos because they showed the interconnections between concepts. Gaps in logic that were illustrated in the diagrams were challenged throughout the study and refined.

During the selective coding process theory was challenged and iterated based on feedback from conference presentations (ASERA 2021, 2022, 2023), teacher conferences (AISNSW 2022, STASNW 2023 and STANSW 2024) and discussions with academic supervisors. Iterations of the developing theory following feedback, supported iterations relating to the connections between data sources around the central theme of instructional practice.

Both Urquhart, (2013) and Glaser and Strauss (1967) recommended the 'scaling up' of GTD research with a literature review to add substance to the developed theory. It was noted that Glaser and Strauss (1967) warned against completing a substantive literature review of the phenomena under investigation at the beginning of the research. Urquhart, (2013) also recommended using a substantive literature review to 'scale up' a theory. A literature review was conducted in this study before data collection as required in a doctoral thesis and after data analysis to further inform the developing theory.

Following the development of the selective codes outlined in Section 4.5, five distinct instructional phases that the expert teachers used in this study to cluster their instructional practice emerged from the coded data. The literature influenced the development and naming of those observed phases and enabled the scaling up of the findings using an existing model and framework which showed some consistency with the findings (Bybee et al., 2006; Pedaste et al., 2015) (see Section 2.7). The subsequent naming of the instructional phases adopted the conventions of these works. By developing instructional phases that aligned to previously developed models and frameworks a deeper understanding of teacher practice could be understood (see Section 6.4.1).

Within each identified instructional phase, the data was further scaled up using two typologies for a deeper analysis of the teaching strategies that were selected by the expert teachers: regulation practices (Dobber et al., 2017) and guidance levels (Lazonder & Harmsen, 2016) which were introduced in Section 2.6. Within each of the five identified instructional phases, each of the identified teaching strategies were categorised according to both typologies. This enabled a deep analysis of teaching practice within each instructional phase and allowed for further patterns and connections between other data sources to emerge. This detailed analysis is included in Section 6.5.

4.6.2 Theory Development

Theory development in this study involved a process of systematic open, axial, and selective coding (Section 4.5.5). Emerging themes were scaled up by a second literature review following the coding process and enhanced through a process of comparing data, considering feedback and developing a series of memos. The development of theory occurred after a series of draft theories which were initially developed after data analysis and redeveloped during the remainder of the study.

The nature of a developed theory can be represented in different forms. A theory is:

> A set of well-developed categories (themes, concepts) that are systematically developed in terms of their properties and dimensions and related through statements of relationship to form a theoretical framework that explains something about the phenomena. (Hage, 1972, p.34 in Corbin & Strauss, 2015, p.62)

The theoretical framework has been presented as a flow diagram consistent with a GTD study and integrated the developed categories from both study phases around the central theme of instructional practice (Creswell & Guetterman, 2021; Corbin & Strauss, 2015). The theory was developed after several iterations which were reflected in Figure 9. The developed theory was scaled up after a literature review and a further data analysis to develop the Guided Inquiry Science Teaching framework presented in Chapter 7.

4.7 Study Credibility

This study sought to deeply investigate the phenomena, and the rich interpretative data collected supported the development of a proposed theory. Validity, reliability, and study rigour must be considered in any qualitative study (Corbin et al., 2015). Lincoln and Guba (1985) speak of the “credibility” and “trustworthiness” of findings in the evaluation of a qualitative study. The credibility or trustworthiness of the findings can be considered using eight criteria according to Creswell, 1998 (pp 201-203): “prolonged engagement and persistent observation in the field”, “triangulation”, “using peer review or debriefing”, “negative case analysis”, “clarifying researcher bias”, “in member checks”, “rich, thick description” and “external audits”. Every effort has been made to adhere to these principles in this study.

The quality of quantitative research relies on the study's validity (Corbin & Strauss, 2015). The validity of a study centres on whether it achieves what it is designed to do (Corbin & Strauss, 2015). This study’s two research questions have guided data collection and processing since. In arriving at the study's central themes, the analysis has constantly been evaluated against the research questions.

4.7.1 Reducing Researcher Bias

Every effort has been made to recognise and address researcher bias. The researcher's experience as an educator brought perceptions of IBL derived from previous professional experiences. These experiences were a potential risk to the impartial interpretation of the collected data. The chosen research method attempted to reduce researcher bias, which required an unobtrusive researcher position. The issue of potential bias is significant in interpreting the data, and a student voice has been included in the method design to inform the interpretation of teacher practice further.

The data has been represented accurately, and the data sources have been triangulated to make interpretive judgements. At times, the data disagreed with the researcher’s perceptions of the phenomena, and academic peers have been sought to provide their added interpretations of teacher practices.

4.7.2 Prolonged and Persistent Observation

The observation period occurred over consecutive IBL classes and included 7-14 hours of classroom observation of each expert teacher including their interactions with their students. Observations were hand-written in a journal to record the teacher's actions and interactions with the students and the student's reactions. After each observation session, the journal was transcribed digitally, and a memo was written as a researcher's reflection on the observations.

Persistent observation occurred at each case school where the expert teachers interacted with participating teachers and students within the school. This enabled some insight into teacher practice, including routines that they were using and processes that they had adopted. A possible constraint was rescheduling of classes due to other school activities. Only one planned lesson observation was missed throughout the observation period due to rescheduling during the final inquiry phase. Data saturation occurred during the final teaching phase when there were no new phenomena emerging from the data (Corbin & Strauss, 2015).

4.7.3 Evaluating and Triangulating Data

Multiple data sources were used, including semi-structured interviews, informal interviews, conversations, focus groups, documented evidence, and artefacts of student work. During data collection, memoing occurred in the form of diagrams to determine the connections between data, which were later triangulated through a systematic method of open, axial, and selective coding to answer the research questions.

Digital coding software was used to collect and code all scripted data and images systematically to increase the rigour and thoroughness of the coding process. The digital software enabled thorough capture and consideration of all relevant data and secure storage under each code.

4.7.4 Negative Case Analysis and External Audits

Data that appeared to be anomalous or contradictory was interrogated. In this study, Physics IBL was reported to be different from biology, chemistry, and earth and environmental science. Study participants offered reasons for this and pointed out differences that might limit IBL in Physics. It was felt that specific questions about the nature of the Physics course were outside this study's scope. This resulted in Physics not being considered for Phase B of the study.

During Phase B, there were differences in instructional practice between teachers, and in most cases, only consistent practices were reported. Reasons for the differences were investigated and reported if there was a reason for the difference. At Currawong High School, the Exploration instructional phase was conducted prior to the observation period to suit the school timetable using an external education provider, and this was chosen to be unobserved since it did not profoundly reflect the practice of the expert teacher.

The academic supervisor included external audits and review panels to interrogate and challenge the data further.

4.7.5 Peer Debriefing and In-Member Checks

Peer debriefing occurred during data collection and analysis through regular discussions with academic supervisors from the University of Technology Sydney. Analysed work was also presented at three academic and teacher conferences where feedback was provided and memos in the form of diagrams supported rigorous discussion and evaluation at each of these forums. The visualisations generated rich feedback, which was considered at different points in the dissertation's writing.

In-member checks with the expert teacher participants were carried out during the classroom observation period through informal conversations with the expert teachers. These conversations at each of the case schools enabled critical analysis of the interpretated classroom observation. The student focus groups enabled some clarification of the pedagogical approaches of the expert teachers and provided a further opportunity for data interpretation.

4.7.6 Rich Thick Descriptions

Thick, detailed descriptions have been sought to reduce researcher bias and provide support for the interpretations and claims proposed. Rich descriptions using the transcribed interview data and journal notes highlighted phenomena critical to the research questions. These descriptions have been used in this dissertation to provide detailed evidence for the interpretations made and provide evidence to address the two research questions and propose a theory.

Coding of the data enabled the efficient location of significant quotes and data sources that could be used as examples to describe each claim. The recorded quotes of the participants were further grouped and tabulated before writing, and memos were written to summarise their thoughts.

Journalling limited the number of participant quotes that could be recorded during observation, which may have limited the availability of some quoted descriptions.

4.7.7 Transferability and Confirmability

This research comes from a pragmatist viewpoint and is designed to have practical application and transferability over other research contexts. The findings shed some light on those pedagogical approaches that might be important to teacher education and development. It also has relevance to education authorities, who might need to consider their support for teachers in delivering a curriculum that includes IBL. The adopted methods can be transferred to other research contexts, and a systematic and pre-planned GTD methodology supports transferability.

A negative case analysis was also conducted throughout the analysis process to confirm the findings further. In conducting negative case analysis, questions were asked of anomalous or contradictory data. Data evaluation involved investigating whether there was a particular circumstance that was different to other observations and conducting in-member checks to clarify interpretation. An example was the different instructional approaches taken by Robin and Elle at the same school. Discussions after class clarified their awareness and the reasons for the different practices they managed in their team-teaching approach.

4.7.8 Methodological Issues

Field notes were chosen as a method of recording unobtrusive data to eliminate the effect of the presence of a researcher in the classroom as much as possible. The advantage was that field notes highlighted emphases during the lesson, unlike video or audio-recorded data, where the emphasis might need to be determined during analysis. While observations of the teachers and their classes were conducted over a long period, it was also understood that a single researcher conducting the study may have missed some conversations and teacher actions. The limitation on the number and length of quotes that could be hand-recorded was a further possible disadvantage.

A public health pandemic occurred during data collection and limited the researcher from conversing with the students while they were working. The restriction was required by University Ethics approvals. The imposed restriction had minimal effect on teacher observation since the teacher-to-student interactions could be heard. Students were included in the focus groups and were able to provide their perceptions of their teachers’ practice in that forum.

4.8 Chapter Summary

A systematic Grounded Theory Design (GTD) was selected, which sought to deeply investigate teacher perceptions and practices. This study's broad research questions required a method that included flexibility for deep investigation that allowed phenomena to emerge from theoretical sampling. This chapter outlined the research design and considered ethical practices inherent in qualitative research using human participants.

Adherence to the University of Technology's Responsible Conduct of Research and the National Statement on Ethical Conduct in Human Research is mandatory for research with human subjects. Permission was applied through the UTS Human Research Ethics Committee (HREC) before any research was carried out and approved in 2020 (UTS HREC REF NO. ETH19-4039). All aspects of the ethics approvals were applied to the study methods.

The study was conducted in two phases consistent with systematic grounded theory design (GTD). Phase A included science education leaders. Phase B was situated at three case study schools and included four expert teachers, students, and an additional four teachers who consented to be observed as a part of the study.

The credibility and trustworthiness of GTD adopted in this study centred on extensive observation of data in the field and the triangulation of several sources of data in each context until data saturation was complete (Creswell & Guetterman, 2021; Corbin & Strauss, 2015). The researcher selected an unobtrusive stance in GTD research and limited their influence through a process of self-reflection and rigorous data collection and analysis. The methods included theoretical sampling, constant data comparisons, memoing, drawing diagrams, and developing core categories. Generating a broad theory followed a sequence of open, axial, and selective coding added robustness to the methods.

Methodological issues due to the public health pandemic at the time of data collection were minimal and controlled. While the selection of journalling limited the number of quotes that could be recorded during observation, it had the advantage of recording visual cues, gestures, and actions, which the teachers also used in their interactions with the students.

Chapter 5

Perceptions of Inquiry-Based Learning in Senior School Contexts

5.1 Chapter Overview

This chapter reports on findings from Phase A of the study, drawing on the secondary science education leaders' perceptions of IBL concerning the Depth Study component of the senior science curriculum in NSW, Australia. It addresses Research Question 1 (RQ1): "What are science education leaders' perceptions relating to inquiry-based learning in Depth Studies in senior secondary science?"

As outlined in the previous chapter, the first study phase involved selecting ten participants who participated in semi-structured interviews. All participants were experienced secondary science education leaders sourced through the Science Teachers Association of NSW (STANSW) and the researchers' professional contacts. Participants' pseudonyms and associated notes are summarised in Table 11 for reference.

Table 11

Phase A Study Participants

Name (Pseudonym)	Education position	Notes
Ali	Head Teacher Science at a Sydney School	Researchers' own contact
Ann	Assistant Principal/Science teacher	Sourced from the STANSW
Elle	Science Teacher/Senior school leader	Researchers' own contact
Greta	Teacher educator in a school sector	Sourced from the STANSW
Matt	Education consultant/science teacher	Sourced from the STANSW
Megan	Head Teacher Science at a Sydney secondary school.	Researchers' own contact
Nadia	Head Teacher Science at a Sydney secondary school.	Researchers' own contact
Peta	Education consultant	Sourced from the STANSW
Sasha	Head Teacher Science at a Sydney secondary school.	Sourced from the STANSW
Tom	Head Teacher Science at a Sydney secondary school.	Researchers' own contact

Each participant was a highly experienced science educator and leader who regularly observed the practices of other teachers. Therefore, they were able to offer broad insights into IBL in senior school science contexts, informed by their perceptions of their own practices and the practices of other teachers.

Participants answered five broad semi-structured interview questions that were recorded and transcribed in a series of semi-structured interviews. The broad survey questions, included in Chapter 4, invited the ten participants to provide detailed their insights into relevant phenomena that were important to them. The open conversation encouraged by the interviews elicited education leaders' views of pedagogical approaches of IBL, including rich descriptions and examples. As described in the Chapter 4 (see Section 4.4.5), data codes using the actual words of the conversations were developed as the first step in the coding process, and these were further grouped into common themes. Two significant themes emerged and addressed RQ1 as follows:

1. The role of the teacher in Inquiry-based learning
2. Curriculum impacts on teachers' practices.

In reporting these findings, quotes from the study participants were included to evidence claims. Selected IBL examples provided in the interviews are also presented to provide context.

Education leaders welcomed the opportunity to provide their perspectives and were forthcoming with relevant examples of teacher practice. They provided compelling evidence that IBL is implemented in senior secondary science using a range of models in the NSW Australia context. They highlighted some of the difficulties that some of the teachers were experiencing were able to cite what they considered to be good practice. Several factors were proposed that might limit IBL in senior secondary science contexts, including the compulsory curriculum and external testing.

5.2 The Role of the Teacher in Inquiry-Based Learning

Education leader participants highlighted a range of considerations required to manage students' IBL projects. There were four main themes highlighted: the benefits of Inquiry-Based Learning, choosing open and guided approaches to IBL, the use of teacher developed topics, supporting students to develop their own inquiry questions, and the changing role of the teacher. All study participants described examples of IBL which reflected a socio-constructivist approach where students and teachers worked together in social groups.

5.2.1. The Benefits of Inquiry Based Learning

All study participants interviewed generally felt that the curriculum requirement of the Depth Study was a positive step to promote IBL in the Years 11 and 12 science courses and a welcome addition. Three participants (Sasha, Robin, and Nadia) spoke about the Depth Study as being reflective of the nature of science: “I actually think that it’s a really good idea. I like [the Depth Studies] and I say to the girls this is real science. This is what’s happening in the real world.” (Sasha).

A further advantage included student motivation and Ann saw this a key advantage for her students: “I love how much the kids get invested in [the Depth Studies], the Depth Study has opened up kids’ eyes and teachers’ eyes to be honest.” (Ann) Robin saw a key advantage of IBL enhancing her students’ confidence levels: “I think seeing them have those ah-ha moments, it really buoys their confidence, and it also allows us to engage in scientific dialogue and also talks about the scientific method and how we could improve methodology.”

Student agency and placing students in charge of their learning was a third highlighted advantage: “So I think that they’ve [Depth Study] got a wonderful opportunity to give the kids the agency and the appropriate depth.” (Nadia) and “We know that for students to succeed as learners they need to be the ones that are driving the learning and inquiry-based learning allows them to do that.” (Robin). All study participants saw great value in students being able to regulate their own learning.

5.2.2 Choosing Open and Guided Approaches to Inquiry-Based Learning

Education leaders in Phase A of this study frequently discussed the suitability of guided and open approaches to IBL. In this phase of the study, broad definitions were used to describe the level of inquiry under the headings of "structured", "guided" and "open" IBL as defined in Table 1 (Chapter 1) and are referred to as general terms to indicate the level of guidance provided by the teacher. In this phase of the study, the participants decided what they felt were the successful approaches to IBL that they had implemented or observed in their experience. Providing a definitive level of inquiry in this study is only indicative of practice, because participants also reported that some elements of IBL activities were guided, and other elements were less guided or open.

A range of examples of Inquiry-Based Learning were described during the semi-structured interview. The range of examples provided were classified as levels of IBL according to the descriptions provided and the emphasis that participants described relating to the level of teacher support. Table 12 tentatively classifies the levels of IBL for each of the described examples situated within each science discipline.

Table 12

Levels of IBL Guidance Reported by Science Education Leaders.

Subject	Open inquiry (reported examples)	Guided inquiry (reported examples)	Structured inquiry (reported examples)
Biology	2	14	0
Chemistry	4	3	0
Earth and Environmental Science	0	4	1
Physics	1	4	0
Total	7	25	1

Note. Education leader participants were able to discuss more than one example of Senior Secondary Inquiry-Based Learning in their interviews. Levels of IBL indicative and were tentatively categorised according to Banchi and Bell (2008), levels of inquiry which relied on the level of teacher involvement in designing the inquiry question and the method.

Of interest are the greater number of IBL examples that were described and emphasised as Biology examples. Biology examples were emphasised with great enthusiasm in all interviews. A strong preference for guided IBL was described in this context where the teacher provided a topic and allowed some student independence while they were working.

The challenge of managing student anxiety when students were required to work with greater independence during open IBL was raised by interview participants, Sasha, Megan, Ali, Greta, Elle, and Matt. These participants described their experiences and observations of open IBL and highlighted student anxiety as being an issue when students were required to conceptualise their projects and make independent decisions during their investigations. Sasha said: “We’ve had tears but … and it’s been a huge learning curve for us as well.” Matt pointed out that some of his students felt overwhelmed: “Also it can be like ‘Oh my goodness it is so big I just can’t do it’. So, they shut down at multiple ends there.” Student anxiety was described as a significant factor that required classroom management yet was also justified by Matt and Sasha as an expected student reaction and part of learning. Greta and Megan also suggested that it was the reason why they preferred guided approaches to IBL so that student anxiety could be better managed.

Megan had tried unsuccessfully with an open IBL approach in earlier attempts to implement IBL in the senior years. She described student anxiety when her students were required to formulate a suitable investigable inquiry question that she and her teachers were not able to manage. In the second year of her teaching programme, she adopted a guided approach and considered this to be more successful. “This year we’ve done a much better job … by guiding them a lot more and breaking it down into parts …” (Megan). She also discussed how her interpretation of, and definition of IBL had changed from open to guided IBL. She had earlier thought that students should investigate their own questions without teacher support, and this had changed more recently to a guided approach where the teacher divided the process into manageable chunks. She reported that her students asked questions throughout the Depth Study “the inquiry occurs within the Depth Study [process]” (Megan). She had also opted to provide a guiding question for her students to explore to provide direction.

Greta reported observing student anxiety in open IBL classrooms led by less experienced teachers. In her role as an education consultant, she noted poorly managed instances of open IBL causing chaos and anxiety among students, exemplified by one teacher's noisy, disorganized class where students required guidance despite choosing their own topics for practical work:

> I am seeing in Chemistry at one school which was completely open-inquiry, it was a complete 'shemozzle' — the equipment, and the time, and it never reappeared. This year [the open-inquiry Depth Study] did not come back because it was just not manageable for one teacher to do it with that many students. (Greta)

Greta reported that this example in a Chemistry classroom raised high anxiety for the students at this school where the students became overwhelmed by the choices that they needed to make. She had followed up on this situation by supporting these teachers to implement a guided approach to IBL in the following year to reduce student anxiety and burden on the teachers through the implementation of a professional learning programme. She also described the use of guiding topics and a learning sequence where the activities were grouped into inquiry phases.

Study participants recognised the value of students being able to work independently on their own unique IBL projects but were conflicted by the difficulty that teachers had in managing a classroom where students were all completing different projects. One of the common features of guided IBL was that teachers developed broad topics which supported students in being able to conceptualise their project.

5.2.3 Teacher-Developed Topics

Education leaders reported developing broad topics to frame and guide guided IBL in addressing interview question 2. These were developed at the start of planning with careful consideration (Elle, Tom). Topics were often posed as broad driving questions to support students to develop a question within a narrow range and offered scaffolded guidance. The use of guiding questions is well referenced and can be used as a basis for students to change or add to (Fowler et al., 2020) or direct the IBL within a particular topic range (Sezen-Barrie et al., 2020). There were pragmatic reasons for opting to narrow the choice, particularly for large cohorts of students where available equipment might be limited, or the management of completely different topics might be difficult to manage. The limitations of available resources were noted by Ali, Nadia, and Sasha as being a reason why teachers preferred to limit student choice. This insight was suggestive that open inquiry might be limited in less resourced schools.

A range of reported teacher developed topics reported by education leaders are reported in Table 13.

Table 13

Reported Topics Developed by Teachers

Leader participant	Reported IBL Topics
Megan	Chemistry (Year 12): pH
	Biology (Year 12): Recombinant DNA and gel electrophoresis
	Biology (Year 11): Enzymes.
Elle	Chemistry (Years 11 and 12): Water quality testing
	Biology (Year 11): Ecology fieldwork
	Physics (Year 11): Waves and thermodynamics
	Physics (Year 12): Advanced mechanics.
Tom	Biology (Year 11): Water dragon theme
	Biology (Year 11): Creek organisms
	Biology (Year 12): Indigenous people and medicinal plants
	Physics (Year 11): Machines.
Ali	Biology (Year 11): Stomata and transpiration.
	Biology (Year 11): Ecology Field study.
	Biology (Year 12): Koch's postulates practical with melt marmite agar.
	Chemistry (Year 11): Surface area and reaction rates.
	Earth and Environmental Science (Year 11): Rock cycling modelling.
Greta	Biology (Year 11): Environmental science theme
	Biology (Year 11): Enzymes
Nadia	Biology (Year 11): Ministerial report writing (environmental issue).
Peta	Earth and Environmental Science (EES) (Year 12): Mining
	EES (Year 11): Salinity and land-based issues
	EES (Year 12): Human impacts on the school site
	EES (Year 11): Tectonics and the Super-Cycle model.
Ann	Physics (Year 12): Electromagnets
	Biology (Year 12): Public health infographic
Matt	Biology (Year 11): Local Ecosystem fieldwork investigation

The examples discussed included 11 examples of topics relating to a local natural ecosystem which were spoken about at length and with great enthusiasm (Elle, Matt, Peta, and Tom,). Further examples of IBL which focused on ecosystems were also reported in Chemistry (Elle) and Earth and Environmental Science (Peta) and were significant to the local area and context of each school. The importance of local context that was relevant to the students was reported by the education leaders to be important to their learning. Elle emphasised that her school placed great importance on students learning about the local environment which she strongly supported.

Peta made a pertinent point in reflecting on a range of topics that were relevant to the students in Earth and Environmental Science. She compared this science subject to Chemistry and Physics where she had observed that teachers had difficulty in choosing interesting topics for their Depth Study programme, and said:

> I think that it's harder in some of the other subjects because it's obviously connected to the everyday experience. So, if you can't make Earth and Environmental Science interesting it's in the news all the time, it's happening all of the time. So, it's probably easier to come up with a really good Depth Study in our course… (Peta)

Tom expressed that it was difficult for teachers at his school to choose interesting topics in Physics and as a Head of Department he selected the topic of machines which was a departure from the compulsory curriculum content. A recent study also noted the difficulty that Physics teachers had in implementing IBL in a Malaysian study which concluded was attributed to intrinsic and extrinsic factors such as a lack of pedagogical knowledge and teacher experience (Roslan et al., 2023) which was also indicated by Tom as being a significant factor.

The topics that education leaders highlighted related to forms of IBL where varying levels of guidance were described. Examples of where students chose the IBL topic are not included in Table 14 since they were not situated under a teacher selected topic. In most cited examples, students were supported in developing their own inquiry questions under a broad theme or a broad "driving" question and only Sasha and Ann gave examples of where students chose the topic.

5.2.4 Supporting Students to Develop Their Own Inquiry Questions

The broad topics and themes were discussed as being supportive of students developing their own specific inquiry questions to investigate. Despite this support, education leaders spoke about the difficulty that students often experienced in developing an investigable inquiry question. Greta and Tom spoke at length about the difficulty that teachers have with great emphasis, while Ann, Peta and Tom spoke of some strategies that they had used to support student question development.

With reference to teachers having the capacity to facilitate students' inquiry question development, Tom pointed out that: "Most of them (teachers) forget about questioning. The questioning and predicting outcome." He elaborated on this statement and felt that many teachers at his school had difficulty in supporting their students to develop an inquiry question and tried to avoid it. Tom described Physics teachers at his school who also avoided supporting students in developing investigable inquiry questions for their own projects. He had also reported that this had changed following implemented professional development and modelled practice at this school.

Teachers having difficulty in supporting students to develop investigable inquiry questions was noted by Greta who described teachers she had observed who had great difficulty supporting their students. While Greta reflected on the teachers that she supervised: "There's a big issue about asking the (inquiry) questions. The teachers don't seem to be very skilled at [supporting] the students to develop their own question …" (Greta).

Ann, Peta, and Tom described some strategies that they had used to support their students to generate an inquiry question when discussing interview Question 3 which asked teachers to comment on teacher approaches to facilitating IBL. The guidance strategies involved collaborative discussion approaches "… we've had brainstorming, just in different types of questions that you could ask." (Peta). Her approach gave visibility to the students' ideas and supported her ability to provide feedback and guidance during that process.

Ann emphasised student collaboration and the social aspects of learning as being important to support students to develop inquiry questions and adopted a similar approach to Peta: “We use the model where the kids just talk to the teacher and they are set up in small teams like a think, pair, share activity but there are usually three in a group and they take a role in that think, pair, share group.” (Ann) She saw benefit in supporting her students to work in a team and worked with her team of teachers to develop processes which she called ‘protocols’ to support student thinking which were visible to the teacher and to other students.

Tom’s approach to support students to generate an inquiry question drew on the students’ interests: “I get them to stop and reflect on what they are actually interested in.” (Tom). He felt that his students would engage in their project if they could see personal significance in their inquiry question. Personal significance of the topic or inquiry question was also considered to be important by Elle in her environmental chemistry example.

Another important theme is that there was a perception amongst most study participants that some teachers were challenged and felt uncomfortable when students selected topics that were outside of the teachers’ subject area or outside of their own sphere of knowledge. Elle reported on the perceptions of teachers both at her school and teachers whom she had spoken to through her external teacher networks:

> I think that there are some teachers out there that feel uncomfortable with the uncertainty of what a Depth Study can bring because you get thrown questions and you go, ‘I have no idea’. But that’s good and I think some teachers are uncomfortable with uncertainty and other teachers [aren’t]. (Elle)

The discomfort of IBL for some teachers, according to Sasha and Megan, stemmed from not knowing the answers to all the student questions that were posed. Elle made a pertinent point that this discomfort was the reality of IBL, and teachers needed to be able to address this uncertainty and not be expected to know everything.

5.2.5 The Changing Role of the Teacher

Participants in the study identified the teacher's role as crucial in implementing IBL practices (Greta, Matt, Peta, Tom). They expressed concerns that many teachers lacked understanding of this role, which they viewed as a significant challenge. The exemplary role of the teacher, in most cases discussed, involved guided IBL where the teacher embraced varying levels of guidance and supported a socio-constructivist philosophy. During the semi-structured interviews, participants evaluated different pedagogical approaches under Interview Questions 3 and 4, discussing successful classroom practices and challenges. They criticised traditional teaching methods where teachers held authoritative roles and used highly guided instruction (Matt, Tom), as well as approaches where teachers offered minimal guidance (Greta).

The importance of teacher instruction in differentiated classroom practice was emphasised by Ali and Ann, who provided explicit examples of their own practice. Peta also recognised the changes to the teacher role and described the essential use of explicit instruction along with a range of other strategies that she had observed and implemented in her own practice. Differentiated guidance was highlighted as an essential supportive feature of IBL instruction (Ali, Ann, Peta).

Ali was highly conscious of the need to provide different levels of guidance within a class appropriate for each student and described her own guidance practices in her biology example. She included modelling laboratory techniques and a staged process for all students, yet she recognised the need for varying levels of support within her class after the initial inquiry phase. To differentiate her levels of guidance, she developed some student laboratory activities to further develop student skills prior to engaging in microscope work. She scaffolded the activity using a written method and explicit guidance for some students. The range of guidance that she offered was for the purpose of meeting the needs of individual students “I think that it’s one of the very good things in our senior years that we can do a little bit of differentiation.” Her practice described her classroom position between providing high levels of guidance through explicit instruction in combination with lower levels of guidance and therefore described the teacher role as being one that changes.

Guiding students by modelling practice was raised by Erin as an important differentiation strategy in Phase B of this study during an interview. Like Ali, she felt that students needed to build on previously learned skills "Teaching them the skills. I think it's important to – if you're expecting a high level of critical thinking and problem-solving … you need to show them how to do that" (Erin). This strategy was later observed in her classroom alongside a range of different approaches.

Ann was also an advocate of establishing a differentiated approach in her guided IBL example of a "student-led inquiry" (Ann) and therefore varying her role as a teacher to support student group work. She described differences between classes and between students and saw the need to differentiate practice and model practices. She gave the example of a student with intellectual disability: "Like I might look at the Life Skills course and got my Year 12, boy, {[to make] a solar oven and researched how solar cookers work." (Ann). She described that her position as a teacher might be more authoritarian in teaching this student compared to students in her Physics class who were able to work independently, where her guidance was much more reduced. Like Ali, Ann described a varied level of guidance that she offered for the purpose of differentiating learning.

Peta described using explicit instruction early in guided IBL to enhance her students understanding about the use of secondary sources. She followed up this guidance with a library lesson for her students: "…take them to the library where books are to help them carry on with this [research]. I think it led to a really good understanding". To prepare her students for practical work she also explained that she had used explicit instruction "They (students) need to be prepped so they know what they are doing beforehand. Having a class activity that gives them the necessary skills then go and work on a Depth Study." She also described the use of peer review, brainstorming activities which involved a reduction in the levels of teacher guidance. Her description of what she considered to be suitable teacher practices included a range of teacher guidances. She illustrated some of the complexity of IBL teaching by recognising the changing role of the teacher. Other participants also spoke about at minimum two different teacher roles in IBL.

Some participants spoke with more emphasis on deficit practice than positive practices during the interviews as they considered the role of the teacher. Three study participants felt that some teachers who normally adopt a traditional and authoritarian role in the classroom felt disempowered in their role as a teacher in IBL. Ali, Matt, and Tom raised this issue and discussed the hesitancy of some of the more experienced teachers within their science faculties. "…so, I guess that's the challenge it's … acting as a facilitator and being scared to take that next step back." (Matt) Ali agreed: "I'm finding that the more experienced teachers are less inclined to let them go and allow them [the students] to do it without too much guidance." They felt that it was often the more experienced teachers who were less confident in changing their position in the classroom and felt threatened when their current teaching approach was challenged.

Four participants discussed the use of different forms of instruction and the difficulty that some teachers had in adapting their practice when required (Matt, Ali, Tom, Greta). Adapting classroom practice was reported to be difficult for inexperienced teachers who were less able to adapt teacher strategies in a responsive way (Greta, Tom, Matt). However, Tom and Matt also agreed and emphasised that this was also an issue for experienced teachers who strongly relied on direct instructional methods in their teaching. Tom reported physics teachers where "there was no inquiry" and had opted for recipe-like practical tasks for their students. The tendency of some teachers to adopt a static instructional role using heavily guided instructional practice was also discussed as being influenced by the pressure of a content-heavy compulsory curriculum and external examination (Megan, Nadia) and is discussed further in the following section.

5.3 Curriculum Impacts on Teacher Practices

Curriculum impacts were reported to have both a positive and a negative effect on the role of the teacher and emphasised to have a profound impact on IBL. While the constraints of a compulsory curriculum in NSW Australia, and a formal external examination were reported to impact IBL negatively (Ann, Nadia), study participants also reported that the curriculum requirement to engage in IBL through the Depth

Study was a positive inclusion and primarily supported (Greta). These findings contrasted to reported impacts on teacher practices in other jurisdictions such as the lack of resources and the lack of quality professional learning in the United Arab Emirates (Baroudi & Rodjan Helder, 2021), and lack of exposure to science inquiry prior to teaching in a meta-analysis of teachers' self-efficacy of IBL (Chichekian & Shore, 2016), which further highlight the importance of localised research.

While all participants in this study agreed that IBL in senior secondary science was beneficial, most participants also added a qualifier where they recognised that there were also some inhibitors to both teaching and learning. Ali regularly engaged with educators outside of her school through professional learning activities and had some reservations about teacher practices at and outside of her school. Ali's response to survey question 1 was pertinent and captured the essence of others' responses when speaking about the positive impact of the curriculum requirement to engage in IBL while expressing some doubt about teacher practice: "I would cage my answer by saying it can. It can and gives incredible opportunity to do it and give the kids a foundation so they can go off and do their inquiry." (Ali).

The factors that were reported by participants that inhibited teacher practice were the impacts of formal assessment and an imposed crowded curriculum which did not allow sufficient flexibility.

5.3.1 Managing the Impacts of Formal Assessment on Teaching Practice

Two external assessments made compulsory by the NSW, Australia jurisdiction were reported to negatively impact IBL pedagogy. These were the external NSW Higher School Certificate Examination, and the formal assessment of students' Depth Studies which was assessed at each school. It was the perception of some participants that these restricted the openness of IBL (Nadia, Megan, Greta, and Peta) by restricting available class time. In contrast, two participants supported these assessments (Greta, Megan).

Participants raised the issue of the impact of the external examination on teaching practice (Megan, Greta), and the tendency of teachers to restrict student choice and avoid open IBL approaches (Matt, Tom). They explained that the tendency to spend more time preparing students for assessment was more beneficial by some teachers. Megan, Greta, and Nadia proposed that the impact of the final examination might reduce the confidence that teachers have in the value of IBL. This issue was mentioned by Tom and Matt who quoted examples in Physics where teachers had chosen not to engage in IBL at all because it was not assessed in the external HSC examination.

In contrast to the negative impact of the compulsory curriculum on teacher practice, Greta and Megan spoke of the benefits of formal assessment. Greta felt that if the final external examination were to be removed teachers would not be as accountable for their teaching:

> Take away the exam and would you see a change in the classroom? … in some classrooms, you would see students explode with enthusiasm and a depth of learning, [but] you would also get the opposite, teachers not 'toeing the line' and doing nothing much, and that comes down to teacher quality and teacher experience (Greta).

This was agreed by Megan who also added that she felt that her students would not engage in IBL if a compulsory IBL assessment were to be removed. Megan summarised her student's reaction to completing work tasks in senior science: "Do I need to do this for the exam? 'cause if I don't, I've got enough on my mind. I've got enough to learn; I've got so much to learn and it's something that I don't need" (Megan). The lack of teacher accountability according to Megan and Greta might also have a negative effect on pedagogy if compulsory assessment were to be removed, because there would be no curriculum requirement for teachers to adopt IBL practices.

5.3.2 Balancing the Completion of Curriculum Content With IBL

Curriculum content in the NSW Australia curriculum is compulsory and examinable at an end of course formal examination called the Higher School Certificate. It was highlighted as impacting the quality of IBL by limiting available time and restricting creativity in IBL due to the recommended assessment practices (Greta, Matt, Megan, Nadia, Tom).

Study participants expressed concern over balancing preparing their students for this examination and spending time on IBL that is not externally assessed. The influence of a content-heavy curriculum, limited by time, in senior secondary science and a lack of adequate pedagogical guidance was raised by Matt, Greta, Tom, and Megan who felt that the prescribed content of the curriculum did not allow enough time to engage fully with IBL.

Nadia spoke about the benefits of the Depth Study project and how it can be restricted by the way it is assessed since creativity is rarely recognised and celebrated: “It’s really not the ability of the child to come up with amazing things to do and to research and then to develop … and (this) is constrained by us having to assess it …” (Nadia). Most education leaders, including Nadia spoke of using standards-based marking rubrics to assess the Depth Study which rely on making qualitative judgements based on course outcomes. Nadia pointed out that students only complete the required elements on the rubric and are not stretched to write a report that goes beyond what is required.

There was a strong view that teachers were interpreting the requirements of the Depth Study differently and not using it as an opportunity for the students to engage in practical scientific inquiry. The misinterpretation of the curriculum was an issue raised by Tom and Matt. Tom described one example of this of a Physics Depth Study designed by a Physics teacher in his faculty where he believed there was no inquiry. “It was really, really restricted, everyone does the same prac[tical], it’s more a test with a write-up rather than a Depth Study.” (Tom) Despite the compulsory requirement for student inquiry in senior secondary science, some teachers at Tom’s and Matt’s schools were reported to be implementing recipe-style practical activities due to a misinterpretation of the requirements for the Depth Study.

5.4 Chapter Summary

This chapter discussed the dominant themes relating to RQ1 following a thematic analysis of semi-structured interviews of science education leaders. The two identified themes include:

- The role of the teacher in inquiry-based learning

- Curriculum impacts on teacher practices.

The teacher's role was reported to be complex and multi-faceted, where teachers adopted various strategies and varying levels of guidance. In this research context, explicit instruction was described as a helpful teacher strategy in combination with less guided approaches such as facilitating a peer review discussion. A lack of teacher confidence in changing their classroom role was reported to be a challenge for some teachers. However, flexible guidance, which recognised the diversity of students were reported as being beneficial.

In managing IBL projects, guiding the Depth Study was the preferred teaching approach to manage student anxiety. A teacher-developed topic supportive of IBL was vastly preferred over IBL approaches where students selected their own topic and inquiry question. Participants recognised that student independence was desirable, and most of the participants preferred balancing independence with teacher guidance.

Education leaders valued the inclusion of the Depth Study in the curriculum and were able to report on challenges that teachers experienced in implementing IBL. They provided descriptive illustrations to emphasise the points that they made. Despite their support of the underpinning educational intentions of IBL projects, they were adamant that the implementation was inconsistent, that some teachers are challenged by the required teacher role in the classroom and that the impact of the compulsory curriculum requirements in senior secondary science was thought to limit opportunities to engage in IBL.

Of the impacts on teacher practices, the compulsory curriculum requirements were reported to limit students' ability to engage in open IBL due to the ‘high stakes’ external testing environment. A crowded curriculum that emphasises content is reported to further restrict open IBL due to time constraints and the reluctance of some teachers to allow for student autonomy.

The findings from Phase A of this study indicate the current “state of play” of IBL in senior secondary science in NSW, Australia. Study participants indicated a positive perception of the value of IBL for student learning in senior science. Education leaders recommended a range of teaching strategies for IBL which warranted further exploration in Phase B of the study which are analysed in Chapter 6.

Chapter 6

Pedagogical Practice in Inquiry-Based Learning

6.1 Chapter Overview

In the previous chapter, following a thematic analysis to address research question RQ1, the perceptions of education leaders were discussed under two broad themes: the role of the teacher, and curriculum impacts on IBL. The themes that emerged from Phase A of the study depicted the nature of the Depth Study program and indicated its challenges and the successful approaches of teachers. These themes were enhanced with empirical evidence in Phase B to provide a deep analysis of the practices of highly experienced teachers, called here *expert teachers*.

In this chapter, data is analysed to address research question RQ2:

> RQ2: "What are expert teachers' practices relating to inquiry-based learning in senior secondary science?"

The expert teachers were introduced in Chapter 4, along with the inclusion criteria for participating in the study. It was emphasised that they were not heralded as being perfect in their practice; however, their experience and confidence in using IBL would be of interest in this study to identify existing expert teacher practices. In this chapter, the school contexts for the observations are introduced, along with the additional study participants, Erin and Robin, who did not participate in Phase A. Expert teachers Megan and Elle are reintroduced.

Classroom observations of the expert teachers at schools which have been deidentified with pseudonyms, involved 13 hours at Cockatoo High School (Cockatoo HS), 11 hours at Lorikeet High School (Lorikeet HS), and 11 hours at Currawong High School (Currawong HS). The observation schedule is represented in Appendix G. Analysis of the observed teacher practices were further informed by the student participants (n=32), who provided their perceptions of their teacher's practice, artefacts of student work, written student resources, and curriculum documents provided by the expert teachers to provide in-depth interpretation.

Section 6.2 introduces the schools that were the Phase B study contexts, and it reintroduces the expert teachers (Section 6.2). Section 6.3 examines in depth the complexities of teacher planning practices in IBL, and Section 6.4 proposes the IBL instructional phases. Analyses of the expert teachers' instructional practices as the dominant coded themes of pedagogical practice within each instructional inquiry phase are presented in Section 6.5. These classroom practices are analysed using the frameworks of regulation practice (Dobber et al., 2017) and guidance levels (Lazonder & Harmsen, 2016). Section 6.6 summarises the chapter.

6.2 Phase B Study Contexts

This section describes the school cases and the scope of the observations at the schools where the expert teachers worked. The expert teacher participants were selected based on their own professional attributes with respect to the selection criteria described in Chapter 4. It should be noted that they were not selected according to the school in which they worked; rather, they were selected to provide further insight into the dominant themes raised in Phase A of the study relating to different levels of guidance arranged their IBL using broad topics and recognising the need to differentiate their approach in the classroom. To determine their perceptions, the researcher interviewed them prior to observing them.

For researcher accessibility reasons, each of the expert teachers was from an independent school in the Sydney region, and observations of them were conducted during 2021. The school observation schedules are included in Appendix G. It is acknowledged that while the number of hours of observation were similar in each school, the observation periods were different. Both Cockatoo HS and Currawong HS allowed a block of time for the guided IBL, which compressed the observation period, compared to Lorikeet HS, which was observed over a 3-week period.

6.2.1 Cockatoo High School Observations

The case study school with the pseudonym Cockatoo HS was a coeducational, socio-economically advantaged school in Sydney. The observed expert teachers at this school were Elle and Robin (pseudonyms). The two observed classes they taught included 36 students studying Year 11 Chemistry, with the students working in groups.

Elle had already participated in Phase A of this study, and she accepted an invitation to participate in Phase B as an expert teacher. Robin also requested that she be included since she and Elle were team-teaching together. Both teachers fitted the selection criteria and consented to participate. Robin was interviewed just prior to her observation period and Elle was interviewed as part of Phase A.

Robin was the head science teacher, and she described the guided approach to IBL that she promoted in her faculty. The topic that she and her teachers had selected was “water chemistry” and she nominated the local water sources for investigation. She described how the observed guided IBL activity drew strongly on an interesting local water context and was developed after several iterations. She provided documented evidence of her program development, the student resources, and student work samples for further investigation.

Robin said she had different views to Elle about the level of support to be provided to students. She said, “I believe that you need to front-load the students,” meaning that students needed to be able to build on existing skills and knowledge. It was evident from the observation that Elle preferred to conduct just-in-time teaching by demonstrating apparatus and providing contextual information in response to student questions when required. Having different practices did not appear to cause any tension between the two expert teachers, who were acutely aware of their different views. Both teachers saw value in promoting the social aspects of learning, and they were seen to support students to work together in teams.

Elle and Robin taught in the same space in a team-teaching arrangement for the first three observed classes, which included an outdoor field site and a school science laboratory, and they used separate laboratory spaces for the remaining classes.

Students had access to a range of chemical reagents and laboratory apparatus, which they negotiated with their teachers. Two focus groups were conducted at the end of the observation period with consenting students (n=17), who were of mixed abilities.

6.2.2 Lorikeet High School Observations

The third expert teacher, Megan (pseudonym), was the head science teacher at a large co-educational independent Sydney school given the pseudonym Lorikeet HS. She was also interviewed in Phase A of this study as a science education leader. Megan was observed in her own Year 11 Biology classroom and in discussions with teachers and students in the science staffroom. Her class of 15 students was one of two Year 11 Biology classes at her school, and her students were working in social groups. The other Biology class at her school, which was taught by another teacher, was not observed for this study.

Megan's students were studying enzymes in her class prior to the observation period, and she had chosen a broad inquiry question for her classes IBL activity: "How do cells coordinate activities within their internal environment and their external environment?" (Student-printed booklet, Lorikeet HS). Her students were expected to choose their own hypothesis under this broad question for their practical work, along with a topic of secondary-source research, by posing their own inquiry question. Megan had earlier spoken of using an open-IBL approach, which according to her, "didn't work", and she had since adopted a guided approach. She had restricted the choice of topic for the practical investigation to manage the classroom and reduce student anxiety. Megan had previously found that students took a long time to produce an investigable question, and she justified her approach of using guided question based on her previous experience. As a part of the observation, Megan provided samples of student work and of resources that she had developed.

Megan had chosen to complete the IBL activity over a 3-week period in class. Her students were allowed an additional 3-week period to complete their written reports outside of class. The students were also able to contact her via email between classes to clarify their ideas. One student focus group was conducted at the end of the observation period with some of the participating students (n=12), who were of mixed abilities.

Although the same classroom – a science laboratory – was used for the entire observation period, Megan adapted the space, and its arrangement as needed. Her students had access to laboratory apparatus and a limited range of chemical reagents, which included a range of enzymes and chemical substrates.

6.2.3 Currawong High School Observations

The fourth expert teacher, Erin (pseudonym), was a head science teacher at a large, socio-economically advantaged independent school for boys in Sydney given the pseudonym Currawong HS. She was observed when teaching her Year 11 Biology class and when working in four additional Biology classes to support other teachers in her faculty. All her students were working in social groups. Her conversations with participating teachers were observed in the staffroom and with participating students in the corridor spaces. Class sizes at this school were 13 to 19 students from a total of 78 Year 11 Biology students. Prior to the observation period, her students attended an outdoor field-study excursion to learn about ecology field techniques. This excursion was conducted by an external education provider and not observed as part of this research.

Erin was observed to develop a strong rapport with the students in her class. When her students entered her classroom, she would acknowledge them, and her students would often stop and speak to her briefly before class began. Two participating students spoke of her as being a “good teacher”. Erin also had a strong rapport with her staff, who, at her invitation, were very willing to be observed in their classrooms. She operated an open-door policy within her large science faculty to encourage open dialogue, and she was often seen supporting other teachers to gain a consistent approach across all classes. Erin said it was important for a faculty leader to work alongside teachers: “We sit down together. In fact, we meet once a week as a bio[logy] team and we talk about what we’re teaching, we talk about what are some of the pedagogy approaches.”

Erin described the importance of her Year 11 students completing an IBL activity with the theme “The local ecosystem”, which she and her team of teachers had developed. She and the participating teachers posed a broad inquiry question that they had previously developed: “How can we reduce the impact of a specific human practice on a biotic or abiotic factor in a specific ecosystem?” (Student information booklet, Currawong HS). She said this guidance would enable the students to develop their own questions for the investigation.

For observation in this study phase, Erin showed the digital blog that she had set up and provided samples of student resources and artefacts. The participating students (n=3) were observed interacting with Erin in her class. Her interactions with the additional consenting teachers with the pseudonyms Amanda, Brad, Christine, and Kate were also observed. At the end of the observation period, one student focus group was conducted via videoconference.

Erin and the other participating teachers at Currawong HS taught in the same classroom space and used the same science laboratory classroom configuration throughout each lesson. Students were required to collect data using their own equipment, and Erin and her teachers gave them examples of what they might like to use.

6.3 Teachers’ Planning Practices in IBL

Planning practices included planning the IBL program, its topic, and the necessary resources. This section addresses RQ2 by considering planning as a practice that supports classroom practice, and it analyses why the participating teachers developed their topics and their approaches to levels of guidance, as reported in Phase A (Sections 5.1.2 and 5.1.3). The three dominant features of the expert teachers’ planning practices were collaborative planning, teacher developed topics, and the development of student resources. Planning was also informed by the evaluation of teaching and learning, which was both reported and observed.

6.3.1 Monitoring and Evaluation of Student Work

Section 6.2 highlighted evaluation being reported by Megan and Robin as a key influence on the iteration of the Depth Study program during the years of the program. One practice that occurred throughout the observation period and informed the evaluation of the teaching program was the constant monitoring and evaluation of student work. Monitoring student work enabled teaching practices to be iterated in response to the students' needs during the Depth Study program (Elle, Robin, Erin).

Throughout the observation period, each of the expert teachers monitored her students by reading their written work, observing their practical work, and discussing their work generally. This enabled the teachers to adapt their approaches and choose suitable teaching strategies in response to her student's needs. The changing of the strategies was observed to often occur after the teachers discussed and evaluated their students after class (Erin, Elle, Robin). Evaluative discussions occurred as scheduled meetings (Elle, Robin) and informally in the staffroom (Erin, Amanda, Brad, Christine, Kate, Megan).

Topics of discussion that were observed included individual students (Erin, Robin, Elle), the process and timing of the Depth Study (Erin, Megan), and evaluations of equipment availability (Megan, Elle, Robin). Each discussion resulted in a variation of practice such as a change of teaching strategies, modified or expanded provision of laboratory equipment, or an extension of time for the Depth Study (reported by Erin and the participating students).

Evaluations of the broad program were reported prior to collaborative planning. Robin showed records of meeting notes as evidence of the iterations to the Depth Study program each year. The changes to the teaching program were reported to be responsive to the student and teacher evaluations of the program from the previous year.

The close monitoring of student work enabled each expert teacher to adapt her teaching as a responsive process. The evaluation of the program following the Depth Study informed future programming. While the monitoring and evaluative processes were observed to be informal, some formal monitoring checks of student work were also included (Megan, Erin) and reported within each inquiry phase (see Section 6.4).

6.3.2 Expert Teachers' Collaborative Planning Practices

The collaborative planning practices of the expert teachers were highlighted at each of the case study schools as being a regular part of teacher practice in guided IBL. Filippi and Agarwal (2017) proposed that the creation of teacher communities is a strong determiner of effective design of IBL programs, while also noting the difficulties that teachers can have when engaging in an external community. The expert teachers chose to form their own communities within their schools and to collaborate internally. They strongly evaluated the teaching program before the IBL (Erin, Megan, Robin) and made slight changes during it in response to circumstances (Elle, Robin, Megan, Erin). The education leaders in Phase A also reported collaborating within their own schools (Ali, Ann).

Elle and Robin (Cockatoo HS), Megan (Lorikeet HS), and Erin (Currawong HS) were key participants who provided evidence of planning meetings and the products of their planning that were developed at regular faculty meetings. Planning was reported to be collaborative and observed to be iterative at the case study schools. Each expert teacher planned collaboratively with other teachers in her school prior to the IBL in response to evaluations of previous IBL programs (Megan, Robin).

The expert teachers provided artefacts of their planning for analysis. These included scaffolded student materials, assessment information, marking rubrics, ways of sourcing information, and skill and conceptual information relevant to the IBL activity. Informal planning practices were also observed. Planning was reported to respond to the evaluation of previous Depth Study programs (Robin, Megan, Erin). The products of teacher planning were later used in the classroom, and this important practice was integral to providing a variation in the level of guidance that the teachers used along with their interactions with students.

All participants reported a collaborative planning process that had occurred before the observation period. The planning process was strongly emphasised at Currawong HS due to there being five Year 11 Biology classes. Erin explained that she and her teachers Amanda, Brad, Christine and Kate would meet: “We sit down together. In fact, we meet once a week as a bio[logy] team and we talk about what we’re teaching, we talk about what are some of the pedagogy approaches” During the period of observation, she and her teachers informally planned and iterated their teaching in brief discussions between classes and during their lunch break.

Megan at Lorikeet HSand Robin at Cockatoo HS explained that planning at each school was between two teachers of the Year 11 classes and had been less formally structured prior to the observation period. Iterative planning was observed during the IBL and between classes, with informal conversations that were reflective of their practice. Robin and Elle also had a debriefing meeting after the first practical lesson to make slight changes to the procedure and to discuss individual students. Evident at both case study schools was a flexible approach to planning that was responsive to the students. To a lesser extent, Megan also met with another teacher and was observed between classes discussing the Depth Study and two of their students. The products of their planning practices at the case study schools were evidenced by the written materials that they had produced for their students and by their reported practices, which will be discussed in a later section. These materials were observed to act as program planning documents for both the teachers and the students. The teachers regularly referred to them during the observation periods.

6.3.3 Teacher-Developed Topics

In Phase A of this study, as a part of teacher planning practices at the case study schools, the expert teachers described how broad topics were designed early in the planning process for the guided IBL activity and were emphasised by the participants. Erin’s and Megan’s use of topics and broad driving questions is also a feature of IBL approaches in the literature that support the development of students’ own research questions (Meulenbroeks et al., 2024). A list of teacher developed topics from both phases of this study are represented in Table 13.

In study Phase B, the expert teachers reported that they carefully selected broad topics at the start of the planning process to guide the IBL. These topics are discussed in the next section. The topics were carefully selected by the expert teachers, and they are shown in Table 14. These are discussed further by considering the teacher's rationale for their choice.

Table 14

Case School topics and Guiding Questions

School	Topic/broad driving question
Cockatoo High School Year 11 Chemistry	Field study topic: "In this Depth Study, students are encouraged to observe, study, and investigate the water sources (freshwater/seawater) …" (Student booklet Cockatoo High School)
Lorikeet High School Year 11 Biology	Enzyme Depth Study driving question: "How do cells coordinate activities within their internal environment and their external environment?" (Student booklet Lorikeet High School)
Currawong High School Year 11 Biology	Field Study driving question: "How can we reduce the impact of a specific human practice on a biotic or abiotic factor in a specific ecosystem?" (Student booklet Currawong High School)

Students at Cockatoo HS reported that the topics were supportive of them developing their own questions, and they agreed with one student's comment: "We've made inquiry questions before but it was given context so we didn't get lost and didn't have to think too hard on our inquiry question which was helpful." Additional benefits that justified the use of teacher-developed topics and guiding questions included engaging students in a topic that was interesting to them in their education context and that would enhance their learning. A summary of these justifications is shown in Table 15.

Table 15

The Expert Teacher's Justifications for Topic Selection

Expert teacher	Student engagement	Learning Enhancement
Elle	Relevant to the students	The topic supported a school curriculum direction that focused on the local environment. Laboratory skill development.
Robin	The local environment was relevant to the students	To build knowledge and understanding of stoichiometry from the jurisdiction curriculum.
Megan	Not discussed	Build knowledge of enzymes from the compulsory curriculum. Build on laboratory skills.
Erin	The local environment was relevant to the students	Build conceptual knowledge outside of the curriculum.

In her justification, Robin said that the local environment was of personal significance to the students: "I think that's what a lot of teachers miss sometimes from the Depth Studies, the importance of that [context]." As typified by the following comment, the student participants at Cockatoo HS confirmed their interest in the selected topic of the Depth Study:

> Well, we learned the different sections of the pond [related] to different sections of the water system, so the outer pond is more of like the ocean water where the pond goes to the ocean water ... I found that really fascinating. (Student, Cockatoo HS)

During both the observation period and her semi-structured interview, Erin spoke of her attempts to make the learning relevant for her students by using an engaging topic:

> [It's about] trying to find those problems that boys will question. Sometimes you have a problem, and the boys don't really relate to it, they don't really want to know the answer to it, so it's finding the right [topic]. (Erin).

The curriculum relevance of the selected topic was mentioned by all the expert teachers to be an important justification of topic selection. Megan related student engagement to the relevance of skill development, instead of developing an interest in an engaging theme, and emphasised knowledge of enzymes as being important. Robin also placed importance on the application of previously learned content and skills in Stoichiometry as a consideration for topic selection. At Lorikeet HS, the student focus group discussed skill and knowledge development as being important to topic selection:

> I now have a good understanding of all those topics, even though we just did a few of each like the pH, the concentration, and the temperature (Student, Lorikeet HS).

When asked what they had learned from the Depth Study, one student at Cockatoo HS described how the topic enabled him to think more broadly about the kinds of chemical tests that he could conduct:

> It was just interesting 'cause if you had that kind of knowledge that, oh they'll be using these kinds of chemicals on these plants, you could take your learning further and make sure you were considering all possibilities. (Student, Cockatoo HS).

For this group, the practical skills that they developed through the IBL topic were important to their learning.

In explaining how the curriculum was enhanced by IBL between Years 11 and 12, Elle said the teachers in her faculty had used the water sources context to promote students' critical and creative thinking across both Years 11 and 12 of the Chemistry course :

> They start the process in Year 11 and start by thinking "How do I test chloride ions? What are total dissolved solids? What is the importance of total dissolved solids?"… The process gets deeper and deeper [as they proceed] into Year 12. (Elle)

Both Robin and Elle saw a benefit to their students engaging in the same topic of IBL over a 2-year period to develop their laboratory skills in support of the curriculum outcomes.

The use of a broad driving question to introduce a topic was developed by Megan and Erin to support their students. Erin emphasised the importance placed on selecting topics and the care taken in developing them through collaborative planning. Her justification for the use of a driving question was "…requiring some kind of driving question to bring them to … that inquiry model. I find that's the hardest, to try to sit down together as a team and come up with some relevant problems." (Erin).

All the expert teachers developed a relevant topic, and two of the case-study schools developed carefully crafted guiding questions to support their students. The teachers justified their topic selection by highlighting student engagement (Robin, Erin) and curriculum relevance (Megan). Teacher-developed topics were a reported practice in Phase B of this study and included in Section 5.1.3 as being significant to all of the education leaders interviewed except Sasha, who required her students to develop their own topics. These supportive topics were also integrated into the expert teachers' instructional practice in Section 6.4. and highlighted as being foundational to the expert teachers' planning practices (Erin, Robin).

6.3.4 The Development and Implementation of Student Resources

This section reports on the planned written resources developed by the expert teachers prior to the IBL sessions that were observed in the classroom. This is an important theme because the use of the pre-planned resources was observed as part of classroom instructional practices. According to Meulenbroeks et al. (2023), written resources, including worksheets, can support students in IBL and increase intrinsic motivation without decreasing their autonomy if they are balanced with an appropriate level of guidance. The expert teachers described these resources as scaffolded materials (Megan, Robin, Elle), even though the written resources were later observed to support a variation of guidance levels. Scaffolded templates and marking rubrics were used at each of the case study schools, and they will now be described for context.

The development of written materials for students allows for a range of levels of guidance, including scaffolds. In Meulenbroek et al.'s (2024) a study of Years 11 and 12 students in the Netherlands, scaffolds in the form of worksheets and instructive videos were tested to support students in IBL work. The researchers found: "An IBL physics practical that is designed to support the students in an adequate, but not restrictive, way will support the basic psychological needs of students and, consequently, foster their IM [intrinsic motivation]" (p. 352). Scaffolds can replace some of the more difficult tasks to allow students to progress their work, and in the current study a range of templates were developed to provide scaffolded level of support.

Each of the expert teachers at the case schools was conscious of the balance between not providing enough support and providing too much using a guided IBL approach, and they opted to develop what they termed "scaffolded" materials to support their students. Their reasons for providing the printed and digital materials are exemplified by the following comments: "I think you've got to scaffold the task according to the students that you've got" (Robin), and "I think if you give them too much freedom, the kids could get lost. I think you really need to scaffold it" (Megan). Megan had tried an approach without the supportive materials and concluded that her students were better supported by scaffolded materials.

In Table 16, the second column shows the types of printed and digital materials provided to students at each case study school. They include written representations, audio files, maps, rubrics, tables, text, and images. The provision of student resources is an important part of IBL, and the advantages of multimodal meaning-making in science learning are well documented (Nielson & Yeo, 2020). They were part of the pedagogical practices of the teachers in this study. The teacher-developed representations were integrated into their classroom practices.

Table 16

Printed and Digital Materials Provided to Students at the Case Study Schools

School	Resource description	Observed purpose
Cockatoo High School	Printed Depth Studies booklet	Background information about the field studies site including maps, first nations connections with the environment, and assessment information
	Marking guidelines and report structure information including scaffolded templates	To support assessment requirements for the formal assessment and guide student work
	Digital scripted Chemistry investigations	Resources that supported exploration of laboratory skill development
	Digital information/library support	To support information searching and provide some links to suitable resources
Lorikeet High School	Printed Depth studies booklet	Assessment information which included extensive marking rubrics, deadlines, and submission dates that supported student work and work submissions. Topic and inquiry question were included.
	Digital Lesson intentions	Digital list of expectations for each lesson that guided student work
Currawong High School	Printed Depth Study booklet	Provide background information about the selected topic, a driving question, scaffolded templates for question development, and reflections. To provide dates for checkpoints of student work.
	Digital Poster template	A scaffolded template to indicate the structure of the poster presentation
	Digital and audio assessment information and marking guidelines	Written and audio communicated assessment information to outline the assessment requirements including a marking rubric.

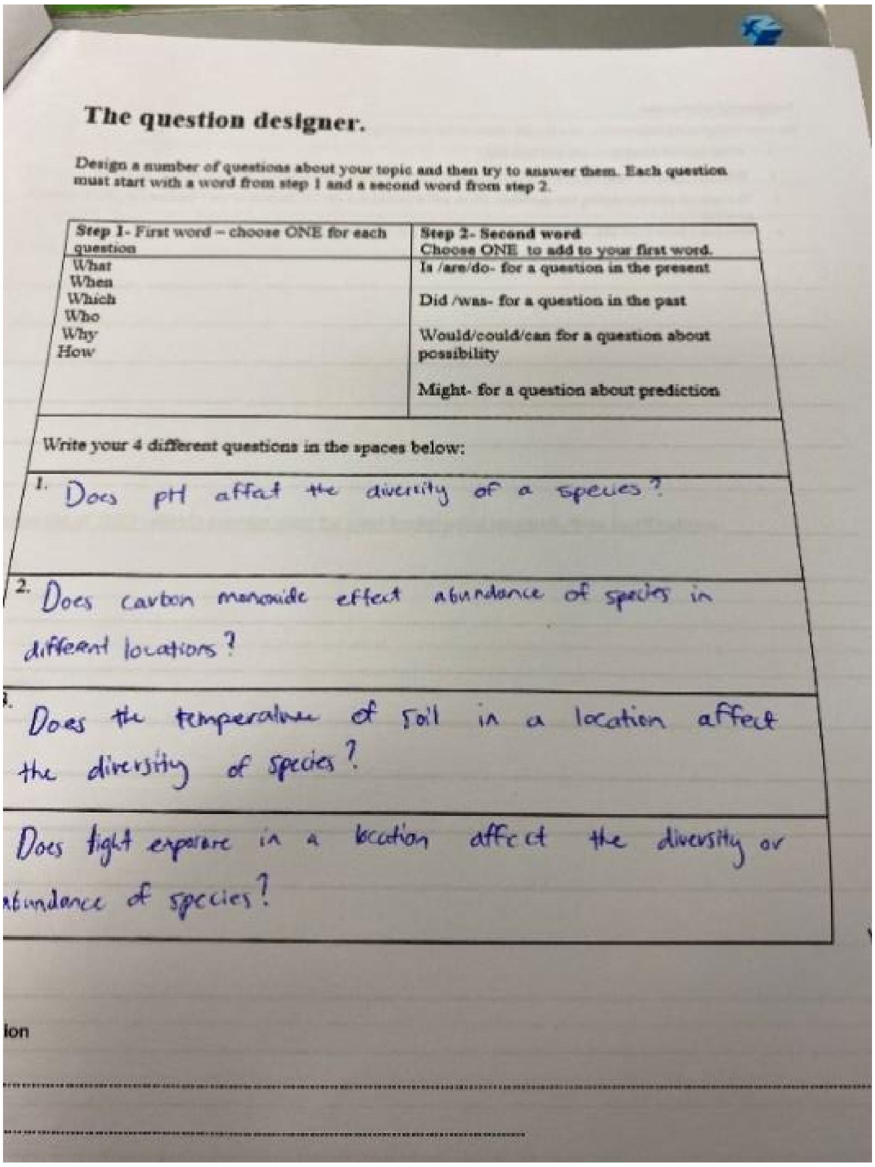
Students were provided with background information related to the study context that the expert teachers provided for their students. Students from Cockatoo HS generally appreciated the resources provided and information about the location: “Before the excursion we were given lots of resources to use to help us find our inquiry question and provide us with help, so we don’t just get lost on the excursion” (Student, Cockatoo HS) and “I think the main thing that helped was a lot of the online resources” (Student, Cockatoo HS). The purpose of these resources was to guide the learner without providing a sequence of structured activities. When integrated into the classroom, they allowed for a range of guidance levels.

During the observation period, a small number of students used the written resources, although their teachers used them to scaffold some of the more difficult tasks. An example of a scaffolded template is shown in Figure 12. This was used at Currawong HS as an optional template for a brainstorming activity that supported the development of an inquiry question. It was designed to remove barriers that might prevent students from performing some classroom activities by directing the structure of the developed question with guiding phrases.

The scaffold shown in Figure 12 supported students at Currawong HS in writing an inquiry question by offering a suggested format.

Figure 12

Inquiry Question Designer Template



The question designer.

Design a number of questions about your topic and then try to answer them. Each question must start with a word from step 1 and a second word from step 2.

Step 1- First word – choose ONE for each question	Step 2- Second word Choose ONE to add to your first word.
What When Which Who Why How	Is /are/do- for a question in the present Did /was- for a question in the past Would/could/can for a question about possibility Might- for a question about prediction

Write your 4 different questions in the spaces below:

1. Does pH affect the diversity of a species?

2. Does carbon monoxide effect abundance of species in different locations?

3. Does the temperature of soil in a location affect the diversity of species?

Does light exposure in a location affect the diversity or abundance of species?

Note: Student work sample Currawong High School

Only one student was observed to require the support of the template, the other students seemingly able to work independently. Even though the scaffolded materials were seen to be used in all classes while the teacher was interacting with the students, they were not highlighted by the students as being significant when they reflected on their teacher's practice.

Megan's justification for providing printed resources at Lorikeet HS, including a detailed marking rubric, was based on her first experience of open inquiry when she did not provide enough guidance to her students. Megan described how her school's open-inquiry approach in the first year of the Depth Study was reconsidered in the second year after the new curriculum requirements of the Depth Study were introduced. She described the first iteration as follows: "The first year [wasn't] as successful as I would have liked. I don't think we quite grasped the concept well and I think that we left them on their own". She considered that a guided approach was more successful because it included written scaffolds, verbal instruction, and lesson intentions.

Student perspectives related to the use of printed and digital resources to support their learning were mixed. Some students were observed to use the printed resource materials, while others did not. The students at Cockatoo HS unanimously agreed that during the initial inquiry phases of their Depth Study there were too few support the materials available to them. One of the students expressed initial frustration of the lack of direction through the support materials: "I had no idea" (Student focus Group 1, Cockatoo HS). Only one student mentioned the positive value of the printed resources made available to support their laboratory work: "Heaps of information to get like a preliminary start of what we were going to do, and I thought that was really helpful" (Student Focus Group a, Cockatoo HS).

The scientific practical report was the preferred form of assessment at Lorikeet HS and Cockatoo HS. At Cockatoo HS the practical report was assessed as evidence of learning, and at Lorikeet HS the practical report and a source research paper were assessed. Erin at Currawong HS had a much larger cohort of work submissions to mark and opted to assess a poster and an in-class test.

Observations of students at each case study school demonstrated that summative assessments promoted positive commitments to complete work that would be formally assessed. In an unstructured interview, Megan said, "They just don't do it if it is not assessed." For her students, the motivation of formal assessment positively influenced the quality of their work.

Among the assessment materials provided to the researcher for analysis, the marking rubric was the one most often referred to in the classroom by the expert teachers and their students. All four teachers used a standards-based rubric to formally assess products of learning, and they provided their students with written materials that included information about the Depth Study topic and its assessment guidelines. According to Chan and Ho (2019), the desirable features of marking rubrics include standardisation, objectiveness, guidelines for student work, and transparent evaluation of the marking process. With the exception of the evaluation process, which was outside the scope of this study, these features were observed to guide the students' work at all the case study schools. In particular, students were observed to refer often to the marking rubric for guidance. Sample sections of each of the marking rubrics are shown in Figure 13.

Figure 13

Marking Rubrics

Curra-wong High School Mark-ing Rubric

MARKING CRITERIA FOR POSTER COMPONENT TOTAL MARKS= 20

	1 mark	2 marks	3 marks	4 marks	5 marks
Summary of a chosen ecosystem and a human practice impacting it	Some relevant information is provided.	Student attempts to summarise an ecosystem of their choosing.	Student soundly summarises an ecosystem of their choosing and a human practice impacting it. Attempts to include data.	Student thoroughly summarises an ecosystem of their choosing and a human practice impacting it. Include data.	Student extensively summarises an ecosystem of their choosing and a human practice impacting it. Includes data.

Lorikeet High School Mark-ing Rubric

		concise (5-4)				
Develops and evaluates inquiry questions to identify a concept that can be investigated scientifically, involving primary and secondary data.	**Writing an aim and hypothesis** Experimental Report	Produces a suitable aim and measurable hypothesis that indicates the objective of the experiment **(4)**	States an aim and hypothesis that indicates the objective of the experiment **(3)**	States an aim or hypothesis that indicates the objective of the experiment **(2)**	States an aim or hypothesis **(1)**	Insuffi evider (0)

	Outcome Assessed	Marks Allocated (/40)	Section of Report *(as outlined on task notification)*	A Excellent
Cock-atoo High School Mar-king Rubric	CH11/12-1 - develops and evaluates questions and hypotheses for scientific investigation	5	**Inquiry Question** (2) • *Clearly states purpose of investigation* **Hypothesis** (3) • *Suitable prediction provided* • *Correct scientific reasoning for prediction*	Develops an appropriate and thorough aim that includes variables and can be tested. Hypothesis stated with predictions which are backed up by scientific research. 5

Note: Each sample is an excerpt from each of the marking rubrics.

Megan said the marking rubric provided her students with strong guidance, and she spoke at length about Lorikeet High School's use of marking rubrics as consistent across the school. In contrast, the student participants at Lorikeet HS did not highlight the rubric as a practice that was of ongoing benefit, one student saying, "I haven't looked at it [rubric] yet but at the end once I've finished, I'll probably go back and check, just see I've done everything" (Student, Lorikeet HS). Despite such comments, at each of the case study schools, all participating students were observed to regularly refer to the marking rubric for guidance during class.

6.4 IBL Instructional Phases

This section reports on the IBL instructional practices of the expert teachers and the ways they arranged their instruction. Each of the expert teachers in this study signalled the pre-planned and intentional IBL instructional inquiry phases by giving explicit lesson intentions at the start of each phase and by making a change in their classroom environment. They used the five distinct instructional phases highlighted as being a practice by Peta who was an education leader interviewed in Phase A of the study and explained that the teachers she observed had divided IBL instruction into "manageable chunks". The segmenting of IBL instruction has also been reported in the literature as having the advantage of reducing the student's cognitive burden (Martin et al., 2020) and anxiety (Kuhlthau, 1993). Ali and Ann also spoke of the distinctly different processes of instruction they used during their IBL, which suggested a change of instructional practices. The phases of instructional practice warranted further investigation in a natural setting during Phase B of this study.

This section also presents a finding that recognises the terminology of existing conceptual IBL models specific to science education that centre on the cognitive aspects of learning in IBL. The instructional phase names are adapted from two conceptual IBL models described by Bybee et al. (2006) and Pedaste et al. (2015) and based on common terms. These models and the terminology are used as a framework for analysing the instructional practices according to the activities the students were engaging in. The Bybee et al. (2006) 5E instructional model is a well-researched phased IBL model. In a recent meta-analysis of science process skills between 2010 and 2021, researchers examined 185 empirical studies where the 5E model was used to investigate science process skills (Zorluoglu et al., 2022). The Pedaste et al. (2015) phase model is also well referenced in the literature on the middle years of schooling, and it recognises the naming conventions used in the 5E model.

6.4.1 Inquiry Phases and Sequence of Instructional Practice in IBL

At each of the case schools in Phase B of this study, the expert teachers developed a sequence of manageable chunks of instruction for the guided IBL investigations that were observed. Five distinct instructional inquiry phases of IBL instructional practice were identified from these observations. As the students progressed within each instructional phase, they iterated by repeating and revising their work. Formulaic and step-by-step instruction is recognised as being a factor that might limit the inquiry process (Bevins & Price, 2015). By using instructional phases, the students could cycle through a range of activities within each phase using a supportive structure, which allowed for a balance of student independence.

The guided IBL activity at each of the participating case study schools in Phase B included 14 to 15 hours of allocated class time, with some expectation that the students would complete further work at home. The teachers addressed a curriculum requirement called the “Depth Study” (NESA, 2017 a,b,c,d) during the observed lessons. The inquiry phases of IBL shown in Table 18 are summarised according to the types of student activities observed. The names of each inquiry phase reflect the range of student activities observed to be occurring concurrently. This study focuses on the phases of instructional practice.

The expert teachers did not name the guided IBL phases they used in their instruction; the phases and their names have been developed by the researcher based on the lesson observations and adapted from the two well-cited frameworks mentioned earlier, the 5E BSCS 5E Instructional Model (Bybee et al, 2006) and the Inquiry-Based Learning Framework (Pedaste et al., 2015). These IBL conceptual models focus on the student activities that were completed during IBL, and they can assist teacher planning by providing a sequenced series of phases. IBL conceptual planning models have proven to be useful for teacher planning, yet they provide minimal detail about the role of the teacher in the classroom. The inquiry phase naming conventions from the two models have been adopted for use (Table 17).

Table 17

Observed IBL Instructional Phases at the Case Study Schools

Inquiry Phase Presented by the Teacher	Description of Student Activities During Guided Inquiry-Based Learning
Orientation (Pedaste et al, 2015)	Students are introduced to the theme of the Depth Study Expectations for the investigation are explained. Conceptual and procedural knowledge are introduced and revised.
Exploration (Bybee et al, 2006)	Skill development and semi-structured practical work is introduced and facilitated. Information sourcing and interpreting is introduced and revised. Conceptual knowledge is developed and extended.
Conceptualisation (Pedaste et al, 2015)	Inquiry question and hypothesis are developed. Investigation method is developed. Laboratory and fieldwork risk are assessed.
Investigation (Pedaste et al, 2015)	Students engage in their own practical investigation. Data is collected and processed.
Discussion (Pedaste et al, 2015)	Process and analyse data. Represent data. Communicate the IBL. Reflection.

It should be noted that a separate analysis phase, which is described in the Pedaste et al. (2015) model, is not included because students were observed to be analysing data during the Investigation and Discussion phases in this study.

Student activities were grouped in each of the inquiry phases. For example, in the investigation phase, students at Cockatoo HS and Lorikeet HS typically conducted their investigations and recorded and processed their data during the same observed instructional phase. Elle and Robin had grouped these activities together to allow some flexibility for their students. The suggested durations of these inquiry phases, as communicated by the teacher and identified through a change in classroom environment, are shown in Table 19.

The phase sequences between the case study schools were also influenced by external factors and school programming. For example, the positioning of the Exploration inquiry phase at Currawong HS prior to the start of the observed guided IBL activity was due to the timing of a scheduled field trip, which, according to Erin, could not be adjusted. This also meant that Erin had to opt for two Orientation lessons. The first introduced the theme and the second set the expectations for the student's investigations. Erin explained that she would not normally include two Orientation lessons.

Even though the inquiry phases were observed to be in linear sequence and clearly defined by lesson intentions, there was flexibility to allow students to iterate between inquiry phases or choose from activities within each phase. Iterations between phases included some students at Cockatoo HS completing the Exploration and Conceptualisation inquiry phases in the same lesson (Table 18). At Lorikeet HS, students were observed completing the Exploration and Conceptualisation phases during the same lesson (Table 18). After the students had started their investigations, they were not observed to return to previous inquiry phases and therefore a cyclic sequence of instructional phases was not observed in this study. Students also chose from activities within each phase, which was highlighted by the Discussion phase in which students at both Cockatoo HS and Lorikeet HS were observed to complete their data analyses and write their reports in the same lesson.

Table 18

Teaching and Learning Sequence at the Case Study Schools

<table>
<tr><th rowspan="2">Duration (hours)</th><th colspan="3">Sequence of IBL And Activities</th></tr>
<tr><th>Cockatoo High School</th><th>Lorikeet High School</th><th>Currawong High School</th></tr>
<tr><td>1</td><td>Orientation
Conceptualisation</td><td>Orientation</td><td>Orientation</td></tr>
<tr><td>2</td><td rowspan="4">Orientation (Field Study)</td><td rowspan="3">Orientation
Exploration</td><td rowspan="6">Orientation and Exploration (Field Study)</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td><td rowspan="2">Conceptualisation</td></tr>
<tr><td>6</td><td rowspan="3">Exploration
Conceptualisation</td></tr>
<tr><td>7</td><td rowspan="6">Investigation</td></tr>
<tr><td>8</td><td>Orientation</td></tr>
<tr><td>9</td><td rowspan="3">Investigation</td><td rowspan="2">Conceptualisation</td></tr>
<tr><td>10</td></tr>
<tr><td>11</td><td rowspan="2">Investigation</td></tr>
<tr><td>12</td><td>Investigation
Discussion</td></tr>
<tr><td>13</td><td rowspan="2">Discussion</td><td rowspan="3">Discussion</td><td rowspan="3">Discussion</td></tr>
<tr><td>14</td></tr>
<tr><td>15</td><td></td></tr>
</table>

Note: Hours indicated are those scheduled during class time. Students completed additional hours at home during the final discussion phase. Currawong High School students completed additional hours outside of class time collecting data during the investigation phase.

The timing of each instructional phase varied between the case study schools. Despite each school completing a similar total number of class hours (14 to 15 hours), Cockatoo HS opted to complete the activity over a more intensive period of one school week, compared to three school weeks at Lorikeet HS and two at Currawong HS. This difference in time allocation caused a hurried approach at Cockatoo HS and limited time available outside of class for further work. The slower pace at Lorikeet HS allowed its students to work outside of class between class sessions. Megan spoke to the whole class after her students had explored a range of pre-planned practical activities: “Now you have played, you’re going to design a method. Does everyone understand what they are doing over the weekend?” Her requirement indicates that she expected her students to work on their projects outside of class.

The observed students took time to transition between classes and to recall previously learned information. This was highlighted at Cockatoo HS between the transition from the Exploration to the Conceptualisation guided IBL phases, where the students appeared to be confused and hurried when they arrived at the laboratory after a half-day field excursion. This was communicated by a student participant: “I thought the challenge immediately after we got back to the lab and once we got to the pond, they were challenging just because I didn’t quite know what I was looking for both times” (Student, Cockatoo HS Focus Group a). The students took some time to become reorientated in the science laboratory. The sudden change in environment between locations made it difficult for them to adjust, although it also signalled the start of a new inquiry phase.

At Currawong HS and Lorikeet HS, the transitions between classes were visible and had been highlighted by lesson intentions at the start of the lesson to reorient the students. The Lorikeet HS students found the transition to independent learning difficult when they started to explore the Depth Study topic: “I feel like she threw us in, so I think it was just understanding it at the beginning was the hardest part” (Student, Lorikeet HS). Apart from the transition between the Orientation and the Exploration instructional phases previously discussed, there was no visible student frustration or commentary about difficulties of transitioning between classes and phases at either Currawong HS or Lorikeet HS.

The expert teachers did not intentionally use a known conceptual model to plan their guided IBL. During the semi-structured interviews of the science education leaders in Phase A, there were very few descriptions of an adopted process for each Depth Study, which is surprising considering the range of available models that support student learning. The flexibility of the sequence of inquiry phases evidenced in this study would have been recognised by Pedaste et al. (2015) as important for encouraging an iterative approach to IBL and for balancing student independence with guidance.

The next section presents the observations made of the expert teachers communicating their lesson intentions and changing their classroom environments to signal instructional inquiry phase changes. The inquiry phases that framed the range of pedagogical practices occurring within them are analysed in Section 6.5

6.4.2 Transitions Between Inquiry Phases

As a part of the expert teachers' practices, two signals were used to transition from one inquiry phase to another. Using the first signal, the teacher clearly articulated expectations for student work at the start of each lesson; and the second signal was an intentional change in the learning space arranged by the teacher. The teachers were observed to use strong guidance and explicit instruction during each transition. Explicit teaching practice is reported in the IBL literature (de Jong et al., 2023), followed by a reduction of guidance over the course of IBL (Dobber et al., 2017). This pattern of guidance was observed over the course of each lesson, however guidance was observed to be cyclic across a series of lessons.

The use of clear lesson intentions using explicit instruction is recognised as an effective teaching strategy in IBL (de Jong et al., 2023; Martin et al., 2021). During the observations, lesson intentions also represented a clear signal of a change in the inquiry phase. All the teachers in this study used lesson intentions to introduce each lesson as a verbal instruction, and they communicated clear signals of a change in the inquiry phase through this introductory communication. Lesson intentions prompted the students to set goals for the lesson and work within a defined time. They also suggested a clear program sequence to the observer.

Further to the verbal instructions provided by all the teachers, Megan reinforced her instruction at Lorikeet HS by displaying her lesson intentions, as formed from her weekly goals, on the electronic whiteboard at each lesson (see Table 20). The lesson intentions served to signal transitions between inquiry phases. The student participants appreciated the lesson intentions because they provided explicit guidance: "Well, I think that she kept us on track quite a lot like with the stuff on the board" (Student, Lorikeet HS).

Details of the identified lesson intentions communicated to the students during observation at each inquiry phase of the guided IBL are shown in Table 19.

Table 19

Lesson Intentions Communicated by the Expert Teachers

Guided Inquiry-Based Inquiry Phase	Elle and Robin – Cockatoo High School	Megan – Lorikeet High School	Erin – Currawong High School
Orientation	Session 1: Introduction to the guided IBL investigation by both teachers and a teacher librarian Session 2: On arrival at a field site teacher explained that students needed to "make observations" and "collect water samples"	Introduction to the guided IBL	A broad question was presented to the class to frame the guided IQ "How can we reduce the impact of a specific human practice on a biotic factor in a specific ecosystem" Discussion of assessment notification and expectations (expectations displayed on the electronic whiteboard)
Exploration	Elle introduced the range of equipment and methods that students should follow to practise their skills. "You will feel uncomfortable, leave that at the door".	Communicated lesson goals: "Must haves: 6 journal entries 2 experiments completely finished" "Amazing: Start research"	Unobserved: Student field excursion conducted by an external provider
Conceptualisation	Robin and Elle communicated that the students were to develop their Inquiry question and method.	Complete "Risk assessment, Aim, Hypothesis, Method, variables Complete the practical Amazing: Research nearly complete."	Communicated goal: "You need to start on your background information, and you need to start on your inquiry question today".
Investigation	Elle communicated that the students were to "start your investigation"	"Complete your investigation"	End of conceptualisation lessons. Teachers communicated that the students were to start their own investigation (conducted at home)

Guided Inquiry-Based Inquiry Phase	Elle and Robin – Cockatoo High School	Megan – Lorikeet High School	Erin – Currawong High School
Discussion	Elle and Robin communicated to the students that they had a further "two weeks to write the report for submission"	Teacher communicated that they would be completing their written work at home following the lesson and communicated the deadline.	Teacher communicated deadlines for written work which was to be completed at home

The lesson intentions at Cockatoo HS were brief and direct at the beginning of each lesson, and they encouraged students to begin their work quickly. Elle introduced the Investigation instructional phase by saying "Start your investigation" as students were moving into the classroom. This clear signal highlighted what the students needed to do and that there was a change of phase, as did the emergence of new laboratory equipment such as burettes and new chemicals stored in the fume cupboard. Robin followed up this direct instruction with brief instructions about the new chemicals and how to handle them safely in the fume cupboard.

The transition between the Exploration and Conceptualisation inquiry phases was pronounced at Currawong HS and Lorikeet HS. Erin, at Currawong HS developed some set activities to support her students to conceptualise their inquiry questions, and she introduced those at the start of the lesson as part of the inquiry phase. At the start of the Conceptualisation phase Erin introduced a scaffolded approach to illustrate a starting point for her students after saying, "You need to start on your inquiry question." At Lorikeet HS, Megan's lesson intentions at the start of conceptualisation included explicit instructions on the specific items that her students would need to complete, such as "aim, hypothesis", along with a reminder to include "variables".

The transition between the Investigation and Discussion inquiry phases was clearly communicated and supported by changes to the learning environment. The arrangements of the classroom spaces observed at each phase are presented and compared in Table 20. These provided an additional signal of a change in instructional phase.

Table 20

Learning Environments Arranged by the Expert Teachers

Guided Inquiry-Based Learning inquiry phase	Elle and Robin – Cockatoo High School	Megan – Lorikeet High School	Erin – Currawong High School
Orientation	School library location. Students are seated at desks.	As a lecture in the classroom with the teacher at the front of the room and students seated at desks	Students were seated and invited to sit closer to the teacher in the front of the room in rows.
Exploration	Outdoor field site	Students worked at laboratory benches with laboratory equipment and the teacher moved around the room	Outdoor field site (reported by Erin)
Conceptualisation	Session 1: School Library location Session 2: Laboratory location, seated in collaborative groups	Students seated at tables in groups	Students seated at tables in groups
Investigation	Students working at laboratory benches with laboratory equipment that they have chosen	Students working at laboratory benches with laboratory equipment that they have chosen	Students completed their investigations at home
Communication	Students seated in the classroom using laptops.	Students seated at their desk using laptops	Students completed their investigations at home. The teachers set up a communication blog to support the students.

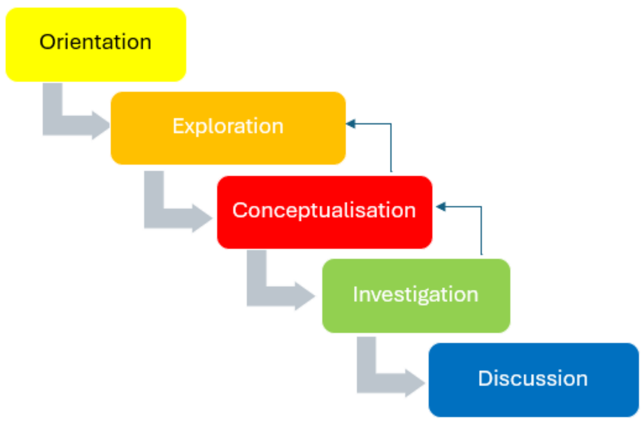
At all the case study school classes, lesson intentions were communicated to the students verbally at the start of each lesson and often followed by explicit instructions to reinforce conceptual understanding. For example, Robin reinforced laboratory safety instructions at the start of the Investigation phase and Erin showed her students how to use the scaffold for designing questions at the start of the Conceptualisation phase. A more detailed analysis of instruction within each phase is included in Section 6.5.

The visual and distinctive changes in each learning environment supported a range of student activities occurring simultaneously. Each expert teacher intentionally organised flexible seating or work areas, or a different environment such as an outdoor setting (Cockatoo HS, Currawong HS) or a library classroom (Cockatoo HS) to support the student activities occurring at each phase.

An unintended change in the learning environment occurred for the Currawong HS students and teachers at their final lesson of allocated class time. All schools in the jurisdiction were ordered into a public health lockdown due to COVID-19, and the students needed to stay at home. This is of interest because, according to the students, they felt that they were supported during this time by a range of digital platforms they could use to communicate to their classmates and teachers. The students in the focus group felt that this did not impact them: “Then having to adapt and we hopped on frequent [audiovisual] calls to be able to finish off the booklet or do the poster with that two-week extension” (Student, Currawong HS). The teachers also compensated the students during this transition of class location by allowing them additional time to complete their work and increased opportunities to interact with the teachers. At the time of the student focus group, the students were still working from home and willingly participating in the study focus group on a digital platform. The instructional phases are shown in Figure 14.

Figure 14

Instructional Inquiry Phases



Note: Naming of the inquiry phases references Pedaste et al. (2015) and Bybee et al. (2006)

The flexible sequence of chunked instructional practices presented in Figure 14 as phases allows instruction to be repeated and recycled; this is denoted by the faded arrows. Flexibility of phases is also supported by Pedaste et al. (2015) and represents a difference from the linear Bybee 5E model (Bybee, 2009; Bybee et al., 2006). In this study, Cockatoo HS students were observed to return to previous inquiry phases, which are indicated by thin arrows, resulting in some iteration of instructional practice between the instructional phases.

The transition between the instructional phases was highlighted by clear lesson intentions, which set the expectations for each lesson and the inquiry phase, with changes in the learning environment also providing a visual cue. The instructional practices, including the classroom strategies of the expert teachers within each phase, are analysed in the next section.

6.5 Expert Teachers' Instructional Practices

This substantial section draws together the instructional classroom practices of the expert teachers as a part of their overall pedagogical practice and analyses the teaching strategies they used within each instructional inquiry phase. The changing role of the teacher was raised as being an important element in IBL instruction during Phase A of the study, and some examples of good practice were suggested that warranted in-depth exploration during the Phase B. Section 6.4 introduced the observed instructional practices that were analysed within each interpreted discrete instructional inquiry phase, along with the interpreted integrated teaching strategies that were analysed within each instructional inquiry phase.

The previous sections established the supportive structures for classroom practices and the development of those that underpinned classroom instruction during collaborative teacher planning. These were very much a part of the reality of instructional practice. The products of the planning processes were analysed alongside the classroom strategies. Instructional practice was shown to be highly integrated with planning processes, as the expert teachers integrated their classroom practice with the multi-modal resources they were developing.

The emergence of a combination of social and personal constructivist perspectives is reported in the IBL literature (Bächtold, 2013). All expert teachers adopted a socio-constructivist perspective that recognised the role of the teacher in supporting their students toward increased self-regulation while the students were working in social groups. Elements of personal constructivism were also apparent in the discussion instructional phase at Cockatoo HS and Lorikeet HS, where students were working independently on their own written work without their teachers' support. The slight differences in the expert teachers' philosophies translated to slight differences in teaching strategies between the teachers and between the instructional phases. The differences between strategies were further influenced by the need to differentiate practice for different students.

The teaching strategies and guidance levels used by the expert teachers were analysed according to the theoretical typologies proposed by the authors of two significant meta-analyses: Dobber et al. (2017) and Lazonder and Harmsen (2016). The regulation practices by Dobber et al. (2017) and adapted from earlier work by Furtak et al. (2012) are valuable for identifying the regulation practices. Guidance levels as a significant instructional practice were analysed according to Lazonder and Harmsen's (2016) well-cited typology proposed, which offers a detailed explanation of IBL guidance levels. In the current study, guidance levels were observed to be purposeful, adaptive, and situated alongside regulation practices.

An integration of these important practices was significant in the development of the Guided Inquiry Science Teaching (GIST) framework, which is proposed in Chapter 7. In all their instructional practices, the expert teachers used a regulation practice to guide student self-regulation and a specific level of guidance appropriate for each student. The dominant teaching strategies used during each inquiry instructional phase are analysed in following sub-sections.

6.5.1 Regulation Practices and Guidance Levels

During Phase A, the education leaders spoke about the levels of guidance and gave examples of the strategies that they and other teachers had used in IBL. The purposes of the instructional practices were not always well articulated, which was of interest in Phase B, where the expert teachers were observed to use purposeful practices to support students to develop self-regulation. Dobber et al. (2017) described these as regulation practices that could be used as a typology to analyse instructional practice. Regulation practices include metacognitive regulation, where "teachers use metacognitive regulation to teach students how to think and act as scientists" (p. 204); conceptual regulation, where teachers convey information and classroom rules; and social regulation, where teachers guide the social process of learning. Regulation practices were introduced in Section 2.5.2 as a framework for analysis, and they are summarised in Table 21.

Table 21

Regulation Practice Typology

Regulation Practice	Teacher Regulation Practices (Dobber et al., 2017, p. 205)	Teacher Role Examples (Dobber et al., 2017)
Metacognitive	"Focus is on learning to act and think as a scientist".	The teacher encourages student questioning and discussion
Conceptual	"Focus is on subject specific knowledge and rules"	The teacher uses explicit teaching to draw on previously learned work and link it with new information
Social	"Focus is on guiding the social processes of learning"	The teacher supports groupwork.

This sub-section also recognises that teachers intentionally use specific levels of guidance. Lazonder and Harmsen's guidance level (2016) typology proposes six levels of guidance. Table 22 depicts these levels in the context of this study.

Table 22

Levels of Guidance in Inquiry Based Learning

Level of Guidance	*Definition*	*Examples*
Process constraints	IBL is divided into manageable parts and there is no overt instruction.	The use of the marking rubric enabled guidance of the written work (Cockatoo High School, Lorikeet High School, Currawong High School).
Status overviews	Summarises what the student has learned and provides feedback on how they perform.	Students were provided with feedback after Conceptualisation (Currawong High School, Lorikeet High School).
Prompts	Verbal and non-verbal signals that remind students of what they need to do.	Example: Teachers used nods to indicate that students were moving in the right direction. (Erin, Megan)
Heuristics	"Remind learners to perform an action and suggest how to perform that action." (Lazonder & Harmsen, 2016, p. 689).	Teachers made suggestions about the use of enzymes (Megan)
Scaffolds	"Explain or take over the more demanding parts of the action." (Lazonder & Harmsen, 2016 p. 689)	Elle took over the initial part of the titration to help a group of students to get started.
Explanations	Specifies how to perform an action by providing information.	Robin spoke directly to the students about chemical safety.

Note. Table based on Lazonder and Harmsen, (2016); de Jong and Lazonder, (2014)

The Lazonder and Harmsen (2016) typology provides an approach to guidance that enables a deep analysis of practice rather than assigning high and low levels of guidance to differentiate teaching strategies. The instructional practices and teaching strategies that the expert teachers chose were observed to include a purpose (regulation practice) and varying levels of guidance. These were used to analyse the teaching strategies that each teacher chose in their practice. Classroom practices were observed to be supported by evaluative practices and planning practices.

The teaching strategies that students found to be important to them in this study are represented in Table 23 and are analysed according to regulation practices and guidance levels. Student perceptions provided further insight into the range of practices that were both highly guided and minimally guided that supported them to regulate conceptual understanding, metacognitive development and social regulation.

Table 23

Important Teaching Strategies Identified by Student Participants

Teaching Strategy	Regulation Practice	Guidance Level
Explicit instruction to communicate lesson intentions (Cockatoo, Lorikeet, and Currawong High Schools)	Conceptual regulation	Explanation (highly guided)
Use of a digital blog to answer student questions (Currawong High School)	Social regulation	Explanations, prompts
Writing reflections and using logbooks (Lorikeet High School)	Metacognitive regulation	Process constraints and status overviews (low level guidance)

The expert teachers used the lesson intentions at the start of each lesson to articulate expectations for student group work. This strong level of guidance was interpreted as explanations, according to the Lazonder and Harmsen (2016) typology. The explicit instruction of the lesson intention was followed by the prompts typified by Robin and Megan, who were both seen to gesture to students to re-engage with their work during class.

The student participants in the focus groups (Cockatoo HS a and b, Lorikeet HS, Currawong HS) emphasised the strategies that the expert teachers used to manage social groups as being important to them. The students at Currawong HS particularly emphasised the value of "working with your mates". The students at Lorikeet HS saw value in working together and how the teacher supported them to develop both conceptual and social regulation practices:

> So, she helped us get the base understanding before we all started and then we helped each other get an understanding from what we took from each part of the experiment. (Student, Currawong HS)

To support social regulation, the students at Currawong HS used a blog that the teachers had set up for them. Erin explained, "When they ask a question, everyone can see the answer." The students were able to contribute to collaborative discussion, which the focus group students found supportive. For these students, the blog was set up during the discussion phase so that they could clarify their work submissions in their social groups.

Writing reflections for each lesson in a logbook was important to the students at Lorikeet HS. Student reflection is an important activity in IBL, and a recent metanalysis suggests that this metacognitive regulation practice enhances higher order thinking skills (Antonio & Prudente, 2024). The Lorikeet HS students were observed to be enthusiastic about completing their entries at the end of each lesson, with one participating student saying:

> I liked how at the end of each lesson you could write in your logbook just to summarise what we learned and just put everything together like helps formulate opinions and stuff and judgement. (Student, Lorikeet HS)

In addition to their own thinking, one student also pointed out that it was useful for the teacher to review their work during the IBL and provide feedback:

> I think she really helped with the logbooks 'cause at first, I was really confused about it and then her checking in like reading our logbooks, making sure we were on track really helped. (Student, Lorikeet HS)

This student focus group agreed that the logbook was a helpful addition, both for their own reflection and for the teacher to review and provide additional feedback. Writing in logbooks supported critical thinking and metacognitive regulation with a process constraint level of guidance. It also allowed for Megan to provide feedback and a status overview guidance to her students. The students at Currawong HS were observed to write notes in their resource booklets or digital files as informal reflections to inform their thinking.

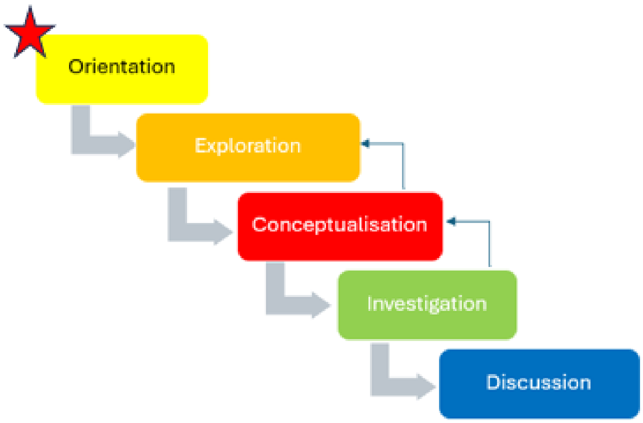
The tandem nature of the teaching strategies that the expert teachers chose were supported by the purpose of their instruction as both a regulation practice and a specific level of guidance appropriate to the needs of each student. The following sections describe the analysis of the teaching strategies according to the two typologies during each inquiry phase.

6.5.2 Expert Teacher Practices During the Orientation Inquiry Phase

The five instructional inquiry phases introduced in Section 6.3.1 are depicted in Figure 14. These are Orientation, Exploration, Conceptualisation, Investigation, and Discussion. This section analyses the instructional practices in the Orientation instructional inquiry phase that introduced the IBL program.

Figure 15

Instructional Inquiry Phase: Orientation



Each expert teacher in this study included Orientation lessons at the start of an IBL instruction sequence (Section 6.3.1) and favoured explanations using a strongly guided approach. The highly guided explanations in these lessons were designed to introduce the guided IBL activity and convey conceptual knowledge through the teachers' conceptual regulation practices. Supportive of including Orientation lessons in IBL, Tytler et al. (2021) recognised that students need to establish "what is worth noticing" (p. 32), and Pedaste et al. (2015) promoted Orientation as "the process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement" (p. 54). During this phase, explicit instructional practices, which supported conceptual regulation, dominated each teacher's instructional practice.

Table 24 summarises the dominant expert teacher practices during the Orientation Phase and analyses the practices under regulation practices and levels of guidance, which were described in Section 6.4.1.

Table 24

Integrated Practice During Depth Study Orientation Inquiry Phase

Expert teacher	Level of guidance	Regulation Practice/Purpose	Examples	Resources used
Elle	Explanations	Conceptual regulation: To convey information abou the field-site.	Elle explained that there was a "freshwater and saltwater site."	Printed information was being referred to.
Robin	Explanations	Conceptual regulation: Procedural instruction	Robin instructed students about how to collect water samples safely	Water bottles, extended handles to collect water.
Megan	Explanations	Conceptual regulation: To convey lesson intentions.	"There should be four entries in the journal at the end of the lesson."	Digital lesson intentions displayed on the electronic whiteboard.
Erin	Explanations	Conceptual regulation: To convey assessment intentions.	Erin briefly introduced the assessment requirements added an audio recording"…they can play it back if they need to".	Digital lesson intentions, assessment guidelines displayed on a whiteboard and pre-recorded audio information
		Conceptual regulation: To revise the concept. of a skill	Erin demonstrated a transect to her class and revised the concept of capture/recapture.	String and tape measure
Elle	Heuristics	Metacognitive regulation: Extend thinking: to promote critical thinking	"What would change in water quality [after] the recent rains?"	Referring to a map of the location.
Megan	Heuristics and prompts	Metacognitive and social regulation: To check student understanding and elicit a response from the student group	"What are you thinking?" "Has anyone picked the enzyme [that you'll be using]?"	Printed materials were referred to includin assessment guidelines, conceptual information
Erin	Heuristics and Prompts	Conceptual regulation: To revise and elicit student discussion	"Anything else?"	Verbal discussion in the classroom
		Metacognitive regulation: To revise invite and critical thinking Social regulation: To invite students to think togeth	"How could you make quadrats?" Perhaps straws, string, or rope."	Verbal discussion enhanced by displayed written information
Elle	Prompts	Conceptual and social regulation: Elicit further responses	"Anything else?" the student built on each others responses in their replies.	Verbal discussion in the field
Robin	Prompts	Conceptual regulation: To elicit pre-knowledge.	Verbal gestures by smiling and nodding.	Verbal discussion in the field

The following sections highlight the following two dominant instructional practices during the Orientation phase:

- Explicit instructional practices including procedural and conceptual instructional practices as conceptual regulation practice, and
- Reducing the level of guidance from highly guided to less guided instruction.

6.4.3.1 Explicit Instructional Practices that Orient the Learner

The introduction to the topic involved explicit instruction strategies. During this instructional phase, conceptual regulation practices included conveying information about the context of the study (Elle, Erin, Megan), setting expectations for the work that was to follow (Elle, Erin, Megan, Robin), and establishing rules and norms for practical work (Robin, Megan). This highly guided instructional practice is situated within the explanation level of guidance according to Lazonder and Harmsen's (2016) guidance typology.

The expert teachers supplemented their instruction using learning resources that had been pre-planned, such as booklets that included assessment advice, templates to support scaffolding, and a marking rubric. The intentional use of classroom space – by seating students in front of and facing the teacher – ensured that all students were engaged in and referring to these resources. These findings suggest that verbal interactions were integrated with both the pre-planned resources and the configuration of the classroom. This traditional classroom configuration was adopted by all the expert teachers. Erin utilised explanations at the start of the first lesson and asked her students to move their chairs to the front of the class, explaining that this was to ensure "you are all listening". Elle and Robin used the outdoor environment to illustrate the natural features of the water sources in their study using explanations. Elle supplemented her explanation by pointing out the locations and features of the water sources the students could see. At the same time, she spoke about the differences in salinity within the location by standing in front of the class.

Additional resources developed by the expert teachers before the IBL were also observed to be integrated into their pedagogical practice during this inquiry phase. In their classrooms, Megan and Erin used electronic visual displays to illustrate features of their chosen IBL theme. Their students were observed to look at the visual displays of information with the teacher positioned in front of the class during verbal discussion. The teachers' non-verbal communications, such as the use of a nod, smile or hand gestures, also indicated that discourse was not an isolated practice.

The use of lesson intentions typified the instructional practice during the Orientation phase. The intention was to present procedural knowledge such as assessment requirements and work expectations in a highly guided manner. When analysed according to the regulation and guidance level typologies, this use of lesson intentions presents as a conceptual regulation practice and an explanation level of guidance.

Megan used explicit instruction to communicate lesson intentions. Megan communicated the requirements of journal entries and modelled some examples of the type of information that students should include in them: "For example, this [chemical] concentration is better" She also told them of the purpose of the logbook entries as being a reflective process: "So that when you do all three experiments you know what you are doing". Her presentation did not rely solely on her verbal interactions and Megan also used gestures as she spoke, pointing to her visual display to gain the attention of her students.

Erin mentored four Biology teachers in her department who agreed to be a part of this study (Amanda, Brad, Christine, Kate), who also conveyed lesson intentions that were supported by visual and audio materials. Erin modelled and instructed her teachers to adopt a short explanation about assessment expectations during the second Orientation lesson as a conceptual regulation practice. In their classes these teachers were observed to adopt this routine of revising concepts during the first lesson and introducing the guided IBL during the second lesson. They also supplemented their explanations with digital information sources and printed booklets. The instructions for assessment were also communicated to the students using printed material displayed on a screen and an audio recording so that students "can play it back if they need to" (Erin). According to Erin, the audio file served three purposes: to "differentiate the instruction", to allow "students to hear the [explanation] again at a later time", and for consistency of instruction.

Positioning the topic of the Depth Study and communicating its importance was a reason that Elle and Robin used explicit instruction to present the topic outdoors in a field site. Pedaste et al. (2015) also emphasised the importance of establishing the importance of engaging and supporting students to develop their own investigations during introductory lessons.

Explicit instruction, which is recognised as an essential part of guided IBL approaches to convey essential information such as lesson intentions (de Jong et al., 2023), was the dominant practice of the expert teachers during this inquiry phase. It was supported by a range of resources and visual materials. The explicit instruction approach presents a counter argument for those who put IBL in opposition to it (Sweller, 2021). This reductionist debate is not supported by this study.

6.4.3.2 Reducing the Level of Guidance to Enhance Self-Regulation

The expert teachers were observed to use the dominant regulation practice of conceptual regulation, followed by short periods of metacognitive regulation. Through teacher to student questioning, they invited their students to revise and introduce new knowledge and skills, to think critically, and to generate potential ideas for their own IBL work. During these periods of instruction, the teachers reduced the levels of guidance and often used social regulation practices to support student group work.

The expert teachers tended to use heuristics and prompting by verbal questioning to implement guidance levels. Erin's practice typified this change in guidance levels, and she was careful not to stop her class's suggestions by asking, "How could measurements be made at a field study site?" as heuristic guidance, or "Is there anything else?" as a prompt to generate thinking. The class proposed ways that they could conduct fieldwork that might not involve expensive equipment, and Erin quickly responded with some just-in-time teaching using a highly guided demonstration of a line transect, which was followed up with class discussion. She posed questions to make them think. For example, she asked, “How could you make quadrats?” to which the students responded “straws, string, or rope”. This teaching sequence demonstrates how she could change her level of guidance to include heuristic guidance and metacognitive regulation to encourage students to think critically about the choices they might make for their projects.

Social regulation was promoted by all the expert teachers, who asked their students to collectively verbalise their thinking while they were working in their groups. They supported their students to collaborate, and this was often observed to be integrated with metacognitive regulation practices. Elle scaffolded one discussion by asking a group of students, “What important info[rmation] do we need to write on the container?” to remind them to label the container. One student responded, and then Elle asked, “Anything else?” before allowing six students to respond. She paused momentarily to allow further responses before moving to the next point, thereby encouraging the students to build on each other’s ideas. Erin was also observed using the same questioning technique during her Orientation lesson with her class.

Megan engaged in social regulation practices during her questioning strategy by asking her class, “What are you thinking?” Her questioning practice elicited a collective student response, and she invited some of them to share their thinking and build on their ideas in a social setting. Her level of guidance during the initial group meetings involved scaffolding, heuristics and prompts to ensure the students were heading in the right direction. She used non-verbal prompts such as facial expressions and raising her thumb to indicate her approval.

The social regulation practices of prompting and explicit instruction were identified by the student participants Cockatoo HS as important to them. Even though their teams were self-selected by the students, teachers were observed to quickly ensure that all students were included in a group during the Orientation lessons. Erin emphasised the advantages of students working in teams and raised this as an important feature of her guided IBL three times during her semi-structured and informal interviews. Erin and her team ensured that all students were working in a functional team: “One of the main things is making sure that they’re able to work in groups, that they can collaborate”. Students at Currawong HS also spoke positively: “It’s just beneficial, I feel ‘cause obviously, you get their ideas while having fun with your mates like enjoying the time” (Student, Currawong HS). In addition, her modelling of collaboration with other teachers was reported to be intentional.

A summary of the regulation practices and guidance levels used by the expert teachers during the Orientation phase is presented in Table 25.

Table 25

Orientation Regulation Practices and Guidance levels

Inquiry Phase	Regulation Practice	Level of Guidance (Dominant practice from most to least guidance)					
		explanations	scaffolds	heuristics	prompts	status overviews	process constraints
Orientation	Conceptual Regulation	x	x				
	Metacognitive Regulation			x	x		
	Social Regulation			x	x		

Three regulation practices – conceptual, metacognitive, and social – were evident in the Orientation phase. This phase was highly guided, the dominant practice being at the explanations level of guidance and typified as lesson intentions. To engage their students, the teachers established the relevance of the chosen topic and their expectations for student work by communicating lesson intentions.

6.5.3 Expert Teacher Practices During the Exploration Inquiry Phase

The Exploration inquiry phase (Figure 16) supported students to build knowledge and skills prior to conceptualising their own investigations through the completion of hands-on practical work. Practical work included laboratory, fieldwork, and using secondary sources.

Figure 16

Instructional Inquiry Phases: Exploration

Exploration is a distinct inquiry phase that is signalled by lesson intentions and a range of pre-planned student activities. Pedaste et al. (2015) recognised that exploratory activities prior to students conceptualising their own investigations can be of value, and they proposed an exploratory sub-phase in their inquiry model. This section analyses the how the expert teachers established work expectations, differentiated their guidance, and guided the social aspects of learning within the Exploration inquiry phase. The teaching strategies were analysed using Dobber et al.'s (2015) regulation practice typology and Lazonder and Harmsen's (2016) levels of guidance typology. The practices of expert teachers during the Exploration phase are presented in Table 26.

The following sections analyse the dominant themes of:

- Establishing practical work expectations as explicit lesson intentions
- Differentiating guidance to support the learning needs of different learners
- Guiding the social aspect of learning while students were working in groups.

While conceptual regulation practices were dominant, the expert teachers also adopted metacognitive and social regulation practices as a part of their teaching strategies using a range of guidance levels.

6.4.4.1 Establishing Practical Work Expectations

Practical work expectations were communicated through lessons intentions and communicated checkpoints of student work. Highly guided communication practices could be argued to be counterproductive to the constructivist philosophy of IBL (Bevins & Price, 2017) ; however, explicit instructional practices can be supportive of laboratory safety, and well-communicated information between the teacher and the student in IBL can support the building of knowledge and skills, provided these practices are balanced with regulation practices that support students to work independently (de Jong et al., 2022; Kulgemeyer & Geeland, 2023).

To commence the Exploration inquiry phase, clarify understanding, and set clear goals for student work, the teachers used a short lesson intention to signal a new work phase with a focus on conceptual regulation. The student participants at Cockatoo HS and Lorikeet HS said the communicated lesson intentions were useful during the initial phases of the guided IBL to provide guidance, including Orientation, Exploration and Conceptualisation. According to de Jong et al. (2023), direct instructional practices such as providing lesson intentions can promote a “readiness to learn” (p. 8), which was also the intention of each of the expert teachers. Instruction was situated within the highly guided level of explanation in the Lazonder and Harmsen’s (2016) guidance typology.

Table 26

Expert Teacher Practice During Depth Study Exploration Inquiry Phase

Expert teacher	Levels of guidance	Purpose of instruction	Examples	Resources used
Elle	Explanation	Conceptual regulation: Just-in-time teaching	Explanation of ocean acidification explanation in response to a student question.	White board to explain.
Elle	Explanation	Conceptual regulation: To convey lesson intentions	Elle outlined her expectations of student work for the session	White board used to highlight key points
Robin	Explanation	Conceptual regulation: To convey lesson intentions.	Robin outlined her expectations of student work for the session	A limited range of laboratory equipment and chemical reagents, digital and printed.
Megan	Explanation	Conceptual regulation: To convey lesson intentions	Megan displayed the lesson intentions on the whiteboard and spoke about these at the start of the lesson.	A limited range of laboratory equipment and chemical reagents, digital and printed resources to record information
Robin	Explanation, scaffolding	Conceptual regulation: To convey information about safety practices	Robin reminded her class of safe practices at the fume cupboard	Fume cupboard demonstration w silver nitrate
		Conceptual regulation: direct answers to questions relating to practical work	Robin gave her opinion when a student asked for advice	Verbal description
Erin	Scaffolding	Conceptual regulation	Figure 17	Copied template
Megan	Heuristics, and prompting.	Metacognitive and social regulation: to clarify ideas and invite students to reconsider their practice.	"Firstly, what is the best pH for catalase?" (Megan)	Discussion of the test tubes prior insertion of catalase
Elle	Heuristics and prompting	Metacognitive regulation: Clarify practice. Social regulation: To extend thinking collectively.	"Why are you using three different probes?" (Elle)	A limited range of laboratory equipment and chemical reagents, digital and printed.
Robin	Prompting	Social Regulation	Robin reminded students to engage with their group	Verbal description

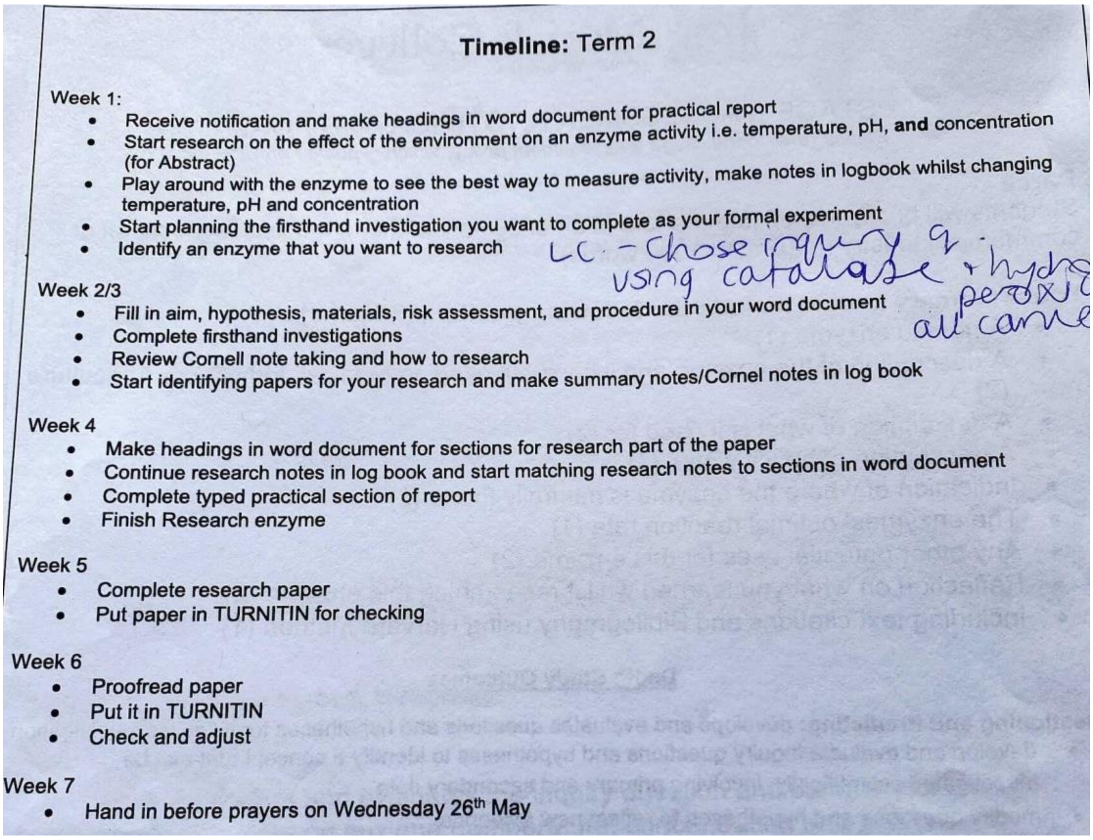
The use of explicit lesson intentions was demonstrated by Megan, who pre-planned and displayed each lesson’s intentions on the whiteboard as goals for student learning. She displayed two levels of intentions as “must haves” and “amazing” and explained the learning goals her students were expected to achieve. She expected them to complete the “must have” goals such as journal entries and the completion of a prescribed activity by the end of each week. In addition, two student groups were observed to consistently complete “amazing” lesson goals. The communicated goals were designed to keep all groups working at approximately the same pace throughout the Depth Study, the result being that all groups completed their investigations. At Cockatoo HS, Elle and Robin also gave verbal lesson intentions at the start of each lesson so set expectations for student work. Compared to the instructions at Lorikeet HS, theirs were less structured and provided general lesson goals.

Further to the observed lesson intentions, the expert teachers communicated a series of ongoing dates, referred to in this study as “checkpoints”, that were verbally communicated as a part of the lesson intentions. Megan also communicated these dates in writing. The checkpoints were deadlines for formative and summative assessments, and the first formative assessment checkpoint occurred during the Exploration phase. Checkpoints are analysed in this section within the conceptual regulation practices of teachers, since the evaluations of student work supported the construction of knowledge and the development of skills through teacher feedback. The levels of guidance used were the highly guided explanations to communicate the intention, followed by status overviews in evaluating student work and providing feedback.

Megan set each of the five checkpoints dates, which were communicated through the students' printed materials and verbal reminders (see Figure 17). These checkpoints were completed at the end of each of Weeks 1 to 5 in the schedule. They provided the students with explicit expectations of their work. The checkpoints in Weeks 1 to 4 were formative assessment, and in Weeks 5 to 7 there was a summative assessment submission that included a process for self-checking in Weeks 5 and 6.

Figure 17

Checkpoints and work expectations Lorikeet High School



Timeline: Term 2

Week 1:

- Receive notification and make headings in word document for practical report
- Start research on the effect of the environment on an enzyme activity i.e. temperature, pH, **and** concentration (for Abstract)
- Play around with the enzyme to see the best way to measure activity, make notes in logbook whilst changing temperature, pH and concentration
- Start planning the firsthand investigation you want to complete as your formal experiment
- Identify an enzyme that you want to research

LC - Chose inquiry q. using catalase + hydr
perox
all came

Week 2/3

- Fill in aim, hypothesis, materials, risk assessment, and procedure in your word document
- Complete firsthand investigations
- Review Cornell note taking and how to research
- Start identifying papers for your research and make summary notes/Cornel notes in log book

Week 4

- Make headings in word document for sections for research part of the paper
- Continue research notes in log book and start matching research notes to sections in word document
- Complete typed practical section of report
- Finish Research enzyme

Week 5

- Complete research paper
- Put paper in TURNITIN for checking

Week 6

- Proofread paper
- Put it in TURNITIN
- Check and adjust

Week 7

- Hand in before prayers on Wednesday 26th May

Source. Student participant resource Lorikeet High School

Megan displayed the expectations on the whiteboard at each lesson, which students were seen to check during their work. This enabled an opportunity for process constraint guidance.

Megan worked with each student as a conceptual regulation practice, and at the end of each week she provided feedback on their logbook entries and possible areas that they needed to explore using a status overview level of guidance. She also provided heuristic level guidance when responding to a student who was asking about the effect of temperature on enzymes; she encouraged the student to explore a new direction as a suggestion during the Exploration Phase: “You’ve got to play with temperature then.”

Elle, Robin, and Erin each provided a written schedule of work their students could refer to. Presented to the students prior to the excursion as a printed booklet, it supported them with process constraint guidance. The list of Cockatoo High School's work expectations is included as Figure 18.

Figure 18

Work Expectations Cockatoo High School

DEPTH STUDY SCHEDULE

Event	Activity	Aim	Teacher/Student Dated & Signed
Introduction	Students introduced to Depth Study. Librarian presentation on research skills. (One lesson prior to Excursion 1).	Background research on the RBG. Develop and evaluate research questions. Develop a hypothesis.	
Excursion	Walk to RBG and obtain samples of water from the Man O War Jetty and the Main Pond. (Tuesday 27th April, 2021)	Collection of samples	
Lab Session	Testing for TDS in SACS labs B101 and B102 Tuesday 27th April, 2021)	Apply research and methodology to investigate the TDS	
Post-lab	Working on the results in the following lesson.	Analysing results	
Lab Session	Testing for chloride ions in SACS labs	Apply research and methodology to investigate the chloride ion concentration	
Final Submission	Submitting task on Schoology through Turnitin. (Term 2, Week 9)		

At the conclusion of the Exploration phase, Erin required her students at Currawong HS to submit their field study reports on an advertised date, and she and her teachers provided written feedback as formative assessments to support metacognitive and conceptual regulation. Elle and Robin verbally told their students they would informally check the practical laboratory methods the students were using during the

Exploration phase, which they evaluated throughout the observation period as a status overview level of guidance.

Megan, Elle, and Robin also included high levels of guidance (explanation) to explicitly instruct and correct laboratory techniques such as the use of a pipette and a volumetric flask (Elle) and a water bath (Megan). This was considered necessary to manage the safe use of materials and prevent wastage. Often this guidance was in the form of demonstrating a technique or providing explicit instruction to groups of students when required. For each example, the teachers demonstrated the technique using just-in-time teaching, and the students were able to ask questions and to implement the technique.

In summary, each expert teacher used high levels of guidance to support conceptual regulation during this phase by communicating the checkpoints of work and instructing their students on the use of equipment. They reduced their levels of guidance to status overviews to give the students feedback at the end of this phase verbally (Elle, Erin, Megan, Robin) and in writing (Erin). The formative feedback supported the students to develop their own investigations during the Conceptualisation inquiry phase.

6.4.4.2 Differentiated Guidance

The expert teachers were required to differentiate their practice during this inquiry phase while their students were working, due to the needs of the learners. This section discusses the range of guidance levels and regulation practices that are reflected in their dominant teaching strategies of just-in-time teaching, responsive questioning and discussion practices, and the use of scaffolded practices. The guidance levels highlighted include explanation, heuristics and the scaffolding the teachers used to support student practical work. During this inquiry phase, they also employed teaching strategies that promoted social and conceptual regulation. The challenge to the teachers during this phase was the rapid changing between strategies to respond to student needs.

The expert teachers were mindful of choosing teaching strategies to differentiate the learning within their classes. Robin pointed out a tension of being able to balance differentiated guidance appropriate for the needs of different learners: “But you’ve then got those other kids that go: ‘Well it’s completely out of my depth’ and ‘I don’t understand where I am’ and so I think you’ve got to try and find that midpoint.” One of Robin’s students said that a greater level of explanation should be provided prior to IBL: “Something I learnt was you actually had to have an understanding of what’s going on before you actually start because I had no idea what was going on.” Like his teacher Robin, this student saw value in being provided with higher levels of guidance prior to engaging in practical work.

At Lorikeet HS, four students discussed the balance between providing the right amount of guidance and too little. One participant evaluated her teacher’s practice positively:

> I think she [Megan] also perfectly balanced giving us our own independence like she wasn’t overbearing and would come and instruct us directly, I think she let us work things out for ourselves but would also guide us in the correct direction when she thought it was getting too out of hand and would give us small tips along the way.

This inciteful statement reflects the balance between not being provided with sufficient instruction and being allowed independence. The contrasting comments of Robin’s and Megan’s students highlight their different needs and the importance of teachers adapting their practices.

All expert teachers used highly guided just-in-time teaching strategies to convey and reinforce expectations and messages relating to laboratory safety. This form of explicit instruction teaching was responsive to the students’ questions, and Elle, Robin and Megan were observed either revising or introducing new safety requirements with student groups. Robin gathered the whole class together to instruct students on the use of the fume cupboard after she had observed two students removing the silver nitrate from it. She used explicit conceptual regulation practices to enhance student knowledge of chemicals through explanations, and she was observed to scaffold student practice by assisting them while they dispensed chemicals in the fume cupboard when following up her instruction. This type of practice is necessary in IBL to ensure the safety of students who have little knowledge of safe laboratory practices and to support them in developing appropriate skills.

Just-in-time teaching was used to communicate new knowledge to students as a conceptual regulation practice. During her highly guided instruction, Elle discussed ocean acidification in response to a student question in a small group and used the whiteboard to write chemical equations. The students interacted by asking questions to construct meaning by clarifying and building on the communicated content. Elle also reiterated some of her explanations by writing chemical equations on the whiteboard. Explaining subject matter in this way is referred to in the literature as dialogic explaining (Kulgemeyer & Geeland, 2023). In Elle's example, she offered the initial explanation, her students provided feedback, and she followed up by adapting her explanation.

The heuristic guidance level became more pronounced as the teachers started to reduce the level of strong guidance using questioning strategies. Heuristic guidance provided direction through hints or subtle directions without removing any of the more difficult work (Herranen & Aksela, 2019). It was typified by questioning strategies to enhance all three regulation practices. Elle's approach illustrated this: "Why are you using three different probes?" By directing her question to something that her students had overlooked, they were able to reconsider their approach using her directed guidance. She also followed up by suggesting which probe might be the most useful by providing a scaffold to remove some of the decision making. This promoted time efficiency and improved the accuracy for the students' laboratory investigations.

The teachers provided scaffolding through written materials in combination with teacher–student discussions for students who required significant guidance (Figure 19). Erin was observed referring also to the hand-written materials when explaining the more difficult task of sourcing reliable information.

Figure 19

Scaffolded Template Currawong High School

Background information:

For your background information, you should research the following items:

- What type of ecosystem are you studying?
- Previous research relating to the question being addressed. (at least TWO referenced reliable sources).
- The reason you are testing the question. (How will it add to our understanding of your location/ topic / science in general)
- Why you chose your site, include map and photo of you conducting your research.

In this example, Erin's students were required to carry out a literature search and write a background to their study. This template replaced the need for some students to plan what they would research by guiding their literature search with specific questions. All student groups were observed to do this in discussion with their teachers.

The practices of teachers were not solely limited to verbal interactions. To enhance their instructional practices, they integrated other resources into their instruction that they had developed prior to the sequence of lessons. These included laboratory equipment, whiteboard displays, and printed materials. The importance of providing targeted written information has been highlighted in recent research on IBL in the Physics classroom to enhance instructional practices (Meulenbroeks et al., 2023). Although not observed, these resources supported the students to work independently and allowed for process constraints to be used as a low level of support.

6.4.4.3 Guiding the Social Aspects of Learning

Through social regulation the expert teachers supported practical group work and collaborative discussion and prompted their students to re-engage in their work. Having students work together in groups aligns with socio-constructivist theories and the collaborative nature of a scientists' work (Furtak, 2005). Each student focus group highlighted that working in a group benefitted their learning. The teachers restricted group numbers to four students and allowed self-selection of groups. While the explanation level of guidance was often used, the social aspects of learning were supported by low levels of guidance, including heuristics and prompting. The teachers provided heuristic guidance through tips or hints to enhance collaboration, and they used prompting to re-engage some students with their work.

All students (n=9) in the two focus groups at Cockatoo HS spoke favourably about the dynamics of group work, agreeing that it was beneficial. One student found that teamwork enhanced the process of completing the Depth Study: “[I] think the collaborative aspect was good because it made it more enjoyable, but it was also more practical, really, it helped you divide and conquer the work.” Elle and Robin managed social regulation as the need arose. One of Erin’s students said: “I enjoyed the collaborative aspect like you got to learn with other people… [and] working with your mates.” Erin was observed enhancing social regulation through her informal interactions with groups of students and by requiring each student to be accountable for their contributions to their team.

Erin highlighted the importance of managing student groups: “We really have to make sure that even in the processes of designing a task that we have to make sure that there’s a collaborative approach and that means making sure that everybody has to provide something.” She pointed out that the design of the Depth Study needed to be conducive to student work. In her practice she ensured through her verbal interactions that each group member had a role to play in their group.

The expert teachers often used a combination of teaching strategies to simultaneously support both social regulation and conceptual regulation. For example, Megan and Elle combined social regulation and conceptual regulation practices in their discussions with students. Megan was observed to ask the whole group questions about their laboratory practices such as, “Firstly, what is the best pH for catalase?” and then invite each group member to speak. This ignited a group discussion, which she fostered through her heuristic level of guidance. Elle also posed questions directed at the whole student group such as, “Why are you using three different probes?” Her question ignited collective discussion, with the students collaborating to provide a possible solution with her support.

Prompting by Robin was observed when she needed to use social regulation strategies with a high level of guidance to directly intervene with a student group to redirect some of them to re-engage. She gave the students directed prompts and gestures to encourage them to work collaboratively. Follow-up gestures reinforced the original prompts and reminded the students to return to work.

The expert teachers informally evaluated the effectiveness of their own social regulation practices. At Cockatoo HS, Elle and Robin were observed after class having a debriefing meeting to recalibrate the amount of guidance they were proving to their student groups. They discussed individual students, suggested supportive strategies, and decided on types of explicit instruction to guide their student groups. At their schools, Erin and Megan also discussed student groups with other teachers in the staffroom to adjust their instructional approaches and enhance group collaboration.

A summary of the regulation practices and guidance levels used by the expert teachers during the Exploration phase is presented in Table 27. Compared to the Orientation phase, the expert teachers used a greater range of guidance levels, accompanied by all three regulation practices, in their selected teaching strategies.

Table 27

Exploration Regulation Practices and Guidance levels

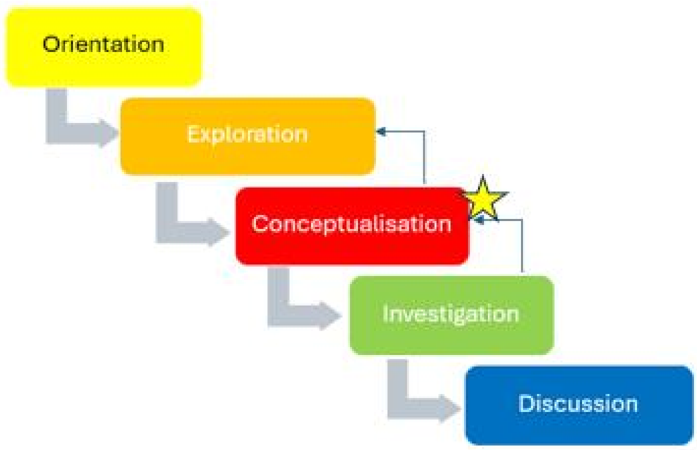
Inquiry Phase	Regulation practice	Level of guidance (Dominant practice from most to least guidance)					
		Explanations	scaffolds	heuristics	prompts	status overviews	process constraints
Exploration	Conceptual regulation	x	x				
	Metacognitive regulation			x	x		
	Social Regulation	x		x	x		

6.5.4 Expert Teachers' Practices During the Conceptualisation Inquiry Phase

The Conceptualisation inquiry phase (Figure 20) supported student inquiry question formulation, development of hypotheses, and practical method development.

Figure 20

Instructional Inquiry Phases: Conceptualisation



This section is significant because it focuses on the dominant practices that guided student inquiry question development, the development of investigation methods, and formative assessment practices. It sheds light onto the difficulties that some teachers have in supporting student inquiry question development and the conceptualisation of the investigation method that was reported in Phase A and in the literature (Gholam, 2019; Herranen & Aksela, 2019). During this Conceptualisation inquiry phase, the expert teachers implemented all three regulation practices: conceptual, metacognitive, and social regulation. The metacognitive and social regulation practices were emphasised and often intertwined. Guidance levels utilised by the expert teachers included explanations, scaffolding, heuristics, prompting, and status overviews that would support a differentiated classroom.

The expert teachers continued introducing this inquiry phase with highly guided lesson intentions, as analysed in Section 6.4.4. The dominant strategies they adopted included scaffolded instruction, explicit safety instructions, and questioning practices, which were analysed according to the regulation practice typology (Dobber et al.,

2017) and the guidance level typology (Lazonder & Harmsen, 2015) adopted in this study. These are shown in Table 28.

The following sections analyse three dominant themes:

- Guiding student question development
- Guiding student development of investigation methods
- Formative assessment approaches

The conceptualisation phase represents the broadest range of guidance levels and regulation practices, thus highlighting the complexities of teacher practice.

Table 28

Integrated Practice During Depth Study Conceptualisation Inquiry Phase

Expert teacher	Level of Guidance	Regulation practice/Purpose	Examples	Resources used
Erin	Explanation	Conceptual regulation: to ensure safe investigation practices when working in the field outside of the classroom and to provide lesson intentions.	"A responsible adult must be factored in" (Erin). Erin Discussed safety in working outside of the classroom in her introductory discussion.	Verbal instruction
Megan	Explanation	Conceptual regulation: To communicate lesson intentions	Figure 18. Printed weekly work goals that were communicated verbally at the start of the lesson	Whiteboard, student materials
Elle/Robin	Explanation	Conceptual and social regulation	Lesson intentions: Observed verbal instruction at the start of the lesson to communicate expectations and provide laboratory safety information	Verbal instruction
Erin (Brad, Christine, Kate and Amanda)	Scaffolding to develop inquiry questions.	Metacognitive regulation: Require students to think about their inquiry questions and hypotheses	A scaffolded template was used for a brainstorming. exercise to develop possible inquiry questions (Erin, Amanda, Brad, Christine, Kate) (Figure 17)	Printed materials and mini-whiteboards were used by the students.
Megan	Scaffolding	Social and metacognitive regulation: to guide students in an appropriate direction	Megan developed a broad inquiry question to support her students to write a hypothesis for their practical investigation. "How do cells coordinate activities within their internal environment and the external environment?"	Printed and digital communication in student booklets
Erin	Heuristics	Social regulation and status overviews: to establish student work groups.	Verbal feedback on investigation plans and group member roles (Erin, Kate)	Teachers moved to the student groups for the discussion
Kate (under Erin's guidance)	Heuristics	Metacognitive regulation	"What do you mean by nutrients in the water?" (Kate)	

Expert teacher	Level of Guidance	Regulation practice/Purpose	Examples	Resources used
Megan	Heuristics	Conceptual regulation and metacognitive regulation: Inviting student to recall and/or think.	“What is the pH of the enzyme?” (Megan)	Digital measuring equipment and internet sources
Elle	Heuristics	Metacognitive regulation: to support students to think about their own investigation.	“What kind of observations would you collect? Odour, taste, flora, fauna, colour, algae, rubbish, solids, weather?” (Elle)	Verbal discussion.
Robin	Heuristics	Metacognitive regulation: to support students to think about their own investigation.	In response to student discussion about water quality: “What would change in water quality due to the recent rains?” (Robin)	Verbal discussion
Megan	Prompts/ Heuristics	Metacognitive regulation: to invite students to think and reconsider.	“Think about the way you are going to measure the gas” (Megan) Megan gestured by nodding once the students started to discuss some possibilities.	Reference to the chemical apparatus
Megan	Prompt	Conceptual regulation	"What are you doing?"	Verbal discussion
Robin	Prompts	Social Regulation	Robin smiled and nodded at a student group that had organised group roles.	
Erin	Prompt	Conceptual regulation	“What are you going to measure?”	Verbal discussion
Megan	Status overviews	Metacognitive regulation: to support students to think about their own investigation.	Megan checked each students’ work at the end of this inquiry phase as a checkpoint and provided feedback for the students to consider. “That’s a good reflection with graphs and tables included”. Put units in the heading of your table”.	Printed materials including assessment requirements and marking rubric
Robin	Status overviews	Metacognitive regulation	Informal feedback of methods and inquiry questions.	Verbal discussion
Erin	Status overviews	Metacognitive regulation	Informal feedback of methods and inquiry questions.	Verbal discussion

Note. Erin mentored Brad, Christine, and Kate who were observed working with Erin at Cockatoo High School and were using the same resources and classroom arrangement. Elle and Robin were team teaching in the same classroom during this inquiry phase.

6.4.5.1 Guiding Student Inquiry Question Development

The Conceptualisation inquiry phase is significant because science education leaders Greta and Tom identified it in Phase A of this study as being difficult for teachers to manage. Developing investigable questions is also identified in the literature as challenging for teachers (Gholam, 2019; Herranen & Aksela, 2019). To support their students in developing inquiry questions, the expert teachers used metacognitive regulation practices and the guidance levels of scaffolding and heuristics. This section highlights scaffolded instruction as a strategy to support question development, including pre-developed templates and the use of broad guiding questions. Herranen and Aksela (2019) emphasised the complex nature of teachers supporting student question formation, which is analysed within this inquiry phase.

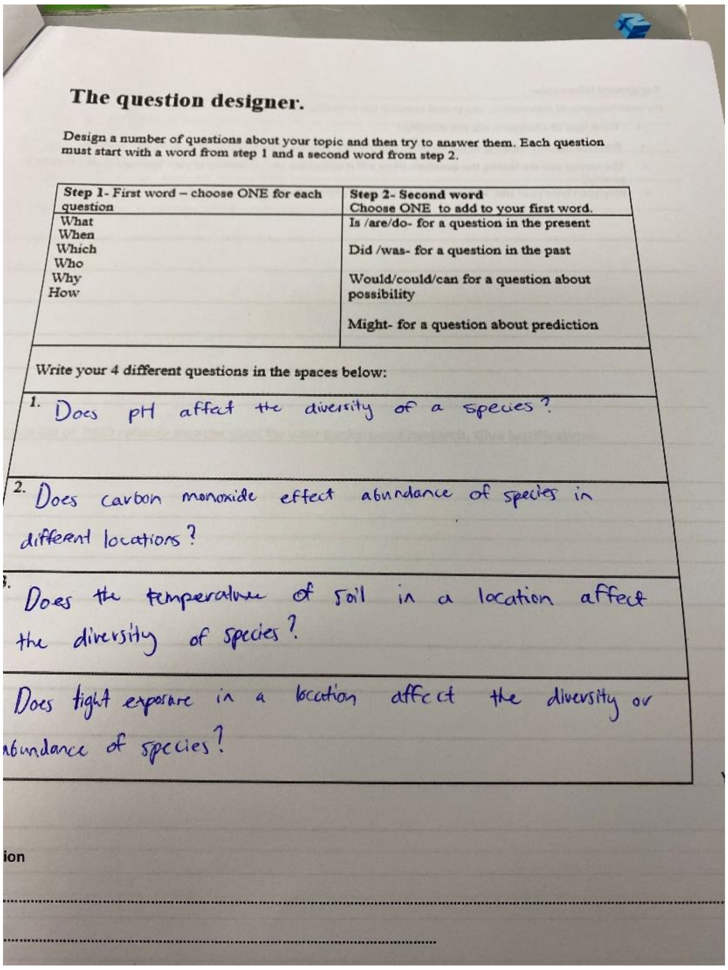
Scaffolding represented the highest level of guidance to support student question formation, although it was used sparingly by all the expert teachers. At Currawong HS, Erin scaffolded the development of the inquiry question with a brainstorming activity, and she supported her practice using a written template as a hard scaffold resource, which she made available to all her students (Figure 21). The template provided a sentence structure for the inquiry question that enabled the removal of barriers for some students. A scaffolded template was also available in the student booklet at Cockatoo HS. When the scaffolds were used, they were accompanied by soft scaffolds as discussion practices.

All of the expert teachers encouraged their students to pose simple inquiry questions by changing one variable. As shown in Figure 21 the student participant at Currawong HS used the scaffold to develop an inquiry question that altered one variable, such as a change in pH or light exposure on species diversity and abundance.

The expert teachers also used a hard scaffold in conjunction with a soft scaffold by using discussion as a strategy to support their students. Scaffolding in IBL can limit a student's epistemic agency and self-regulated practices if overused (Barrie et al., 2019; Bevins et al., 2015). When used by the expert teachers, however, it fostered independence by removing barriers to learning (Alrawili et al., 2020; Barrie et al., 2019). Scaffolded guidance enabled some student groups to progress with greater independence.

Figure 21

The Question Designer Template, Currawong High School



The question designer.

Design a number of questions about your topic and then try to answer them. Each question must start with a word from step 1 and a second word from step 2.

Step 1- First word – choose ONE for each question	Step 2- Second word Choose ONE to add to your first word.
What When Which Who Why How	Is /are/do- for a question in the present Did /was- for a question in the past Would/could/can for a question about possibility Might- for a question about prediction

Write your 4 different questions in the spaces below:

1. Does pH affect the diversity of a species?
2. Does carbon monoxide effect abundance of species in different locations?
3. Does the temperature of soil in a location affect the diversity of species?

Does light exposure in a location affect the diversity or abundance of species?

ion

Megan at Lorikeet HS and Erin at Currawong HS formulated broad guiding questions to scaffold student questioning. Using driving questions is a known strategy that models inquiry questioning and provides a broad direction for the students' questions (Herranen & Aksela, 2019). Megan justified her scaffolded approach, saying that in previous attempts where students posed their inquiry question for a laboratory investigation, "they were lost". She said that for her Year 11 class, a driving question would be more manageable, and the students would achieve better outcomes if she developed a teacher-led driving question as a model to initiate the Depth Study. She gave the students a follow-up task of developing their inquiry question for the source research component activity completed in tandem with the practical work. When asked about her approach, Megan justified it: “The inquiry comes during the [practical] lesson with students asking questions to formulate their ideas.” This was evidenced by her students asking numerous questions, supported by lower teacher guidance.

Heuristic guidance was often used along with questioning strategies to redirect students by providing hints or tips during metacognitive regulation practice. This practice was observed when the teachers supported their students in their investigation methods. During this Conceptualisation inquiry phase, students were often seen to reconsider their inquiry questions following the heuristic questioning practices used by their teachers.

The expert teachers used questioning practices to prompt their students while they were considering their inquiry questions. The student participants at Currawong HS were developing a broad inquiry question that involved variations in water quality due to recent rainfall. In response to a student discussion about water quality after rainfall, Robin asked, “What would change in water quality due to the recent rains?” This question prompted the student group to focus on developing an inquiry question about a particular aspect of water quality that could be investigated.

6.4.5.2 Guiding Students’ Development of Investigation Methods

A strong theme was teacher questioning practices as a strategy that guided metacognitive regulation and the development of students’ investigation methods. According to the literature, using a range of levels of questioning is appropriate in the IBL classroom, and teachers should aim to mostly use "high press questions", which have low levels of guidance and require students to think critically without removing any barriers (McNew-Birren & van den Kieboom, 2017, p. 86). While less-guided questioning is ideal, the expert teachers in this study incorporated some highly guided strategies in their differentiated instruction, and this range is reflected in Table 31.

The range of guidance levels, including explanation, scaffolds, heuristics, prompts, and status overviews, reflected a differentiated guidance level while the students developed their investigation methods. Often, the students would return to redeveloping their inquiry questions and hypotheses in response to the metacognitive regulation strategies that their teachers were using. Questioning was a dominant strategy implemented by the expert teachers that is further analysed in this section. The safety of students in conducting their planned investigations was also important, and this was included as a conceptual regulation practice during this phase.

Conceptual regulation practices were used in this phase to communicate work expectations, including safety procedures, while the students were completing practical scientific work. In a study by van Rens et al. (2010), laboratory equipment and safety were the prime considerations of senior Chemistry teachers enacting IBL. These were also a focus of the expert teachers’ management practices in the classroom. They responded to laboratory safety as the need arose using highly guided, explicit instructional practices. A student participant at Currawong HS asked if he could use his boat to collect data, and Erin answered directly: "A responsible adult must be factored in." The student was then guided on how to obtain permission for his group to collect water samples outside of class. Megan and Robin were also observed pointing out to their students the safety aspects of using chemicals in a fume cupboard. In each example, the students included safety measures in their planning after their teacher's guidance.

The questioning practices of the expert teachers reflected a range of guidance levels dominated by heuristic guidance and prompts to invite metacognitive regulation. According to Correira and Harrison (2020), “Asking questions that probe thinking, encourages articulation of ideas and promotes meaning making of an idea within a broader knowledge network, and creates opportunities for the student to reflect on where they are in their learning” (p. 220). Erdogan and Campbell (2008) identified a high frequency of teacher questions in classrooms where the teacher adopted a constructivist approach, which is also reflected in this study.

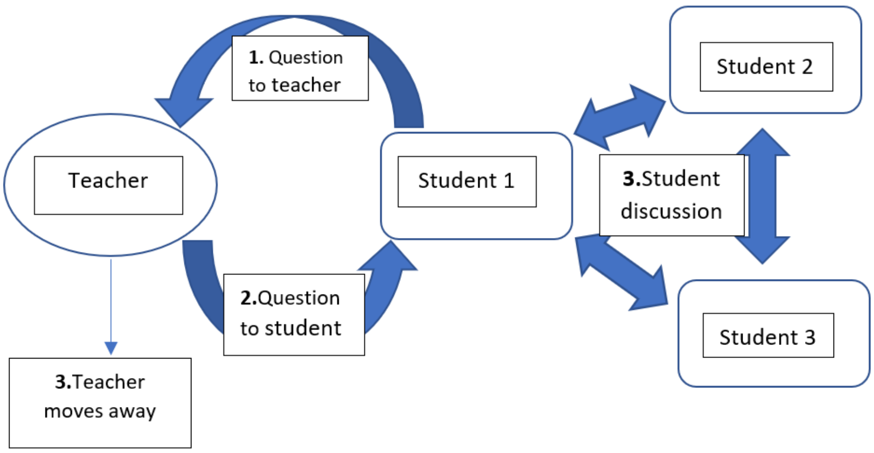
Heuristic guidance was typical of the questioning practices of all participating teachers. Guidance involved directing their students’ attention to an alternative idea or suggesting something previously not discussed by the student groups. Kate, one of the teachers working with Erin, typified this by redirecting student conversation while her students were thinking about their inquiry question; she asked, “What do you mean by nutrients in the water?” This redirected the students to select one nutrient they could investigate, instead of an unmanageable range of nutrients, and to adapt their inquiry question. Erin’s students at Currawong HS noted the heuristic questioning technique as being helpful to them:

> I think at the start we presented our ideas, … we got into our groups and presented our ideas and [the expert teacher] gave us advice … she asked how it would work and what we would do for it. Rather than just saying oh yeah, that’s a good idea, she’d ask: Oh, how are you going to measure this?

Erin’s practice invited metacognition, which the students recognised as a positive practice. It gave them a sense of pride in being able to think critically and work independently. Figure 22 illustrates the process that Megan used to respond to her students’ questions and invite metacognitive regulation and social regulation. Her questions involved heuristics in that she asked a directed question in response to a student question, which enabled her students to turn their attention to an alternate approach by providing them with a hint.

Figure 22

Teacher Response to Student Group Questions



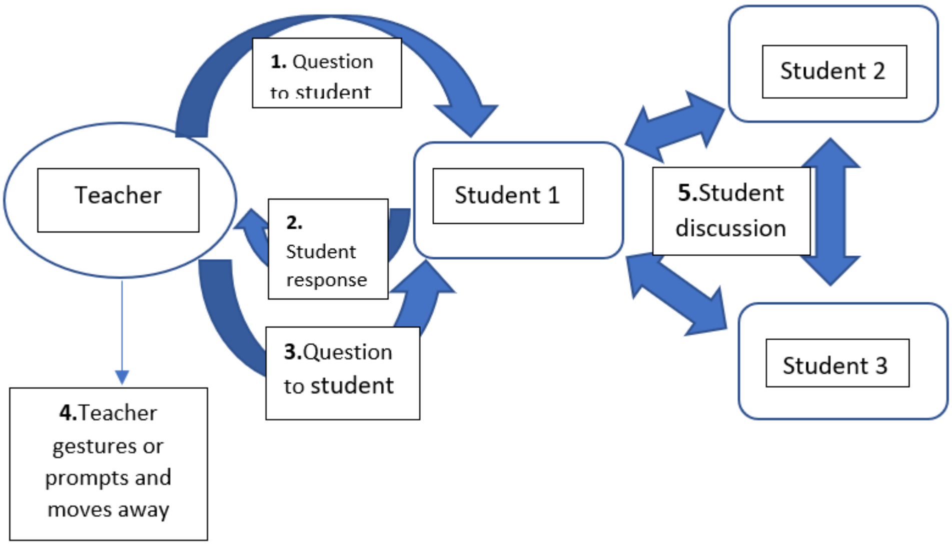
Note. This process was observed by Megan, Erin, and Robin during "Conceptualisation". All teachers observed at Currawong High School also adopted this practice.

Figure 22 depicts how Megan (1) responded to her students' question by (2) posing another question back at the student group which (3) invited them to discuss and rethink their approach. This promoted student group discussion and was also supportive of social regulation practices. After a student asked about catalase pH, "We are really struggling. We changed the pH of catalase … how are we meant to know (what to do)?" she redirected the question with a heuristic response: "What's the best pH for catalase? … Look it up". This prompted group discussion and action, fostering an immediate re-evaluation of their approach after they located the pH of catalase.

A recent study by Soysal and Soysal (2022) highlighted the complexity and diversity of questioning practices in IBL, noting that "eliciting questions" occupied around 36% of the question types used by teachers. The purpose of eliciting questions is to foster discussion, and in the current study these questions were often used as prompts to initiate teacher-to-student discussion. Megan and Erin were often seen prompting their students to initiate discussion by asking them questions. This questioning process is illustrated in Figure 23, drawing on the observed teacher-student conversations in the Conceptualisation phase of IBL. This type of questioning encouraged students to ask another question instead of directly answering a closed question.

Figure 23

Teacher Initiated Discussion to Invite Metacognitive Regulation



As depicted in Figure 23, to highlight metacognitive regulation Megan (1) asked a group of students, "What are you doing?", which encouraged her students to (2) pose questions and share their thoughts. She then (3) replied with a heuristic as a further question for the group to investigate: “Think about the way you are going to measure the gas.” Megan further refined her approach by (4) using non-verbal cues or verbal prompts to ensure her students were on the right track and without directly answering the question before she left each group. This led to (5) productive discussions within the student groups, and in the cited example the students were seen to use their laptops to source some methods for gas collection before agreeing on using an inverted measuring cylinder and tubing.

Prompted levels of guidance are also typified by using gestures such as a smile, nod, or hand gestures to support conceptual regulation. Megan and Robin used this form of guidance at the end of their discussions with their students to indicate when the students were correct or heading towards a resolution. In each example, the students waited for their teacher’s prompt before they continued their discussion.

The purpose of the expert teachers' questioning practices was to utilise a dominance of metacognitive regulation practices to inspire student discussion and thinking. Questioning practices also involved a range of guidance levels such as explanations, heuristics, and prompts. The limited use of closed questions is consistent with recommended questioning practices in IBL to promote student independence (Furtak, 2005).

6.4.5.3 Formative Assessment

After this Conceptualisation inquiry phase, all the expert teachers used status overviews as a level of guidance to provide students with feedback for conceptual and metacognitive regulation purposes. Formative assessment strategies on an advertised lesson checkpoint were used at Lorikeet HSand less formally at Cockatoo HS and Currawong HS, where the expert teachers discussed student work while they moved between student groups. Formative assessment is "the process of finding out what students know and providing ongoing feedback and support to further student learning while instruction is still in progress" (Furtak, 2023, p. 5). For each student, formative assessment provided an opportunity to evaluate their work and improve.

Megan conducted feedback sessions with individual students in a short interview and discussed their logbook entries, which included written drafts of their inquiry questions and methods (Figure 19). Her feedback was often highly guided to ensure she could give some directed feedback to each student throughout each lesson, for example: "That is a good reflection with graphs and tables included. Add units to the heading of your table." In this instance, Megan's student made the necessary changes to the draft table of results in response to the feedback immediately after the discussion.

A summary of the regulation practices and levels of guidance used by the expert teachers during the Conceptualisation phase is presented in Table 29.

Table 29

Conceptualisation Regulation Practices and Guidance Levels

Inquiry Phase	Regulation Practice	Level of Guidance (dominant practice from most to least guidance)					
		explanations	scaffolds	heuristics	prompts	status overviews	process constraints
Conceptualisation	Conceptual regulation	x	x	x	x	x	
	Metacognitive regulation			x	x	x	
	Social Regulation	x		x	x		

All three regulation practices and a range of guidance levels were observed during this inquiry phase. Teacher guidance levels did not visibly fade, as Dobber et al. (2017) have suggested. Instead, the teachers cycled through guidance levels to foster cognitive, metacognitive, and social regulation in their diverse classrooms. Questioning practices and formative assessment were strongly featured strategies. These findings accord with Herranen and Aksela's (2019) statement: "The teacher can give both practical facilitation as well as support in thinking processes, in planning and carrying out the inquiry and in presenting the results" (p. 21). The expert teachers used a range of guidance levels to demonstrate evolving and active roles in the classroom, as well as the unique nature of science.

6.5.5 Integrated Practices During the Investigation Inquiry Instructional Phase

During the Investigation inquiry phase), the students actively participated in practical work to address their inquiry question through scientific investigation. This represented the fourth instructional inquiry phase in Figure 24.

The teachers used conceptual and social regulation practices to direct and redirect their students' practical work. The students completed laboratory work and fieldwork in a social group, and a literature review. Literature searches have been noted in other studies as an essential feature of IBL in science education (Akuma & Callaghan, 2019), reflecting the nature of scientific work (Duncan et al., 2021). In the study context, the students conducted hands-on investigations in social groups supplemented by secondary-sourced research, which they conducted independently. This section highlights social and conceptual regulation practices. Surprisingly, the expert teachers largely used highly guided explanation guidance to support safe work practices and skills development. Also observed during this phase were process constraints, where students relied on the materials provided, including marking rubrics, without direct teacher intervention for conceptual regulation. A summary of the dominant teacher practices during this phase is represented in Table 30.

Figure 24

Instructional Inquiry Phases: Investigation

The following sections analyse the following dominant themes:

- Direct responses to student questions
- Digital guidance structures

The emphasis on conceptual regulation practices were supportive of procedure.

Table 30

Integrated Practice During Depth Study Investigation Inquiry Instructional Phase

Expert teacher	Level of guidance	Purpose of instruction	Example	Resources used
Elle	Explanation Explanation	Conceptual and social regulation Conceptual regulation	Direct response to questions relating to the use of Equipment. Communicated lesson intentions. Just in time teaching: titration (7 demonstrations with small groups to demonstrate aspects of titration)	A limited range of chemical Reagents, Glassware, drying ovens, fume cupboard, heating equipment, filtering equipment. Titration equipment.
Megan	Explanation	Conceptual regulation	Communicated lesson intentions displayed on the screen When asked "Is this right?" (referring to their laboratory technique) Megan replied, "Ok, just stop…"	Planned laboratory equipment
Erin	Explanation	Conceptual and social regulation to prove feedback on different approaches.	Students posed questions and answers were visible to the whole cohort via a digital blog.	Students innovated their own resources to collect data outside of class.
Robin	Explanation Explanation	Conceptual social regulation Conceptual Regulation	Students asked how to use the drying oven which required a direct response. Explicit instruction on using the fume cupboard for hazardous chemicals.	The drying oven Fume cupboard
Megan	Scaffolding	Conceptual Regulation	"What makes peroxide breakdown? Have a look at that."	Chemical equipment and peroxide
Elle	Prompt	Social regulation	"Where are you guys up to?". The group were starting to disengage and Elle prompted them to work together.	
Megan	Prompts	Metacognitive, Conceptual and social regulation	Megan quickly walked around the room to make sure that each group had a hypothesis and a method "Where are you guys up to?" "How are you doing?"	A limited range of chemical Reagents, glassware, heating equipment
Erin	Status overviews	Metacognitive regulation	Teachers provided feedback on written work via email	Digital communications
Megan, Erin	Process constraints	Conceptual regulation	Students were observed using the copied and digital information including the marking rubric to guide their work. (Lorikeet High School, and Currawong High School)	Copied and digital information

6.4.5.1 Direct Responses to Student Questions

The strategies of directly responding to student questions were surprising to observe during this Investigation inquiry phase because they were strongly used by the expert teachers, who intervened for safety reasons or to correct practical skills as conceptual regulation practice. The expert teachers monitored safety and intervened with highly guided explanations when required.

Megan said she was also focused on ensuring that all students completed their investigation and for the reason of time-constraints. She had earlier communicated in an informal interview that this may have been a possible explanation for her reliance on explanation level of guidance. Her schedule and expectations of student work were earlier discussed and represented in Figure 18. The time constraint within a wider program of work and for all case schools limited the time in class to 14 hours, according to curriculum requirements (NESA 2017 a,b,c,d). As Megan pointed out, the time constraint also necessitated active teacher guidance.

The teaching strategies that were selected during this phase focused on the process of the investigation and involved a high degree of social regulation (Table 31). The expert teachers at Cockatoo HS and Lorikeet HS were observed organising laboratory equipment and reducing their verbal interactions with student groups, as compared to the Conceptualisation phase. At Currawong HS, the teachers opted for their students to collect data outside of school and interacted with them via a blog to provide direct answers to questions. While their students were confidently working, these interactions became shorter and more directed, with higher levels of intermittent guided instruction.

Where immediate action was warranted due to safety, all the expert teachers used direct responses to questions that required immediate interventions and guidance levels to support conceptual regulation. For example, during this inquiry phase Robin quickly directed a group of who were using silver nitrate to move to a fume cupboard, thus demonstrating the importance of using direct instruction for safety reasons (Figure 19). Megan and Elle also intervened with direct instructions when required for safety reasons. Erin and her teachers also replied with direct answers to questions concerning safety on their blog using an explanation level of guidance.

The student participants at Lorikeet HS realised that their teacher Megan had to quickly change her practice to offer explicit instruction due to safety considerations and chemical wastage. The focus group unanimously agreed with one student's comment:

> It was good to still have that support [immediate intervention], though like we had our pH experiment go a bit funny and we're like what on earth is going on? Then she said no, you're doing it the wrong way and otherwise we probably wouldn't have realised. (Student, Lorikeet HS)

Robin, Megan, and Elle were all observed intervening when they detected unsafe practices without the students first asking a question. This required them to continually circulate around the classroom and position themselves so that they could view each group as it was working.

6.4.5.2 Digital Guidance Structures

The expert teachers reported instructional practices via digital forms of communication to be frequent until the final inquiry phase. This finding was not highlighted in Phase A of the study and may have been emphasised in Phase B due to the COVID-19 pandemic and the need to establish digital communications during that time.

During the Investigation phase students asked questions about their practical work on a digital blog at Currawong HS, which according to Erin, allowed the students to see each other's questions and the teacher's responses. Towards the end of the Investigation inquiry phase, Currawong HS was forced into a COVID-19 school shutdown. According to Erin,

> We had to be flexible … we extended the time, and we did some work in classes, extra work online in class where we put the boys into their groups in breakout rooms so they could just talk over their project. (Erin)

The participating students at Currawong HS felt that teacher communication was significant, with one saying:

> She [Erin] was staying in communication with us so if we had any questions, we could email her but also, she allowed us to change what we were doing so if due to lockdown if we couldn't access what we wanted to. (Student, Currawong HS)

Digital communication outside of class time was also permitted at Cockatoo HS. One student there said: "So I emailed my teacher, and we had a conversation on maybe what I could do, and she gave the alternative of nitrate and phosphate strips which were probably a lot easier to use." Megan, Elle, and Robin also reported that they answered emailed questions regularly during the Investigation inquiry phase using explanations.

The less-guided status overviews and process constraint levels of support occurred informally during this phase, and Megan was the only expert teacher observed to continue checking written work in the logbooks. The use of process constraints was difficult to observe and evaluate since there was very little visual evidence while students were working on their digital devices. During this inquiry phase, students were seen to be looking at their marking rubrics and the materials provided by the teacher to guide their work as a form of process constraint guidance.

A summary of the regulation practices and guidance levels used by the expert teachers during the Investigation phase is presented in Table 31.

Table 31

Investigation Regulation Practices and Guidance levels

Instructional Inquiry Phase	Regulation Practice	Level of Guidance (Dominant practice from most to least guidance)					
		explanations	scaffolds	heuristics	prompts	status overviews	process constraints
Investigation	Conceptual regulation	x	x			x	x
	Metacognitive regulation				x	x	
	Social Regulation	x		x	x	x	

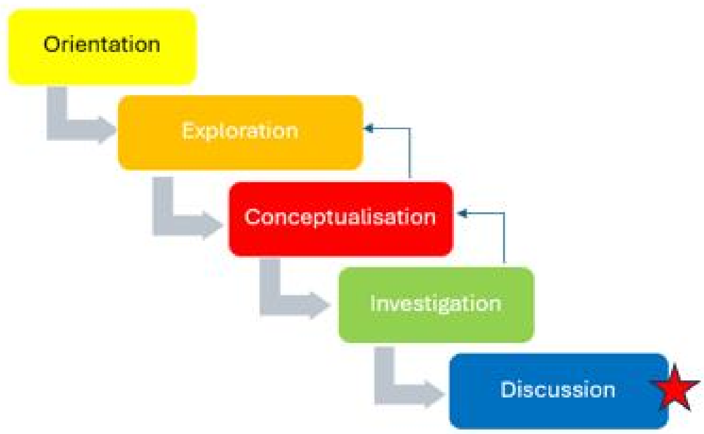
Noticeable features of this inquiry phase were less demand for the teacher and less reliance on metacognitive regulation. All teachers used conceptual and social regulation practices. The expert teachers used short periods of explanation, with most explanations concerning student safety in the laboratory at Cockatoo HS and Lorikeet HS. They also relied on prompts and heuristic guidance levels. Status overviews and process constraints emerged as a level of guidance. Enhanced by digital communications support, the students started to make more use of the materials provided to them.

6.5.6 Integrated Practices During the Discussion Inquiry Phase

During the Discussion inquiry phase (Figure 25), the students processed, analysed, and represented data and communicated their findings.

Figure 25

Instructional Inquiry Phases: Discussion



Unlike with the Pedaste et al. (2015) IBL model, the expert teachers in this study integrated data analysis with discussion in a single inquiry phase instead of separating them into distinct phases. Direct answers to student questions dominated the responsive teacher practices during this phase, and the students relied on the materials provided and the process constraints planned by their teachers to guide their work.

Practical reports were required student products at Cockatoo HSand Lorikeet HS. At Currawong HS, the teachers opted for the students to complete a group poster presentation and an in-class test to demonstrate their learning via multimodal representations. Each school assessed the Depth Study formally and required work submissions. This phase was characterised by the dominant regulation practice of conceptual regulation, and the students were supported with metacognitive regulation through process constraints. Student work was supported by the use of digital communications and the digital and printed materials their teachers provided.

This section highlights:

- Practices that support student independence including the use of resources that support student work.
- Digital collaboration which are established processes that enable students to work collaboratively on-line to support each other.

6.4.6.1 Practices That Support Student Independence

During the observation period, as teacher support faded there was a noticeable change to complete independence for most student participants. The supervised time for this inquiry phase was two lessons for Cockatoo HS, three for Lorikeet HS, and three for Currawong HS. Further time for this part of the Depth Study was expected to be completed in the student's own time, which was not observed by the researcher.

In the observed lessons, the students worked without strong guidance and asked very few questions of the teachers, who only responded when asked. All the expert teachers established process constraints as a level of guidance, and their students were observed referring to the printed and digital resources made available to them. Very few questions were asked by students in class, and the teachers reported digital communications being used outside of class time. The regulation practices of conceptual and metacognitive regulation were supported by the process constraint level of guidance during this instructional phase.

The students at Lorikeet HS and Cockatoo HS were observed reading the marking rubric as a process constraint, along with the information their teachers had prepared.

The teachers used marking rubrics for assessment and evaluation., and the students used them as a form of guidance. Marking rubrics also supporting students with a low level of guidance and can be classified as a process constraint (Lazonder & Harmsen, 2016). The students at Currawong HS also had these materials made available to them, although this was not observed because students completed their writing outside of class.

While most of the teacher support was reported to have occurred outside of class time (Elle, Robin, Megan, Erin), at Lorikeet HS and Currawong HS the students were observed during the Discussion inquiry phase to also communicate with their teachers during lunch periods and breaks from class. They were also reported to communicate to their teachers and to each other via email at Cockatoo HS and Lorikeet HS, and to ask questions in a digital blog at Currawong HS.

6.4.6.2 Digital Collaboration

Digital communication methods were used for most of the communications between teachers and students to provide high levels of guidance outside of class. All schools reported students emailing questions. As already mentioned, Currawong HS had set up a blog so that their students could see other students' questions and the teachers' responses. According to Erin, this was useful during the final inquiry phases of the IBL activity as her school was shut down and, according to a student participant, "They pivoted well." Erin reported that she and her teachers also ran additional online classes "to facilitate discussion … where we put the boys into their groups in breakout rooms". This responsive communication process supported social regulation. Like Erin, Robin and Elle responded to students when required, with much of this communication via email.

During this Discussion inquiry phase, the students at Currawong HS reported digital collaboration to be useful. According to a study by Korkman and Metin (2021) in Turkey, collaborative inquiry was shown to support student achievement in science; however, on-line collaborative inquiry had a higher effect size than in-class collaborative inquiry. A student at Currawong HS saw benefit in the on-line collaboration tools that the teachers had set up for them during a period of working from home during the discussion phase of the Depth Study:

> We hopped on frequent Zoom calls and Facetime calls to be able to finish off the booklet or do the poster with that two-week extension that [Erin] and the Biology Department gave us, or the Science Department. So that was also pretty fun 'cause we were all still connecting through lockdown while also getting all of our work done so it was good. (Student, Currawong HS)

This quotation indicates that social regulation occurred as process constraints during student collaboration during on-line forums. Even though this was forced by the closure of her school during the time, the students were preparing their final submissions. Erin reported that this was an existing practice at her school.

A summary of the regulation practices and guidance levels used by the expert teachers during the Discussion phase is presented in Table 32.

Table 32

Discussion Regulation Practices and Guidance Levels

Inquiry Phase	Regulation Practice	Level of Guidance (Dominant practice from most to least guidance)					
		explanations	scaffolds	heuristics	prompts	status overviews	process constraints
Discussion	Conceptual regulation (Metacognitive regulation) Social Regulation	x				x	x

The Discussion inquiry phase required less teacher support that the preceding instructional inquiry phases. In the observed classes, teachers moved around infrequently, and students worked individually. The students relied on process constraints to guide their work, as seen by their referring to the materials provided. Erin's students, who were reported to be working together on their work submission, were not observed during their digital interactions with their teachers and with each other.

6.6 Chapter Summary

This chapter has addressed RQ2 by analysing the practices of the four expert teachers selected for the study because they implemented guided IBL in their Year 11 science classes. Guided approaches to IBL and the use of teacher-selected topics were preferred by these teachers. Observations of their practices revealed a phased sequence of instructional practice. The instructional inquiry phases were named according to conventions established in earlier works (Bybee et al., 2006; Pedaste et al., 2015). Significantly, within each instructional inquiry phase, the researcher observed the expert teachers using regulation practices, levels of guidance, and strategies that were interpreted as integrated practices. The expert teachers' planning practices involved the production of student resources, which were integrated with their instructional practices. An example of the interactions between these elements is shown in Figure 25.

The purposes of the teaching strategies and the levels of guidance were analysed together using Lazonder and Harmsen's (2016) levels of guidance typology and Dobber et al.'s (2017) regulation practices typology. A summary of the dominant levels of guidance and regulation practices observed during the inquiry sequence is represented in Table 34.

Teacher instruction was most guided during the Orientation phase, where the teacher used explicit instructional practice as the dominant practice. The next two phases, Exploration and Conceptualisation, included a broad range of strategies, the teachers using differentiated strategies that were responsive to the needs of the students. Using just-in-time teaching strategies, the expert teachers selectively employed explicit instructional practices as lesson intentions to communicate laboratory safety information and to impart new knowledge. These strategies were balanced with lower levels of guidance during metacognitive regulation practices such as questioning to support students to think critically.

Although Dobber et al. (2017) suggested that teacher guidance fades or reduces throughout an inquiry sequence, Table 33 indicates that, in the current study, guidance levels did not strictly fade, and all forms of regulation practice were present for the first four phases.

Table 33

Summary of Instructional Practice Observed During Each Inquiry Phase

Inquiry Phase	Regulation Practice	Level of Guidance (Dominant practice from most to least guidance)					
		explanations	scaffolds	heuristics	prompts	status overviews	process constraints
Orientation	Conceptual regulation	x	x				
	Metacognitive regulation			x	x		
	(Social Regulation)			x	x		
Exploration	Conceptual regulation	x	x				
	Metacognitive regulation			x	x		
	Social Regulation	x		x	x		
Conceptualisation	Conceptual regulation	x	x	x	x	x	
	Metacognitive regulation			x	x	x	
	Social Regulation	x		x	x		
Investigation	Conceptual regulation	x	x			x	x
	Metacognitive regulation				x	x	
	Social Regulation	x		x	x	x	
Discussion	Conceptual regulation	x				x	x
	(Metacognitive regulation)						
	Social Regulation						

Note. Dobber et al. (2017); Lazonder and Harmsen (2016)

The conceptualisation phase was observed to be the most demanding for the expert teachers because of the broad range of strategies each was using to differentiate their practice. Other researchers have also noted the intensity of demand on teachers while students conceptualised their inquiry questions (Herranen & Aksela, 2019; Lombard et al., 2013). The challenges to teachers during the conceptualisation phase also support comments from the education leaders in Phase A of the study, who reported that teachers were having difficulty supporting their students with their inquiry questions and scientific investigation methods.

The less-guided process constraints were only observed toward the end of the IBL, where students were observed to use the materials provided to them for guidance. No students in this study worked independently during class time throughout their project, and all required some form of guidance. Elle and Robin were surprised that some of their students could not operate with process constraints using the materials provided since their school had an emphasis on IBL, which they felt the students had learned prior to Year 11. During an unstructured interview, Elle and Robin explained that this might be because of the effect of recent school closures due to health restrictions prior to the observation period and the resulting lack of experience of this group of students working in practical science. A limitation of classroom observations is that they do not allow verification of whether students work independently outside of class.

In developing a theory from this study, the significant findings of this chapter have been further scaled up with the literature to develop a suggested framework called the Guided Inquiry Science Teaching (GIST) framework, which is presented in Chapter 7. The GIST framework summarises a teacher's decision making about their practice within their own unique context while recognising the complexity and flexibility of IBL instruction.

Chapter 7

Discussion and Conclusions

7.1 Chapter Overview

This chapter provides an overview of the findings of this study. It introduces a proposed theory, the Guided Inquiry Science Teaching (GIST) conceptual framework, as a summary of the core concepts. This emergent pedagogical framework has the potential to support teachers in implementing guided IBL in senior secondary science education.

The chapter begins by declaring the problem with IBL (Section 7.1). It then justifies the adopted research methodology, Grounded Theory Design (GTD) (Section 7.2). Expert teacher perceptions are discussed in Section 7.3, and expert teacher practices in Section 7.4. The proposed GIST framework is presented in Sections 7.5 and 7.6. The study's contributions to knowledge are outlined in Section 7.7 and its implications in Section 7.8.

Significant contributions to knowledge of this research presented in Section 7.7 include:

- Contemporary Pedagogical Perceptions and Practices of IBL
- The GIST framework and pedagogical practice
- A strengths-based approach to IBL research

The chapter concludes with suggestions for further research (Section 7.9) and a discussion of the study's limitations (Section 7.10).

Given the long history of constructivist perspectives underpinning the teaching of practical science in schools (Bächtold, 2013; Hand et al., 1995; Tytler, 2002), it is not surprising that curriculum reforms in this field have required an inquiry-based learning (IBL) component in Australia (ACARA, 2009; NESA, 2017 a,b,c,d) and the United States (Next Generation Science Standards Lead States, 2013), as well as in Estonia, Singapore and Canada (Scott et al., 2018). Continuing research into the challenges of IBL in the senior secondary context is vital for enhancing instructional practice.

7.2 Addressing the Challenges of IBL

The perceived challenges of IBL inspired this research into teacher practices. Classroom challenges noted in the literature were due to a lack of teacher confidence (Akuma & Callaghan, 2019; DiBase & McDonald, 2015; Haag & Megowan, 2015). Negative commentary about IBL in the media has also caused difficulties. According to the education leaders in Phase A of this study, science teachers can be confronted by the instructional practice of IBL or require convincing about its merits. The study participants also noted that the compulsory curriculum restricted their IBL practice.

In the study context, participating students engaged together in IBL, as required by the Depth Study component of the NSW Australia curriculum (NESA, 2017 a,b,c,d), which is underpinned by a socio-constructivist education philosophy. In Phase A, education leaders Greta and Matt highlighted how IBL in a differentiated classroom can place demands on early career teachers who were required to constantly supervise students. Tytler and Prain's (2022) research on their integrated Mathematics and Science (IMS) model, which had a guided IBL focus, also included "continuous monitoring and support of student learning" as an embedded feature of the pedagogical model (p. 32).

According to this study's participants, the curriculum requirements of the Depth Study in the NSW senior science curriculum strongly affected the expert teachers' planning of IBL. Megan, for instance, needed to develop broad topics and phased instruction to keep her students "on track". She, along with Elle, Erin and Robin, regularly referred to their concerns about the culminating formal assessment of the Depth Study, which also defined the end point to the IBL activity. While other impacts on IBL enactment such as available resources are evident in the literature (Akuma & Callaghan, 2017), surprisingly only two education leaders from well-resourced schools (Ali, Sasha) pointed out that the lack of appropriate laboratory resources may restrict open forms of inquiry (Sasha) and student choice (Ali).

More recently, the value of IBL has been challenged (Sweller, 2021). A debate that positions IBL and direct instructional teaching methods as opposing practices recently emerged in the Australian media (Adams, 24 October 2022). Because such reductionist debates have the potential to diminish the importance of IBL in science education, they were presented as being significant to this study in Chapter 1. Counterarguments to this ongoing commentary have brought attention to the diversity of teacher practices in IBL (de Jong et al., 2023; Reid, 17 August 2021; Tytler & Prain, 2022). According to Tytler and Prain (2021), positioning IBL in opposition to explicit instruction "demonstrates the over-simplification of the debate around direct instruction versus inquiry" (p. 42). The findings of this study agree with their stance: the empirical evidence supports the argument that IBL involves a diverse range of teacher practices, including direct instruction. The findings contribute to the important empirical evidence base of existing IBL teacher practices in senior secondary science.

The paucity of empirical studies which highlight the realities of IBL has also been noted by Dobber et al. (2017) as a research gap in a significant metanalysis of teacher practice. This thesis proposes a theory called the Guided Inquiry Science Teaching (GIST) conceptual framework. By recognising and leveraging the broad range of observed teacher practices, this clarified understanding of IBL instructional practice contributes to bridging the research gap identified in Dobber et al.'s (2017) a significant metanalysis of existing IBL teacher practices in senior secondary science.

7.3 Strengths of the Research Design

This research has its foundations in a pragmatist and interpretivist paradigm where the research findings are grounded in rich interpretations and the developed theory is of practical use (Corbin & Strauss, 2015). The findings draw data from existing perceptions and practices of selected education leaders and expert teachers. GTD was introduced in Chapter 3 as an appropriate methodology to explore the research questions as it allowed for deep insight into phenomena and for developing theories (Corbin & Strauss, 2015; Creswell & Guetterman, 2021).

The researcher used GTD, an inductive research approach that requires the researcher to reduce their influence as much as possible by working unobtrusively when collecting data (Corbin & Strauss, 2015). The analysis of classroom pedagogical practices was further explored through feedback, memoing, and the locating of connections in the data. Selective coding highlighted nuanced and significant findings (Creswell & Guetterman, 2021).

The GIST conceptual framework introduced in this chapter was developed from the observed expert teachers' IBL instructional practices in senior secondary science and thus provides in-depth knowledge of the topic. Rather than replace existing models, GIST framework has the potential to guide teachers' pedagogical practices alongside the cognitive dimensions of learning.

The research questions are restated as follows:

1. What are science education leaders' perceptions relating to inquiry-based learning in Depth Studies in senior secondary science?
2. What are expert teachers' practices relating to inquiry-based learning in senior secondary science?

Chapters 5 and 6 are the findings chapters. RQ1 was addressed through semi-structured interviews with education leaders during the first phase of the research. RQ2 was addressed in the second phase through prolonged observations of expert teachers' lessons, unstructured interviews and conversations, artifacts of student work, planning documents, printed resources provided to the students, and student focus groups. Data analysis followed a systematic coding system of open coding, axial coding, and selective coding. Triangulation of the data determined the connections and the complexity of the dominant teacher practices that form the basis of the GIST conceptual framework.

7.3.1 Selection of Study Participants

The significance of this study is enhanced by the methods used to select the participants. It was considered important that they be education leaders and expert teachers who could draw on their extensive experience in IBL in senior secondary science education in NSW, Australia. Analyses of their roles and pedagogical processes were further informed by other data sources, including student voices.

Selecting expert or exemplary teachers for a study is a recognised feature of other studies of science IBL (Fang ,2021; Tobin & Fraser, 1990; Tytler & Aranda, 2015). As outlined in Chapter 4, the education leaders in Phase A of the study were selected to address RQ 1 because of the scope of their work with other teachers and their leadership experience in science education. They also reported on the practices of the teachers they observed and thus provided additional insight to inform RQ 2.

The expert teachers in Phase B were experienced educators who demonstrated confidence, rather than perfection, in their pedagogical application of IBL. The slight deficits observed were not significant. Students from each expert teacher's class self-selected to participate in focus groups. Adding students' voices was considered crucial for highlighting the teaching practices that were important to them.

Only a few studies in similar research contexts have included student perceptions of IBL as a data source. Concannon et al. (2020), for example, found that students in the younger years of schooling might not have informed or accurate interpretations of IBL. In the current study, the focus group participants were in their senior years of secondary schooling and able to offer significant insight into their understanding of IBL and their teachers' practices. In Phase 2, their comments on the interactions with their teachers that were most important to them pointed the researcher to areas that required further exploration.

7.4 Insights from the Education Leaders

Phase 1 of the study was foundational because the education leaders' (n=10) perceptions provided deep insight into contemporary views of the curriculum requirement of the Depth Study in the NSW senior science curriculum, which the study participants interpreted as an IBL activity. Their insights into teacher practices in IBL were also triangulated with empirical evidence derived from Phase B of the study to provide further evidence and interpretation.

The education leaders had positive perceptions about the value of IBL in senior secondary science, although three also reported observing poor or inconsistent implementation of IBL pedagogical practices in classrooms. This insight justified a deeper analysis of instructional practice in Phase B to unravel the perceived complexity of teacher practice. Their perceptions have also helped curriculum developers provide support for teachers experiencing difficulties with implementing IBL in the NSW Australia education context (de Ridder, 2021).

A significant finding was in the defining of the levels of inquiry, which, according to the education leaders, had multiple interpretations. They described examples of Depth Studies in their Year 11 and 12 courses, and of levels of IBL they considered appropriate being categorised as Guided IBL, and Open IBL. Ali was the only leader who articulated the need to differentiate teacher practice during IBL, arguing that guidance levels might not be static, as suggested by the other participants. Ali's perception is consistent with those of researchers who proposed fluid models of inquiry levels that are changeable (Bacak & Byker, 2021; Bevins & Price, 2015; Furtak, 2012). Bacak and Byker (2021) proposed a "Flexible Phases of Inquiry Theory" and recognised that "levels of inquiry are not fixed but overlapping and dynamic" (p. 266). The nature of teacher guidance levels was later investigated during Phase B of this study, alongside an existing framework (Lazonder & Harmsen, 2016) to investigate teacher guidance (see Section 7.4). This study found that guidance levels in IBL are flexible and changeable.

All ten education leaders in Phase A interpreted the Depth Study requirement of the NSW Senior Science syllabuses as IBL, with nine of them offering examples of what they considered to be guided IBL approaches. Most examples described the teacher intentionally selecting a general topic to direct the IBL within a particular topic range, which has also been noted as a valid approach in the literature (Sezen-Barrie et al., 2020). The reasons given for teachers developing the topic were pragmatic: teacher guidance, available resources, time constraints, and the impact of a compulsory curriculum and external examination at the end of Year 12. This finding informed Phase B of the study, which sought to observe expert teachers who practised IBL using broad topics with the same curriculum constraints.

Three themes emerged during Phase A that informed Phase B of the study as significant practices, thus providing compelling empirical evidence of the complexities of IBL instructional practices:

- IBL guidance approaches (Section 5.2)
- The changing role of the teacher (Section 5.2)
- Teacher developed topics (Section 5.3)

While the education leaders provided multiple detailed examples of topics they had developed, the complexities of teacher practice were only given cursory attention in their explanations. This warranted further exploration in Phase B.

The curriculum was a significant influence on the nature of the Depth Study and the types of guidance provided by the teachers (Section 5.3). The education leaders emphasised the restrictions placed on IBL due to the demand for a formal high-stakes assessment. In all case study schools, the Depth Study included formal assessment, and the expert teachers supported their students to complete the Depth Study and the required assessment in a defined timeframe. The production of a final assessed product was supported by an inquiry phase where students were observed to be preparing their assessment products, which included scientific reports and posters.

A further curriculum restriction was the impact of the compulsory curriculum, which was evidenced by the selected teacher topics chosen for IBL. Topic choices aligned to the compulsory curriculum in the Biology, Chemistry, Earth and Environmental science and Physics courses (NESA, 2017 a,b,c,d). Teachers' topic choices reduced the range of different projects that were observed at the case study schools. Teacher topic choice was also pointed out by expert teacher Megan as being beneficial to the management and provision of appropriate laboratory resources.

The insights from education leaders, informed by the observations at the case study schools painted a picture of IBL being influenced by the compulsory curriculum. While the IBL requirement of the Depth Study was well regarded by study participants and reports of good practice were reported, other reports of teachers' lacking confidence or not engaging in IBL were of concern.

7.5 Insights of Pedagogical Practice

This section presents the elements of pedagogical practice that are incorporated into the GIST framework in Section 7.6. The practices of the expert teachers changed within five identified phases of a guided IBL instructional practice: orientation, exploration, investigation, conceptualisation, and discussion. To analyse the interactions of pedagogical practice, this section draws together the dominant themes of the study that were identified through the researcher's observations of participating teachers, artifacts, and students' perceptions of their teachers' practices.

All expert teachers were observed to adopt a socio-constructivist perspective by supporting their students who were working in social groups. Their diverse instructional approaches and their positions in the classroom altered between acting as a mentor to support their students, with the occasional use of acting as a mediator in a more authoritarian role. This was consistent with the findings of Liu and Wang (2022). They also used highly guided and less guided strategies. This finding supports de Jong et al.'s (2023) argument that explicit teaching is not in opposition to IBL; rather, it is very much a part of a broad range of teaching strategies.

7.5.1 IBL Instructional Phases

The expert teachers arranged the IBL activities into five discrete instructional inquiry phases, named according to the range of student activities nested within them: orientation, exploration, conceptualisation, investigation, and discussion. These names acknowledge Bybee's (2006) 5E instructional model and the Pedaste et al.'s (2015) inquiry phases.

Within each inquiry phase, the students had the flexibility to iterate the activities, and teachers were observed supporting students who were completing different elements of their work. Some students reported an initial challenge of working independently. Their teachers gave them appropriate guidance levels as they progressed through the IBL activities. This supportive structure also reflected the cyclic nature of science.

All the expert teachers conducted an *orientation* lesson to set the context of the IBL, introduce students to new concepts, and revise existing knowledge and skills.

Orientation is also an identified inquiry phase in Pedaste et al.'s (2015) inquiry model and Tytler and Prain's (2022) IMS model. According to Tytler and Prain, orientation establishes what is "worth noticing" (p. 32). In this IBL phase, library skills were also revisited, and the students were provided with print resources to support their learning and the formal assessment of the task. The students at Cockatoo HS were inspired by the context of their IBL activity, which was communicated to them through their observation lesson.

The exploration inquiry phase was conducted as an initial phase at Currawong HS and a second phase at Cockatoo HS and Lorikeet HS. According to expert teacher Megan, it was an opportunity for students to "play" and trial some suitable laboratory techniques for their investigations. The students also explored the literature to extend their conceptual understanding of the topic, which the expert teachers supported. This iterative phase allowed the students to trial different investigation options before developing their own questions and methods for their projects. It also enabled them to revise and learn supportive skills they might use for their projects.

The third instructional phase, conceptualisation, included students formulating their inquiry questions and developing their scientific investigation methods. The education leaders in Phase A agreed conceptualisation was difficult for teachers to manage. This phase was also highly iterative, and the expert teachers were seen to be supporting students who were completing different activities. Herannen and Aksela (2019) also noted students' difficulties with conceptualising inquiry questions, which require active support from the teacher. The perception that teachers can be challenged in the IBL classroom is supported by the observed range of intentionally selected strategies used by the expert teachers during this phase.

The positioning of the conceptualisation phase was significant since, for two schools, it was positioned after the orientation and exploration phases, rather than at the beginning. The expert teachers at Cockatoo HS needed to revisit conceptualisation after introducing it at the beginning of the IBL. Pedaste et al.'s (2015) inquiry model also includes a conceptualisation phase located after beginning a sequence of phases. In research outside science education, Kuhlthau et al. (2012) stressed the importance of balancing student emotions with IBL and not requiring students to develop questions to investigate too early. The findings of the current study suggest that the expert teachers adopted an approach of immersing students in a range of supportive activities before they were required to develop their own questions for investigation.

The fourth inquiry phase was the investigation phase, where the students were observed working in groups on their planned investigations with teacher support. Different from the investigation phase in the Pedaste et al. (2015) inquiry model, where students also analyse their data during the investigation phase, only some student participants in this study were seen to be analysing their data during this instructional phase. The remainder of the student participants conducted their data analysis during the final discussion phase.

The expert teachers signposted the phases identified in this study while communicating lesson intentions and by altering the classroom's physical arrangement, which supported the nested activities within each instructional phase. Further analysis of teachers' strategies within each inquiry phase enabled a nuanced view of the phenomena.

7.5.2 Levels of Teacher Guidance in Guided IBL

The varying levels of teacher guidance were a key finding of this study that challenged definitions of static levels of IBL instructional practice. This study did not conclude a definitive level of teacher guidance because instructional practices were differentiated, and the expert teachers judged the level of guidance required for each student. The problem of defining levels of guidance as definitive categories, such as open, guided and structured, has been noted by other researchers (Bacak & Byker, 2021; Bevins & Price, 2015; Furtak, 2012), who have also promoted flexible definitions for levels of IBL when describing the student experience. In this study, the level of guidance teachers used in their interactions with students varied considerably, and the expert teachers did not consistently apply a static approach.

The student participants noted the differences in guidance their teachers gave them. Some mentioned times when they felt that guidance was insufficient, particularly at the start of the IBL, and also when they were suitably challenged and were happy with their achievement while working independently. The students' perspectives are pertinent since they point to the expert teachers’ challenge of selecting a suitable level of IBL with each interaction and of making spontaneous and informed judgements of appropriate guidance levels within a differentiated classroom.

Levels of guidance in this study were consistent with the typology of guidance proposed by Lazonder and Harmsen (2016) and included a range from the most amount of guidance to the least, including process constraints, status overviews, prompts, heuristics, scaffolds, and explanations. These terms helped categorise the variety of teacher approaches observed. Within each inquiry phase, the teachers adopted an iterative approach while responding to the needs of the students. They also used planned approaches, such as the use of explicit instruction to introduce or revise concepts.

The frequency of interactions between the teachers and the students intensified during the exploration and conceptualisation inquiry phases, during which a dynamic interplay of a wide range of inquiry and regulation practices was evident. The high levels of guidance evident during the orientation inquiry phase and the low levels of guidance during the discussion phase suggest of some fading of teacher practice from start to finish. However, any fading of teacher guidance between those phases was not evident, although it cycled between levels of high to low guidance. The cyclic nature of the observed guidance levels was not consistent with Lombard and Schneider’ (2013) recommendation that teachers should “[be] weaning students from teacher authority” (p. 167) as a desired aim of IBL to increase student autonomy. Section 6.4 discusses the changes in guidance levels during the observed IBL phases.

The expert teachers balanced their roles with periods of explicit instruction and periods of guided student independence. Throughout the observation period, explicit instruction was apparently deemed necessary to communicate lesson intentions, requirements for student assessments, and safety rules. This finding suggests that the teachers promptly adapted their support and imposed their authority in the classroom in response to the needs of the learners (Herannen & Aksela, 2019; Lombard &

Schneider, 2013). An authoritarian role was replaced by a cooperative role that allowed each teacher and her students to work together in a learning community.

7.5.3 Integration of Regulation Practices with Levels of Guidance

Alongside teaching strategies such as talk practices; regulation practices and guidance levels were observed as significant practices of the expert teachers. An aspirational goal of IBL in senior secondary science is for students to progress towards being able to regulate their own learning and work independently. According to Barr and Askell-Williams (2020), many teachers understand very little about self-regulated learning in the earlier years of secondary school science. This reported lack of knowledge also aligns with the findings of Phase A of this study, where education leaders reported that some teachers did not understand their classroom role.

In addition to selecting an appropriate level of guidance, the expert teachers were also observed using regulation practices. The term “regulation practices” is used to describe teacher practices that support students in regulating their learning. According to Dobber et al. (2017), regulation practices are the “kind of direction that the teacher gives” (p. 198). Depending on the purpose of guidance, the regulation practices adopted by the expert teachers in this study included conceptual regulation, metacognitive regulation, and social regulation (Dobber et al., 2017; Furtak et al., 2012).

Interpretation of the participating students’ perceptions of their teachers' strategies during IBL proved significant in this study. They articulated some of the strategies their teachers were using and how these were integrated with different levels of guidance, such as management of student groups, questioning, and explicit instruction. For example, Megan’s students understood that she would change her interactions and levels of guidance to meet the needs of each student group. Such perceptions were consistent with the research observations, and they highlight the importance of a researcher taking students’ voices into account when interpreting observations.

A broad range of regulation practices and guidance levels were observed in Phase B. During the conceptualisation inquiry phase, when students were developing their inquiry questions and investigation methods, there was a high demand for a wide range of guidance levels and for the teachers' conceptual, metacognitive, and social regulation practices. In Phase A, education leaders noted that conceptualisation is an area that teachers often have difficulty navigating. These findings highlight the complexity of teacher practice during this inquiry phase; it is apparent that the expert teachers would intentionally change their practices in response to the needs of their students.

The exemplary pedagogical practices observed in this study were closely aligned with the levels of inquiry proposed by Lazonder and Harmsen (2016) and the well-cited teacher regulation practices proposed by Furtak et al. (2012) and Dobber et al. (2017). In Chapter 6, the range of instructional practices a teacher would use in IBL were shown to vary according to their purpose and the intended level of guidance. In Phase A, this complexity was identified as significant for supporting teachers in their instructional practices.

Interactions between the expert teachers and their students were not limited to verbal interactions. Herannen and Aksela (2019) raised the importance of supporting student thinking and discussion skills using digital tools, writing tools, discussion, questioning, and argumentation. In this study, during each of the inquiry phases at each school, such tools were observed to complement the verbal and non-verbal interactions between teachers and their students.

In addition to verbal interactions between teachers and their students, pedagogical practices integrated the provision of planned printed and digital resources, as well as and the use and manipulation of laboratory equipment. The resources developed and organised by the expert teachers as accompaniments to classroom interactions are presented in Section 6.2.3. As also found by Lombard and Schneider (2013), the advantages of incorporating diverse resources, including laboratory resources, was not a dominant theme in this study. The students in this study did not raise the range of resources provided by their teachers as being significant to them, despite being prompted in the focus group meetings. Most agreed that the interactions between them and their teachers were much more significant than the supportive materials. In contrast, the classroom observations revealed students and teachers interacting with printed, digital and laboratory resources and that verbal interactions did not occur as isolated practices. This finding points to the value of data triangulation in empirical studies such as this.

Verbal interactions in the form of teacher questioning practices were significant in this study. They are also highlighted in the literature as being significant in constructivist teaching practices. Erdogan and Campbell (2008) used Grasser and Person's (1994) taxonomy of question types to closely investigate the questioning practices of 22 science teachers in the US. The categories included "closed ended questions", "open ended questions", and "task-oriented questions" (p. 1897) during the teachers' interactions with the students. The expert teachers in the current study were observed using same range of question types, open-ended questions being dominant although the purposes of the questions and the guidance levels used would change at different times during observations.

The expert teachers adapted their levels of guidance to differentiate learning through their chosen questioning strategies. Questioning practices were often integrated with accompanying resources and supplementary practices such as gestures. For example, the expert teachers would use the dominant metacognitive regulation practice of student questioning to invite their students to think about their projects. Often, this would be in the form of Socratic questioning, which relied on prompts and heuristics to guide and direct the students. A teacher might use a prompt, offer some direction (heuristics), or change the level of guidance they considered suitable for her students (Section 6.4). At other times, closed questioning would support conceptual regulation practice, accompanied by a demonstration of laboratory equipment.

The intensity of teacher-to-student questioning practices faded once the students started their investigations. The expert teachers reverted to mainly using guided conceptual regulation practices, including scaffolded instruction, to ensure their students were safely engaged in their work. This is of interest because the fading of guidance, as Lombard and Schneider (2013) indicated, was evident in the final inquiry phase, when students were required to communicate their findings. This observation might illustrate the difference between the findings of studies involving senior students and those in the younger years of schooling; the former have more experience in writing practical reports.

Social regulation practices were a feature of the observed classrooms. Working in social groups requiring the students to collaborate, negotiate, and compromise to arrive at a group consensus. If her students were not interacting effectively with their group, the expert teacher would implement both explicit and less-guided social regulation practices. She would use highly guided instruction and explanations to communicate her expectations and, when required, prompt them with verbal and non-verbal interactions. The irregular use of social regulation practices observed in this study, where behaviour management did not present a challenge, may differ in other education contexts. Therefore, regulation practices might feature more strongly in schools needing a broader repertoire of strategies.

These findings demonstrate that changes in regulation practices and levels of teacher guidance need to be considered alongside the purpose of instruction and the level of guidance. Regulation practices can give purpose to a teacher’s instructions, which may be further enhanced by the teacher's level of guidance. The students in this study recognised different guidance levels and were aware of the balance between working with complete independence and the teacher providing explicit guidance. The expert teachers demonstrated a full range of guidance levels, which intensified during the exploration and conceptualisation inquiry phases.

7.6 Theory Development

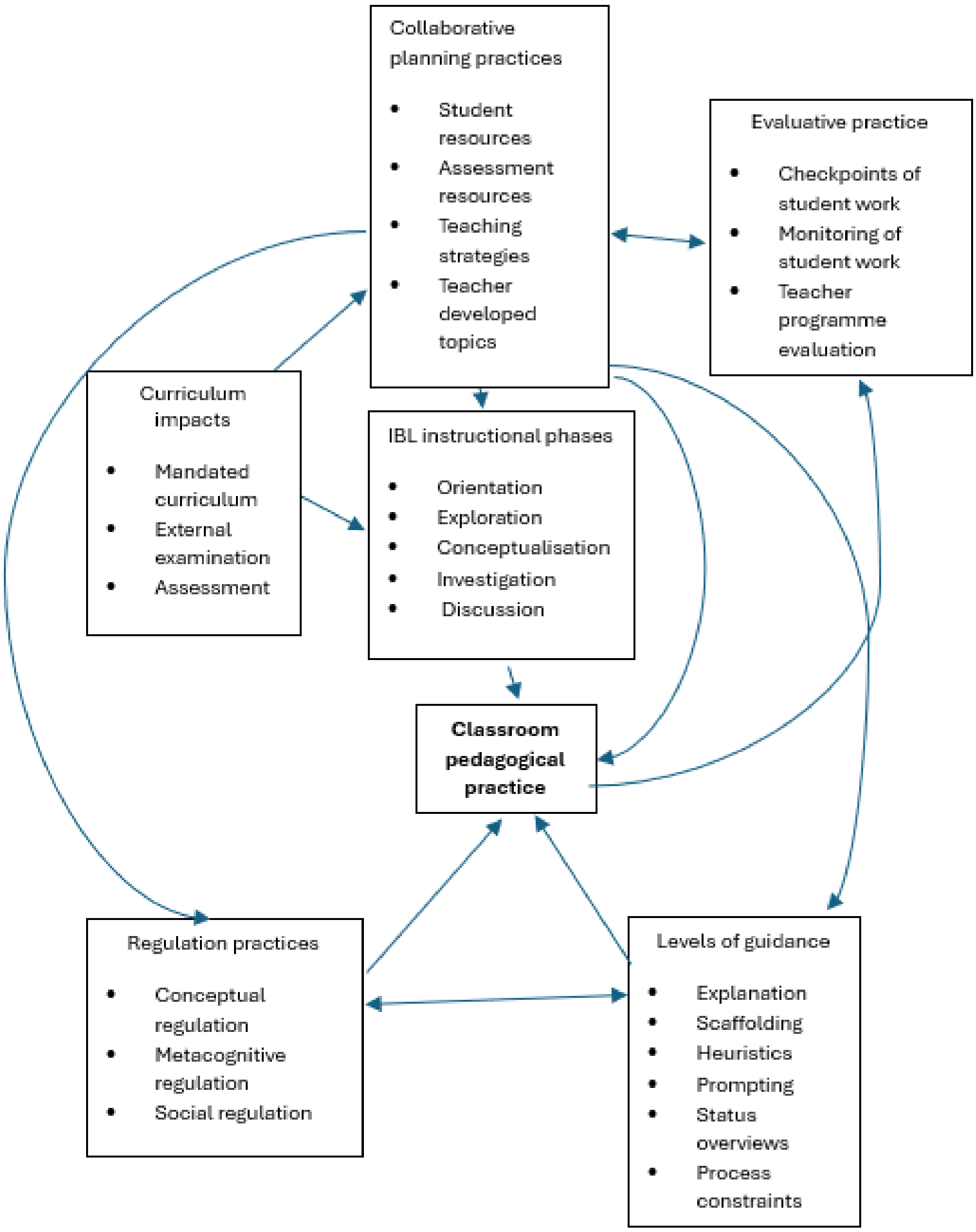
Generating a theory is the aspirational goal of Grounded Theory Design research (Creswell & Guetterman, 2021; Corbin & Strauss, 2015). In this thesis, the theory is presented as a suggested conceptual framework. The Guided Inquiry Science Teaching (GIST) framework summarises the selective codes of the study: curriculum impacts, collaborative planning, evaluative practice, inquiry phases, teacher regulation practices, and levels of guidance. These themes were supported by planning practices, and evaluative teacher practices. The interactions between pedagogical activities are illustrated in Figure 26.

7.6.1 Guided Inquiry Science Teaching (GIST) Framework

The GIST framework exists within each IBL instructional phase: Orientation, Exploration, Conceptualisation, Investigation and Discussion. The theory illustrates the elements of pedagogical practice identified in this study and their interactions to form the theory.

Figure 26

Guided Inquiry Science Teaching Conceptual Framework



The complexity of classroom pedagogical practice, where teachers combined regulation practices and different levels of guidance instruction, is summarised as the GIST framework. Figure 26 illustrates the complexity of classroom pedagogical practice by emphasising the purpose of student interactions (regulation practices) and the levels of guidance that each expert teacher selected in a differentiated classroom.

Evaluative practices are also highlighted as being important and entwined with the constant monitoring of student work and with the reflective processes that informed further iterations of the teaching program. Evaluative practice also occurred in real time and enabled teachers to iterate their own classroom practices.

Collaborative planning practices were informed by evaluative practices between and during each Depth Study program. The expert teachers iterated their planning approaches in response to their students and responded to the impacts of the external school program. Elle and Robin were observed to meet to reformulate their program in response to the slower than expected progress of their students. Collaborative planning practices also occurred before the Depth Study and resulted in the printed and digital resources that were used throughout the observation period.

By drawing on the insights derived through the observations of the expert teacher participants, a summary of the findings of pedagogical practice is presented as a conceptual framework. The GIST framework offers significant affordances to pedagogical practices within phased instructional practice.

7.6.2 Classroom Pedagogy and the GIST Framework

The central theme in this study is classroom pedagogical practice. In the previous section, the proposed GIST framework summarised pedagogical practice, supported by planning and evaluative practices and impacted by curriculum. The GIST framework is embedded within the “chunking” together of grouped students’ work activities as IBL instructional phases. The instructional phases signalled by lesson intentions have similarities with other science IBL models that are process-oriented, such as the 5E model (Bybee et al., 2006) and the cycle of inquiry model (Pedaste et al., 2015). In the GIST framework there is a structured interaction between the instructional phases and the pedagogical aspects. This chapter proposes a model that could have practical application to teaching and draws on phased instructional practice and the GIST framework.

To recapture the student activities occurring within each inquiry phase in a guided IBL science activity:

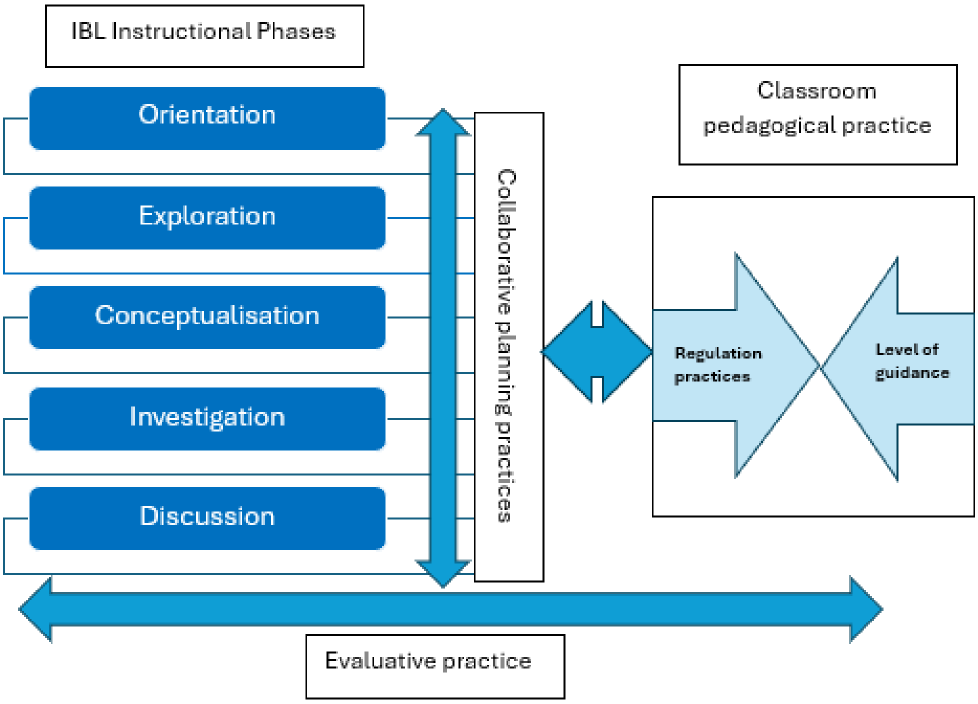
1. Orientation: Students learn about new concepts relevant to the context of the Depth Study and revise previously learned content and skills.
2. Exploration: Students explore the literature on the concepts, practice science laboratory skills, or conduct exploratory fieldwork (this phase might also be included as the first inquiry phase).
3. Conceptualisation: Students propose inquiry questions, hypotheses, and methods. They trial their ideas in the laboratory. They argue and debate their ideas in their groups.
4. Investigation: Students conduct their investigation, process, and analyse their data.
5. Discussion: Students communicate their findings and evaluate their work.

As discussed in Chapter 2.6, well-cited phased IBL models in the science education domain were recognised when developing the suggested GIST framework. The seminal work of Bybee et al. (2006) is of most significance, as it proposed a sequence of instructional phases suitable for teacher planning. In a single literature search using the Education Resource Centre (ERIC), 358 studies referring to the 5E Instructional Model (Bybee, 2006) were cited. In recent studies in 2021 and 2022, ten articles were cited that imposed the 5E model in empirical studies. Other scholars have built upon the 5E phased model, including Eisencraft (2003), Lubiano & Magpantay (2021), and Pedaste et al. (2015), who have produced phased conceptual IBL models that suit different education contexts and focus on student learning.

Inquiry phases were signalled by clear lesson intentions and a change in classroom arrangements that allowed for group discussion, laboratory work, fieldwork, and individual work. Figure 27. is a proposed model which intersects the GIST framework with a phased instructional approach.

Figure 27

Suggested Guided Inquiry Science Teaching Model



Note. The terminology used within the framework is based on Bybee et al. (2006); Dobber et al. (2017); Lazonder & Harmsen, (2016); Pedaste et al. (2015).

The development of the classroom pedagogical aspect as the core theme of the GIST framework is represented in Figure 27. This framework has been informed by the literature, extensive peer and teacher feedback through discussions following conference presentations, and member checks from study participants.

Within each inquiry phase, student learning was shown to be cyclic, and the teachers' decisions were iterative and responsive. Within each phase, the teachers' interactions with their students were intended to "to elicit and acknowledge student responses, to clarify and to extend student ideas" (Tytler & Aranda, 2015, p. 425). Importantly, each teacher made decisions about the purpose of their interactions and the level of guidance required that would not restrict their students from becoming independent and self-regulated learners.

Underpinning the GIST framework are the essential collaborative planning practices that occurred before and during the IBL, informed by ongoing classroom monitoring and teacher evaluation of the teaching program. Continuous classroom monitoring using a guided IBL approach is a recommended teacher practice in the early years of schooling (Tytler & Prain, 2022), and it was also an observed practice in this study of senior secondary school science teachers. Monitoring often accompanied teachers' flexible and informal formative assessment practices, which included providing feedback.

The inquiry phases based on the grouped activities that the students were completing are indicated in Table 34. They are compared to the well-cited Bybee et al. (2006) 5E Biological Science Instructional Model and the Cycle of Inquiry model (Pedaste et al., 2015). The differences between the GIST framework phases and the Bybee et al. (2006) and the Pedaste et al. (2015) models reflect the contextual suitability of the GIST framework to the senior years of science teaching, where students already have some understanding of the nature of science and the scientific method.

Table 34

Comparison of Phased IBL Models with the GIST Framework

Model features	5E. Bybee et al. (2006)	Inquiry cycle. Pedaste et al. (2015)	GIST
A staged process for instruction	Yes (5 inquiry phases): Engagement **Exploration** Explanation Elaboration Evaluation	Yes (5 inquiry phases): **Orientation** **Conceptualisation** **Investigation** Conclusion **Discussion**	Yes (5 inquiry phases): **Orientation** **Exploration** **Conceptualisation** **Investigation** **Discussion**
Sequence	Linear sequence	Partly cyclic model	Some iteration built into the model within and between each inquiry phase
Developed using existing teacher practices	Developed by the researcher and reflects researchers experience	Adapted from Bybee et al. (2006) and a meta-analysis for the European 'Ark of Inquiry' project.	Developed as a summary of the findings of an empirical study
Advice on the purposes of teacher practices	Some general advice for teachers is provided.	No. Focuses on the specific practices of students	Regulation practices (Dobber et al., 2017; Furtak et al., 2012)
Offers advice on levels of inquiry	Guided IBL	Guided IBL	Levels of guided inquiry Lazonder and Harmsen (2016)
Offers explicit advice on differentiation	No. Teachers are encouraged to design strategies.	No	Yes, through application of the levels of guidance

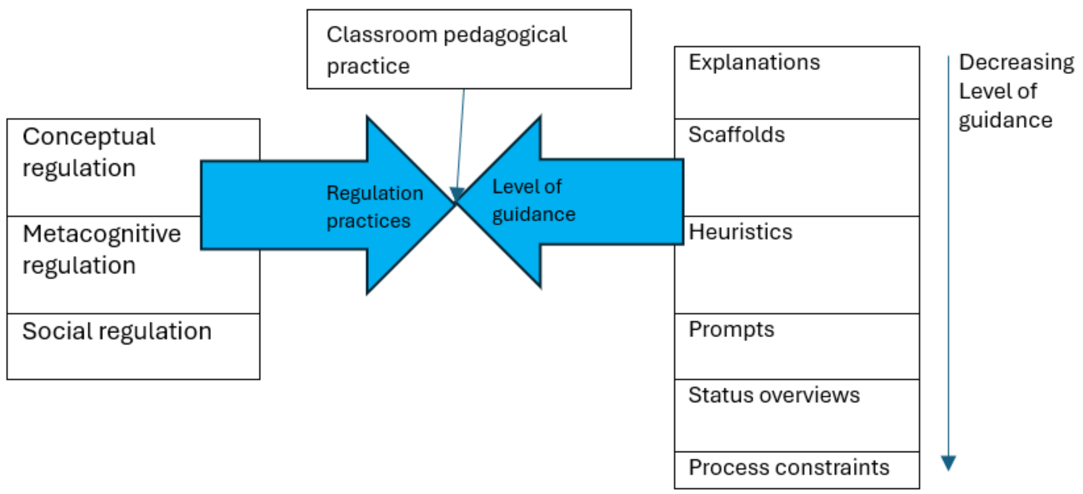
Provides detailed advice on student learning	Yes	Yes	No. Supportive of other conceptual models.

Compared to the Pedaste et al. (2015) model, which was proposed for the middle years of schooling, the GIST framework’s inclusion of broad phases without sub-phases allows for a cycling of activities and greater flexibility for older students. The most significant theme of the GIST framework is classroom pedagogical practice within each of the inquiry phases, which is represented in Figure 28.

Classroom pedagogical practices connect the purpose of instructional practice (regulation practice) and the teacher's level of inquiry when selecting a teaching strategy. Classroom pedagogical practice, represented in Figure 28. is not presented as being a formulaic instructional model. It has the potential to be used in teacher professional learning and to guide teachers to make informed choices about the teaching strategies that they select.

Figure 28

Classroom Pedagogical Practices in the GIST Framework



Note. The terminology used within the framework is based on Bybee et al. (2006); Dobber et al. (2017); Lazonder & Harmsen, (2016); Pedaste et al. (2015).

While most of the observed teaching strategies included one regulation practice, there were times when two regulation practices were combined. The expert teachers often selected social and metacognitive regulation practices together. This is unsurprising since social regulation was a feature of the students supporting each other in their practical group work. The integration of social regulation with conceptual and metacognitive regulation practices has also been noted in the literature (Dobber et al., 2017).

Within each inquiry phase, the expert teachers considered all three regulation practices important to the task, and they developed possible strategies that could use the different levels of teacher guidance. To illustrate how regulation practices and levels of guidance were incorporated in the selection of teaching strategies, summaries are provided in Tables 35, 36, and 37. including observed examples.

Table 35

Conceptual Regulation Practices and Guidance Levels

Conceptual regulation	Guidance levels	Examples of teaching practice
Lesson intentions and revision of work	Explanations	Communicate lesson intentions through explicit instruction.
	Scaffolds	Assist students by providing some ideas of inquiry questions for them to choose from by using templates and providing some information
	Heuristics	Use Socratic questioning to extend thinking and provide suggestions
	Prompts	Indicate when students need to evaluate their work through suggestions and gestures
	Status over-views	Establish a checkpoint for each group to gain feedback
	Process constraints	Provide a structure so that students can work independently by providing written guidelines, a rubric for the assessment, and conceptual information.

Table 36

Metacognitive Regulation Practices and Guidance Levels

Metacognitive regulation	Guidance levels	Examples of teaching practice
To support students in developing a research question and method	Explanations	Communicating expectations for each lesson Communication about the structure for an inquiry question and a method.
	Scaffolds	Guided use of written templates to guide the structure of inquiry questions and methods
	Heuristics	Asking students why they adopt approaches through questioning and offering advice

Metacognitive regulation	Guidance levels	Examples of teaching practice
	Prompts	By gesturing and indicating that students are working well together
	Status over-views	Checkpoints provide group feedback on areas for improvement
	Process constraints	Students independently develop their inquiry question and method using the guidelines in the rubric and support materials.

Table 37

Social Regulation Practices and Guidance Levels

Social regulation	Guidance levels	Examples of teaching practice
To ensure that groups are working together and contributing equally to the project	Explanations	Communicated expectations through direct instruction
		Safety instructions for student groups provided through explicit instruction
	Scaffolds	Demonstrate part of a technique to a group and divide the remaining tasks between group members
	Heuristics	Asking what the students were currently working on and offering a direction for the team to explore
	Prompts	Teacher presence in the room indicating when student groups needed to think about safe practices in the laboratory
	Status over-views	Informal group feedback provided at the checkpoint
	Process constraints	Students work within the established parameters of the investigation without support.

Of interest is that each identified teaching strategy had an identified purpose in regulating student learning, and the expert teachers chose a level of guidance to provide differentiated instruction. This suggests a simple relationship that has potential application, where teachers select a regulation practice and an appropriate level of guidance. The findings of this study have significant implications for teaching, policymaking and research design, which are discussed further in the following sections.

7.7 Contributions to Knowledge

This study makes three significant contributions to a positive narrative of guided IBL instructional practice in senior secondary science: contemporary pedagogical practice in IBL, the development of the GIST framework, and a strengths-based approach to IBL research. In particular, the development of a nuanced conceptual framework is a significant contribution to knowledge.

7.7.1 Contemporary Pedagogical Perceptions and Practices of IBL

The perceptions of the education leaders and the practices of the expert teachers informed the highlighted contemporary pedagogical practices. The contributions to knowledge include the education leaders' regard of IBL in senior secondary science and a flexible definition of levels of guidance. This inquiry-phased instructional sequence aligns with senior secondary science, teacher-developed topics, and the broad range of pedagogical strategies used in the classrooms.

This research strongly supports a guided IBL approach relating to the curriculum requirement of the Depth Study (NESA, 2017 a,b,c,d), where expert teachers selected strategies supported by intentional regulation practices and intentional levels of guidance to support students in their scientific investigations. While the education leaders used the terms "guided", "open", and "structured" to describe an overall level of teacher guidance, only two education leaders recognised the variation of guidance levels used in a differentiated classroom. During the following research phase, the expert teachers were observed to vary the level of guidance they offered and not adopt a static level of guidance.

The sequencing of identified instructional phases varied from those of two cited phased IBL conceptual models (Bybee et al., 2006; Pedaste et al., 2015). Within a guided approach to IBL, the expert teachers organised chunks of instructional practice, including a range of student activities, within each instructional inquiry phase. The inquiry phases were named in this research with consideration to existing conceptual models due to the nature of the activities the students completed within each instructional phase. The inquiry phases identified in this study offered an amended sequence to phased IBL models and recognised the practices of teachers in senior secondary science.

The use of teacher developed topics was highlighted throughout the study by both the education leaders and the expert teachers as a form of guidance. The expert teachers implemented teacher-developed topics for curriculum reasons and to support the availability of equipment resources. While this practice had the potential to restrict student choice, Erin, an expert teacher, pointed out the importance of taking time to develop and select a topic that would enable a wide student choice to support the curriculum requirements. She also highlighted the importance of developing a topic that was of personal relevance to students. The student participants in this study supported this idea. In planning for IBL, the deliberate use of teacher-developed topics required careful development and iteration to enable students' engagement without overly restricting student choice. This finding is significant for supporting inexperienced IBL teachers by providing a supportive structure.

The value of instructional practice coupled with an intentional level of guidance was also a significant finding of this study. Within a guided IBL approach, the expert teachers adopted a range of regulation practices and levels of guidance, both of which have been underexplored in the literature in empirical studies in this research context (see Sections 2.5.2 and 2.5.3). The expert teachers used an interplay of regulation practices (Dobber et al., 2017; Furtak et al., 2012) and guidance levels (Lazonder & Harmsen, 2016) during their interactions with students, while also selecting a wide range of teaching strategies.

A significant finding was that the expert teachers used explicit forms of instruction at different times to orient the students with the topic of IBL they had chosen in addition to regularly providing lesson intentions and explicit instructions to reinforce safety. This finding refutes an ongoing argument that positions explicit instruction teaching strategies in opposition to IBL. The findings indicated that the use of explicit instruction in IBL was included in a range of teaching strategies adopted by the expert teachers in this study (de Jong et al., 2023; Tytler & Prain, 2021).

Education leaders reported that teachers had difficulty in supporting students to develop inquiry questions. During the Conceptualisation inquiry phase, when students were observed to be developing their own questions, teachers focussed strongly on the use of metacognitive regulation pedagogical practices including the greatest range of guidance levels (five levels). The expert teachers were also observed to be in constant demand during this time. Their agility in being able to adapt their pedagogical practice was required to support a differentiated classroom during this intense inquiry phase. This finding should be considered when mentoring early career teachers who may require additional classroom support.

Focusing on contemporary practice is essential in IBL research because of the significant variations in approach and curriculum impacts in different education contexts. This study suggests that the perceptions of IBL amongst educators in the Australian jurisdiction have changed since the time of Goodrum et al. (2012).

7.7.2 The GIST Framework and Pedagogical Practice

The GIST framework is a significant contribution to knowledge because, rather than emphasising the cognitive dimensions of student learning, the framework focusses on pedagogical approaches that support the differentiation of student learning without providing a linear, step-by-step instructional process.

Bevins and Price (2015) warned against formulaic IBL models that do not reflect the messy and iterative nature of science, which follow a strictly linear process. Instead, an adaptive and iterative instructional model has been recommended (see also Duncan et al., 2021). The goal of students being able to regulate their learning in IBL should be an aspirational goal of any framework or model used to support teacher. To support students learning about the nature of science, IBL teachers should consider including an approach that uses broad inquiry phases.

The GIST framework has the potential to support teachers to make choices about their pedagogical practices rather than be a formulaic and linear pattern of instruction. In line with the need expressed by the education leaders for IBL support for some teachers, the practical application of the GIST framework can support teachers working in a range of education settings, including differentiated classrooms, to build a repertoire of strategies that span several levels of inquiry and to support regulation practices. For example, when considering questioning practices, a teacher might consider metacognitive regulation practices, which include scaffolding, heuristics, and prompts. And when planning resource materials for conceptual regulation, teachers might provide contextual information and scaffolded guidance to support diverse learners. The GIST framework recognises the professional experience and decision making of classroom teachers – their knowledge of their students and their monitoring and evaluating of their students' work.

Rather than discounting other phased IBL models, the GIST framework is supportive of other models, such as the well-cited BSCS 5E Instructional Model (Bybee et al., 2006) and redevelopment of the 5E model for the middle years of science (Pedaste et al., 2015) which focus on the student domain of learning (Section 2.6). These well-cited models provide a supportive phased structure for teacher planning, which is supported by the findings of this study. GIST could be used alongside these and other IBL models to enhance these models further with teacher guidance.

The Integrated Mathematics and Science (IMS) conceptual model (Tytler & Prain, 2022) was recently developed to support pedagogy in the younger years of schooling. The IMS model includes elements of the findings of this study such as orienting, exploration, conceptualisation, and continuous monitoring of student work. Where IMS supports the teaching of integrated mathematics and science in the junior years, GIST focuses on the nature of senior science education within a particular curriculum requirement. These differences suggest that future research into a curriculum-specific approach to IBL modelling is warranted, while recognising that aspects of each model may be transferable across learning areas.

The GIST framework supports pedagogical development by supporting teachers to make informed decisions about their instructional approaches. It is specifically designed to accompany the Depth Study requirement of the NSW Australia science curricula as a phased model that is supportive of the required formal assessment included in the curriculum.

7.7.3 A Strengths-Based Approach to IBL Research.

This study contributes to knowledge of research design in IBL that reduces the emphasis away from deficit teacher practice to the practices of highly experienced teachers who have recognised expertise. A paucity of empirical studies in this research context was earlier emphasised in Section 2.4. Through the selection of expert teachers and educational leaders as study participants effective teacher practices were sought, which drew the narrative away from an emphasis of the issues of IBL and placed importance on good pedagogical practices.

Existing studies of teacher practice often rely on reported practices (Dobber et al., 2017) which might not provide an accurate reflection of actual practice. Reported practices have been noted by other researchers as being less reliable than classroom observation (Haig et al., 2015) and the current research places less reliance on reported teacher practices by utilising classroom observation and a range of other data sources. While the selection of highly experienced study participants is not new to research (Fang, 2021; Tytler & Aranda, 2015) and requires a value judgement, this study adds to observation by including multiple data sources including student interpretation.

Unobtrusive and repeated classroom observations were effective in recording actual teacher practices and minimised any impact on the work of the students. This included not using recording devices and using field notes as a method of recording classroom observations over a series of lessons to reduce the 'Hawthorn Effect' consistent with Grounded Theory Design methodology (Corbin & Strauss, 2015). There was very little impact on the teachers on any additional equipment set-up or any requirements to accommodate for the researcher in the classroom. The impact on the research participants was further reduced because they were not required to implement a strategy or model. This was a particular consideration in this research context during a time when the NSW Government focused on moves to decrease the administrative burden on teachers.

A student voice provided an important interpretation in this study and the student focus groups enabled open conversation about their perspectives. The use of student voice is scarce in cited IBL studies in the research context and earlier studies such as Goodrum et al. (2012) may no longer accurately reflect contemporary student perspectives of IBL. This study also required students to make judgements about their teacher's practice. It is recognised that this can be sensitive for a teacher and by focusing the conversation on the positive aspects of their teachers' practices, ethical practices which supported the expert teacher participants were maintained. Students provided useful alternative interpretations which required triangulation with the researchers' interpretation of good practices.

Expert teachers and education leaders were positioned as experts in this study which is different to other cited IBL studies where the researcher enters the research as an expert. A significant meta-analysis of Dobber et al. (2017) on "The role of the Teacher in Inquiry-Based Education" recommended that further studies which included and recognised the expertise of the teacher were required. Hasni et al. (2016) also reported on a dominance of studies where imposed models had been implemented and as a result, contemporary IBL teaching practices were not well documented. The current research approach enabled the study participants to openly express their views without fear of judgement. This positive approach supported the collection of rich descriptive and insightful data to inform the identified research gap.

7.8 Study Implications

This study highlights important implications for teachers, informs a positive argument for IBL, and has important implications for policymakers in teacher professional learning and curriculum development.

7.8.1 Implications for Teachers

The findings of contemporary perceptions and practices of IBL in NSW Australia suggest changes in teacher perception and practice since earlier reports of students completing structured science investigations (Goodrum et al., 2012) and add to the ongoing evaluation of IBL in Australian schools. The optimistic view expressed by study participants about the value of IBL provides the momentum to support the development of IBL in science education and counter opposing arguments that question the value of IBL in recent years (Sweller, 2021).

The use of guided topics was highly supported by the students in this study, who felt appropriately supported. The examples include in the findings of teacher-developed topics might add to a repertoire of possible guided IBL topics that could support teachers and their students in planning IBL if differentiated guidance was required. Differentiated guidance has important implications for supporting students to develop from being reliant on the teacher to being able to regulate their own learning.

The GIST framework has great potential to support teachers in their pedagogical approach. The GIST framework balances the nature of science, which is not sequential, with a broad pedagogical structure. It positions socio-constructivist and explicit teaching approaches together instead of opposing approaches, which is also agreed by de Jong et al. (2023) and Tytler and Prain (2021) when guided IBL is implemented. The GIST framework requires teachers to consider the purpose of their instructional practice with a chosen level of guidance. Rather than being formulaic, GIST supports teachers to make informed decisions about their teaching approaches. The GIST framework developed in this study could be used alongside a range of IBL science activities and has solid benefits for in-service teachers and pre-service teachers who require pedagogical development. It recognises the contextual differences between teachers, their schools, the students, and curriculum requirements and allows teachers to make informed and supported decisions about the practices they adopt.

Evaluative teacher practice, an ongoing element of the GIST framework, is essential. Of importance to teachers is the high value of constant monitoring of student work by the expert teachers, and the formative assessment practices, which were both pre-planned and spontaneous, provide further support for teachers. Grob et al. (2017) and Ruiz-Primo and Furtak (2007) also observed the importance of a range of formative assessment practices in IBL. Grob et al. (2017) recommended presenting examples of good teacher practice and embedding formative assessment into a unit of work. The examples of good practice in this study add to the volume of work in this research area supportive of teacher practice.

In this study, each expert teacher planned five instructional phases. Phased IBL instruction situated student activities into clusters within each inquiry phase and allowed students to cycle through their work while learning about the nature of science. The phased instructional practices that supported a guided IBL approach are also supported in recent research (Duncan et al., 2021; Martin et al., 2021). The inquiry phases in the GIST framework support teacher planning specific to guided IBL in senior secondary science and provide a revision to previous phased models specific to senior secondary science (Bybee et al., 2006; Pedaste et al., 2015).

7.8.2 Implications for Debates that Question the Value of IBL.

This thesis provides evidence for arguments that debate the positive value of IBL. The findings agree with de Jong et al. (2023) and Tytler and Prain (2021), who argue that IBL involves a range of instructional practices and teachers have an active role rather than a passive role in the classroom, which can include direct instructional practices. The findings contribute to a body of literature relating to teachers' contemporary pedagogical approach in IBL in senior secondary science. The research highlights the interactions of pedagogical approaches and changes over a sequence of lessons rather than a single pedagogical practice in isolation. These interactions are significant in teacher education and development since they present a complex system and highlight the need for planning and targeted teacher development.

In this study, the classrooms of the expert teachers and the facilitative role evolved. Expert teachers acted as moderators and challenged, suggested, and supported the students. At times, expert teachers also need to act as mediators to direct and intervene in learning differentiation and support safe practices. They utilised different levels of guidance and purposeful regulation practices. The changing role of the expert teachers in this study challenges the notion that a teacher remains in one facilitation role (Bybee, 2006; Carriera, 2020). The findings of this study have implications for the way teachers learn to flexibly instruct and guide in an IBL classroom.

Arguments that position IBL as a dangerous form of teaching (Kirschner et al., 2006; Sweller, 2019) require an objective view. Recent commentary which argues for a greater use of explicit instructional practices (de Jong et al., 2023) need to be balanced by considering the benefits of IBL and how IBL can be enhanced with some explicit instructional practice. In science education, teachers need to consider the benefits of IBL as being supportive of students learning about the nature of science, which enhances critical thinking skills (Duncan et al., 2021), and balance student independence with explicit forms of teaching as a form of guidance.

7.8.3 Implications for Policymakers

Education policy is reported to reinvent education direction with politically motivated reform agendas instead of relying on good research evidence (Duncan et al., 2021). In this research context the implementation of the Depth Study was informed by the research evidence of the Australian Curriculum, yet there are also lessons that policymakers could learn from past experience. The practices and perceptions of practising teachers found in this study have provided insight into the enactment of the NSW Australia Depth Study curriculum requirement. These insights can be used to inform future curriculum reform such as the support teachers require to implement new curriculum requirements.

This research contributes to knowledge of the enactment of NSW Australia senior science curricula at a point in time (2020-2021). No research cited at the time of the study reported on how the IBL Depth Study requirement in the senior science curriculum (NESA, 2017 a,b,c,d) was enacted in NSW schools and the teacher perceptions of it, apart from anecdotal evidence. This study indicates how the Depth Study curriculum requirement has been interpreted, which presents a significant contribution to knowledge that might inform future policymakers in making further improvements or changes to curriculum design.

The evidence that education leaders, expert teachers, and students in this study welcomed the IBL requirement as a part of the compulsory senior science curriculum through the Depth Study requirement is a positive effect of curriculum change in this research context. Policymakers should look to improve the enactment of the Depth Study requirement with further support for teachers to overcome some of the difficulties that teachers experience. This support should also consider IBL pedagogical approaches and professional learning opportunities.

The current emphasis in the Australian curriculum (Lonsdale et al., 2024) on explicit instructional approaches is not an opposed teaching method; however, policymakers should emphasise that explicit instruction is one of a range of approaches that could be included in guiding IBL. Further empirical studies are required to provide evidence of teacher practices that inform this commentary and influence decision-making.

The impacts of compulsory curriculum, including external testing, were relevant to this study and voiced by education leaders in Section 5.2. The overcrowding of the curriculum and the effect of compulsory testing were reported to restrict the level of inquiry, which might account for the dominance of guided forms of IBL reported in this study. This restriction has been previously reported in other jurisdictions (Bevins & Price, 2015; Hume & Coll, 2010) and is an issue that challenges curriculum reform and policymakers across the globe. The impact of the compulsory curriculum is a significant finding that might inform future curriculum developers who need to consider these impacts to provide the space for students to engage in open IBL. Future curriculum developers must consider the breadth of the curriculum in policy documents balanced with requirements of an external examination to allow space in the curriculum for IBL.

Student participants who participated in the focus groups were highly engaged and held informed views of IBL at all case schools by articulating features of the nature of science and spoke positively about working in a group. This optimistic view is also an essential consideration for policy. It indicated that student motivation and interest were positive factors that supported the continuation of an IBL requirement in the senior science curriculum. Student motivation is an essential feature of IBL, as shown by recent Australian research in science education (Martin et al., 2021). The collaborative nature of a socio-constructivist approach is highly beneficial in mirroring post-school collaborations and has also been identified as necessary for students. Furthermore, the advantages of IBL highlighted by Furtak et al. (2012) strongly support a revised and strengthened curriculum approach.

This research has implications that could inform decisions made about teacher education in science education, in particular IBL pedagogical approaches. A significant effect of professional learning is reported to be a change in teachers' beliefs about IBL, which leads to improved practice (Hofer & Lebens, 2019; Silm et al., 2017). All expert teachers in this study were supportive of IBL and spoke about the benefits of IBL to their students. The benefits of IBL need to be included as a part of teacher education to encourage positive perceptions of IBL.

In addition to teachers developing a positive set of beliefs about the value of IBL, a programme of teacher development which focuses on the use of a wide range of pedagogical approaches would be of value to support teachers. Expert teachers in this study noted the paucity of pedagogical support and they received at the time of implementation of the Depth Study. It is recommended that professional learning programmes be developed to accompany new curriculum requirements in the future.

The value of experienced teachers and the support that they can provide within a school were emphasised in this study. Each of the expert teachers and some of the education leaders in this study provided significant support to other teachers who were enacting IBL within their schools. Therefore, leadership development which strongly supports teachers within their schools is also another highlighted area for further policy consideration.

7.9 Further Research

This study raises a range of additional questions and suggests areas of further research that might significantly support pedagogical practice. The important findings contribute to the current debate over the use of IBL pedagogies, which risks devaluing the importance of IBL in science education, as described in Section 7.2. The methods used in the study provide empirical evidence of teacher practices, which are recommended for further studies in this research context and include a range of interacting pedagogical practices.

A verification study would enhance this research, although it is an optional part of the transferability of this study. The GIST framework relies on teachers making their own decisions regarding their pedagogical strategies. Regulation practices and guidance levels provide that supportive structure within the model to inform the selection of teaching strategies for IBL teaching. The IBL instructional phases proposed in the GIST framework could be adapted in other contexts, and any trials of the model should consider existing planning structures that teachers might already be using. Such a study would need to be conducted in the senior years of schooling at various schools implementing guided IBL. Although the findings have been developed with the NSW curriculum requirement of the Depth Study, they could also be applied to other jurisdictions and courses, including the International Baccalaureate Diploma in the sciences for shorter guided IBL activities.

The reported slow implementation of IBL noted in the literature could be accelerated by using and building on existing practices of expert teachers rather than focusing on deficit models of practice. Design-based or action research would be a welcome addition to IBL research so that the teacher experts can be included in decision-making.

Further research is recommended in specific science curricular. According to the education leaders in this study, there appeared to be a need for a range of examples of IBL in physics compared to the other senior secondary science disciplines of chemistry, biology, and earth and environmental science. The uniqueness of the practical physics classroom and its relationship to guided IBL require additional research to support IBL practice. Recent research in the context of the physics classroom that focused on pedagogical approaches in physics IBL (Meulenbroeks et al., 2024), supported by the findings of this research relating to the challenges in physics IBL.

Pedagogical guidance to support student communication in IBL is also warranted. Although the evaluation of student work was not a part of this study, the observed written responses that were presented were of varying quality, and the expert teachers were not observed to guide this process with responsive practice. Instead, students completed most of this work at home and seemed comfortable in doing that. Feedback provided on this research at a conference presentation, highlighted student communication in IBL as a focus of current IBL research. Further studies which focus on pedagogical practices supportive of student written work, including the use of a range of representations, is supported in senior secondary science.

This study has indicated that IBL research can quickly become outdated because of improvements in and changes to teachers' practice. Emerging digital applications and the current educational research in this area can change IBL and inform the nature of science practices (Sharples et al., 2015; Rodriguez et al., 2020; Sun et al., 2022). The sudden reliance on digital technologies during this study due to a global pandemic, school lockdowns, and the emerging use of generative artificial Intelligence (AI) suggests a rapid change in teacher practice during the study period with a greater reliance on digital forms of communication (Gerard et al., 2016). Korkman and Metin (2021) recently proposed that online collaborative learning in the IBL context has advantages over face-to-face collaboration. Students at Currawong HS cited the advantages of online collaborations in this study, and continued evaluative research is warranted in this area in senior secondary science.

Some studies have suggested that using digital learning environments and software might supplement the role of the teacher. (de Jong et al, 2023; Sharples et al, 2015; Rodriguez et al., 2020) Moreover, AI systems have the potential to provide automated guidance and evaluation of student work (Gerard et al., 2016). These warrant further exploration alongside appropriate IBL conceptual models and teacher practices. According to the teacher and student study participants, a digital blog was shown to be efficient and successful. Further development of digital evaluative and instructional systems using AI technologies could add value to a busy classroom and support teaching and learning.

In this study, digital support during the conceptualisation phase and during the exploratory activities when the demand for teacher support is at the highest would benefit by digital support. Digital evaluation tools and instructional tools could supplement the role of the teacher using the adaptive IBL instructional model proposed in this study as a framework. At the very least, digital processes could include the use of digital blogs where students ask questions and see the teacher's answers collectively (Currawong HS). Digital scaffolds that could take over or support some of the more demanding activities in IBL have the potential to be built into a digital system and some development in that area has been noted (Wang et al., 2021). AI systems that could evaluate student work have already been trialled in previous studies (Gerard et al., 2016), and software that can supplement the instructional role of the teacher have emerged (de Jong et al., 2023; Sharples et al., 2015; Rodriguez et al., 2020). These example are highly recommended for continued research and development.

The challenges in classroom management for a teacher managing a busy and interactive IBL classroom is a further area for investigation. In this study, the expert teachers managed a busy and noisy classroom effectively, and there were no observed behavioural issues; however, a less experienced teacher might require additional support, mainly if student behaviour was a significant issue. Typically, IBL is not a linear process; students might work at different stages and on different topics at any time. According to the literature, many teachers are only sometimes well equipped to decide individual students' needs in a busy classroom (de Jong et al., 2023), and several students might require support at any time. Classroom challenges justify continuing research work on classroom management in the IBL classroom particularly for early career teachers.

The methods used in this study have the potential to turn the research narrative around to support a strengths-based approach to IBL and further build on teacher practices. A strengths-based approach to IBL research is recommended in future IBL research to enhance a science education future that does not discard what can be learned from existing practices and past experiences. The methods used in this study situate the teacher and educator as having expertise in their practice. Highly experienced study participants who could add value to the findings were selected, and a student's voice added an interpretation to the observed expert teacher practices to add rigour to the interpretation. By raising the status of teacher participants, a co-contribution between the researcher and teacher experts can lead to stronger ownership and applications of research findings (Bevins & Price, 2015).

It is argued that where human participant interpretations are made, a value judgement is made, and other data sources must be used to interpret the findings further. This study included the students who could further emphasise the teacher practices that were important to them. Other studies that have sought student views about pedagogical practices in IBL in senior secondary science have expressed limited regard for student perceptions of their teachers' practices (Carvalho et al., 2011; Concannon et al., 2020). In this study, some students could articulate good insight into their teachers' practices and add further interpretation to the observed findings by highlighting what was important to them.

7.10 Study Limitations

This is an interpretative, qualitative, and small-scale study that relied on the impartial interpretation of the researcher to research the phenomena deeply. The researcher's perspectives and biases can potentially influence the interpreted findings of this study (Guba & Lincoln, 1985). Researcher bias was managed by using multiple forms of data and triangulating the findings.

The researcher's own experience as a school educator also brings with it some inherent biases that were considered throughout the study and had the potential to limit the interpreted findings. These biases include the knowledge that IBL is not enacted consistently and that many teachers require support. Therefore, the interpreted findings require multiple forms of data to add study rigour and limit preconceived ideas. Including a student's voice in this study sought to add perspective to data interpretation and has assisted in highlighting and identifying regulation practices and levels of guidance as central teacher practices. Coding the data using the words used by study participants systematically using digital software also limited any data from being missed or interpreted in the analysis.

The small sample size was a limitation that might restrict the transferability of some of the findings into different educational contexts. The practices of the expert teachers in Phase B of the study might be different in other education contexts due to the context of the school and the students. The selection of the expert teachers (n=4) was limited to the teachers located at three independent schools in the Sydney NSW region, and it is acknowledged that this did not capture the diversity of schools in NSW Australia due to the small sample size and the chosen location.

The student participants participating in the focus groups were a self-selected sample from each observed class. Two of the four groups interviewed were perceptive of their teacher's practice, and the remaining two groups were more focused on reporting how they worked and responded under their teachers' guidance. While the focus group format was adequate for two groups (Lorikeet HS and Cockatoo HS focus groups), the other two focus groups would have benefited from a more structured approach to the interview since they required regular prompting during the discussion. A review of the research questions to include some targeted questions might have supported students to think about different aspects of their teacher's practice and avoid discussion that was outside of the scope of the research.

An unforeseen and minor limitation in conducting the classroom observations was slightly impacted by the COVID-19 pandemic and school closures during the range of the study period. Public health directions delayed the observations of schools and imposed health restrictions on the researcher in response to the COVID-19 pandemic when conducting the research in schools. Restrictions related to limiting movement around the classrooms and not working near students may have limited the number of conversations that could be heard and recorded by the researcher in the classroom, and limited the conversations that the researcher could have with the students while they were working.

The scope of this study was limited by the feasibility of a single researcher collecting and analysing the data using an interpretive methodology in the time allowed for a doctoral thesis. The scope of the study did not allow time for a further verification study, which is recommended, although optional, because the GIST framework is supportive of the decisions that teacher make concerning their pedagogical practice.

7.11 Conclusion

This thesis recognised the expertise of teachers in their profession and has drawn on existing perceptions and practices rather than focusing on interpreted deficit practice in the NSW Australia context. The complexity of IBL teaching was noted by education leaders as being a challenge for some teachers which warranted further exploration in the second phase of the study. The expert teachers in this study adopted a range of interacting pedagogical approaches which were analysed as being dynamic and interacting.

This study supports contemporary IBL research which is specific to each education context. The impact of curriculum in senior science education in the NSW Australia context was shown in this study to impact teaching in IBL by placing restrictions on class time, through assessment requirements, and a focus on an external examination.

In this study most education leaders and expert teachers used broad topics to guide their students in response to the restrictions of the curriculum requirements.

This study developed a suggested framework of instructional practice named the 'Guided Inquiry Science Teaching' (GIST) framework, which is situated in the domain of teacher practice. Central to the framework are five instructional phases, regulation practices and guidance levels (Figure 26). The findings of this study have the potential to support pre-service and in-service teacher education by providing a suggested instructional framework.

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Appendix A

Secondary Science Education Leader Information Sheet and Consent

Semi-Structured Interview Participant Information Sheet and Consent

a. SECONDARY SCIENCE EDUCATION LEADER INFORMATION SHEET

Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context. (HREC REF NO. ETH19-4039)

WHO IS DOING THE RESEARCH?

My name is Deborah de Ridder and I am a student at UTS. My supervisor is A/Prof Matthew Kearney.

WHAT IS THIS RESEARCH ABOUT?

The aim of this research is to investigate current teacher beliefs and good teacher practices about inquiry-based learning (IBL) in Years 11 and 12 Science. The research aims to use those findings to develop a model of practice for the Year 11 and 12 IBL which focuses on the NSW curriculum requirement of the *Depth Study.* This research is an important step in promoting IBL practices in Year 11 and 12 Science both in Australian and internationally.

There are three phases to this investigation which include semi-structured interviews of education leaders, case studies and model development. The research utilises qualitative data sources through semi-structured interviews, lesson observation, document analysis, analysis of student artefacts, student focus groups and teacher evaluation, during the three phases of study. Data will be triangulated to gain a picture of good teacher practice. The data will be used to inform the development of a model that can be applied to secondary science in Australia and internationally to improve inquiry-based learning in science education.

WHY HAVE I BEEN ASKED?

You have been identified as being a leader of Secondary Science in NSW who has knowledge of a wide variety of practices in relation to inquiry-based learning in Years 11 and 12 and the NSW curriculum requirement of the *Depth Study*.

IF I SAY YES, WHAT WILL IT INVOLVE?

By participating in the semi-structured interviews during the first phase of the study, you will contribute insight into current teacher beliefs and practices for the *Depth Study* requirement of the NSW curriculum and inquiry-based learning practices in general. Your data and those from other leaders in this field will inform the design of the remainder of the study which involves in-depth case studies and the conceptualisation of a model of good practice. The interview with you will be about 30 minutes in duration as a Zoom interview or telephone interview at a time convenient to you. It will involve broad questions about a teachers' beliefs and practices of IBL in Years 11 and 12. The discussion will be audio-recorded and you and your organisation will be de-identified once the data is transcribed.

ARE THERE ANY RISKS/INCONVENIENCE?

There should be minimal risk since you will not be identified and the questions are not of a personal nature. As much as possible I will fit in with your schedule for the interview.

DOES ANYONE GET PAID FOR PARTICIPATION?

No. Participation is voluntary. The school recognises that the study will contribute to improved teacher practice both in the school and throughout Australia.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you and you whether or not you decide to take part. You may withdraw at any time.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. 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 Deborah de Ridder (researcher) Deborah.L.deRidder@student.uts.edu.au or A/Prof Matthew Kearney (supervisor) at Matthew.Kearney@uts.edu.au

It should be noted that if you withdraw from the study after the completion of data collection, it may not be possible to locate your de-identified data to remove it.

CONFIDENTIALITY

By signing the consent form, you consent to the researcher collecting and using data gathered from you. All information will be treated confidentially and real names and schools/organisations will not be used for this research.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact me on Deborah.L.deRidder@student.uts.edu.au or my supervisor A/Prof Matthew Kearney at Matthew.Kearney@uts.edu.au

You will be given a copy of this form to keep.

NOTE:

This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, 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. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

SECONDARY SCIENCE EDUCATION LEADER CONSENT FORM

I ____________________ *[participant's name]* agree to participate in the research project "Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context" being conducted by Deborah de Ridder, University of Technology, Sydney.

I have read the Participant Information Sheet or someone has read it to me in a 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.

I understand that I will be given a signed copy of this document to keep.

I agree to participate in

☐ Semi-structured interviews

I agree that the research data gathered from this project may be published in a form that:

☐ Does not identify me or my place of work in any way

☐ May be used for future research purposes

I am aware that I can contact Deborah de Ridder at Deborah.L.deRidder@student.uts.edu.au if I have any concerns about the research.

____

____/____/____

Name and Signature [participant]

Date

____

____/____/____

Name and Signature [researcher or delegate]

Appendix B

Verbal Consent Script Semi Structured Interviews

VERBAL CONSENT SCRIPT

(HREC REF NO. ETH19-4039) - **Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context.**

Interview no:

Date:

Time:

Interviewer: Deborah de Ridder

Thank you for agreeing to speak with me today about your perceptions about the beliefs and practices of the Stage 6 Science *Depth Study*. The interview will take approximately 30 minutes. If you feel that you would rather not go on with the interview that is fine too.

[Waiting for participant to confirm they are happy to continue, otherwise thank them for their time.]

Thank you. Now I just need to confirm some information about you, and I'm going to start audio recording. This will help us to accurately record your answers, but all this information will remain completely confidential. Is that OK?

Wait for response

First, I need to ask you some questions to confirm that you consent to participating. Remember, even after you've answered these questions, you can withdraw your consent at any time during the interview. However, it may not be possible to withdraw your data from the study results if these have already had your identifying details removed.

The consent questions are:

Question	Yes	No
Have you read the information contained in the participant information sheet?		
Have you had an opportunity to ask questions and are you satisfied with the answers you have received?		

Do you understand that the research will produce reports, academic work and articles?		
Do you freely agree to participate in this activity, with the understanding that you may withdraw at any time?		
Do you agree to having this interview audio recorded and transcribed?		

(If answered NO to any of these – clarify and/or discontinue interview)

If you have any concerns about the research you can contact

Deborah.L.deRidder@student.uts.edu.au or my supervisor A/Prof Matthew Kearney (supervisor) at Matthew.Kearney@uts.edu.au

If you would like to talk to someone who is not connected with the research, you

If the participant declines to provide verbal consent:

may contact the Research Ethics Officer on 02 9514 9772 or

Research.ethics@uts.edu.au and quote this number: ETH19-4039

Appendix C

Semi Structured Interview Schedule

Semi-structured interview dates and times

Pseudonym names	Date	Length of interview (minutes)
Sasha	14 May 2020	32:33
Megan	15 May 2020	26:32
Elle	14 May 2020	34:33
Tom	19 May 2020	31:52
Ali	22 May 2020	30:52
Nadia	29 May 2020	25:42
Gretta	1 July 2020	50:02
Peta	3 July 2020	39:11
Ann	14 June 2020	40:15
Matt	25 July 2020	46:15
Robin	28 April 2021	45:11
Erin	8 July 2021	42:18

Note: All interviews were conducted via videoconference outside of regular work hours.

Appendix D

Expert Teacher Information Sheet and Consent

Expert Teacher, Case Studies Participant Information Sheet and Consent

Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context.

WHO IS DOING THE RESEARCH?

My name is Deborah de Ridder and I am a student at UTS. My supervisor is A/Prof Matthew Kearney WHAT IS THIS RESEARCH ABOUT?

This aim of this research is to investigate current teacher beliefs and good teacher practices about inquiry-based learning (IBL) in Years 11 and 12 Science. The research aims to use those findings to develop a model of practice for the Year 11 and 12 IBL which focuses on the curriculum requirement of the *Depth Study.* This research is an important step in promoting IBL practices in Year 11 and 12 Science both in Australian and internationally.

There are three phases to this investigation which include semi-structured interviews of education leaders, case studies and model development. The research utilises qualitative data sources through semi-structured interviews, lesson observation, document analysis, analysis of student artefacts, student focus groups and teacher evaluation, during three phases of study. Data will be triangulated to gain a picture of good teacher practice in IBL. The data will be used to inform the development of a model that can be applied to senior secondary science in Australia and internationally to improve inquiry-based learning in science education.

WHY HAVE I BEEN ASKED?

You have been invited to participate in this study because you have been identified as an exemplary Science Teacher who regularly engages with student inquiry in the Years 11 and 12 Science classroom through the NSW curriculum requirement of the *Depth Study*. A science education leader has recommended you and shared your contact details with me.

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate, I would like to include you as a case study teacher. It will involve a commitment of time over the duration of the *Depth Study* over a one week/two week period although it should not be onerous or too time-consuming. Participation in the research is a good opportunity for you to contribute to a body of knowledge in Science Education and IBL and reflect on your own practice.

Semi-structured interview

Initially, I will invite you to a semi-structured interview of approximately 30 minutes at a place and time that is mutually agreed upon prior to the case study. The interview will focus on your beliefs and teacher practices of inquiry-based learning and will be audio-recorded. After the interview, the audio recording will be transcribed verbatim. You and your school will be de-identified in the transcripts. The original recording will not be stored or listened to by any other person apart from myself. If requested, you will have the opportunity to read the transcript and approve its use for the purposes of this study.

Lesson Observations

The case study follows the interview and will include at least one of your Year 11 Science classes who are engaging in a *Depth Study*. This will include observation of the class during the duration of the *Depth Study*. The commencement and completion dates will be nominated by you and it is expected that at least 7 sessions of observation will be included. Class observations will occur via Zoom and you will be required to engage in the Zoom session by placing the laptop or iPad at the back of the room and enabling video and audio. I will have my video and audio switched off while I am observing.

Recording of the classroom observation data will be written using a hand-written journal and will not be audio or visually recorded. The purpose of the observations is to observe the practices that you include to facilitate a *Depth Study*. Students will not be closely observed, although if they agree to be observed I may view their work (with their permission) and speak to them briefly by Zoom, at your discretion during the lesson. I will endeavour to conduct this research in an unobtrusive manner to avoid any interruptions to teaching and learning. Fieldwork or work outside of the classroom may be observed directly and unobtrusively with school permission. I will remain at least 1.5m away from students and will not travel with the class.

You will be asked to distribute and collect student permission forms prior to the study which I will make available to you. The forms will allow the students to choose whether they would like to be involved in the study and participants are not to be coerced. Students who have not been granted permission will conduct their learning as normal within the class the class. I will also ask that all students wear a name tag during direct observations which I will organise during the initial sessions so that I can easily identify students who agree to be a part of the study and avoid embarrassing anyone who has not been granted permission.

Student focus groups

At the end of the *Depth Study*, 4-6 volunteer students from each class will be invited to a focus group of approximately 30 minutes in duration which will be organised at lunch to provide an evaluation of the *Depth Study*. I will randomly select these students from the list of students who have indicated their willingness to participate and have returned consent forms. I will require a staff member to be present at the focus group meeting to supervise. This session will take place via Zoom and it is requested that the interview takes place on a teachers' computer device, in a classroom and not through a student email account. The students will be asked questions about what they found helpful and challenging about the Depth Studies. This session will be video and audio-recorded, stored securely and deleted once transcribed.

Students will require parental/guardian permission to be involved in the focus groups and to allow me access to their work samples.

Work samples and document analysis

During the case study I will also require access to your units of work which include the *Depth Study* as well as any volunteer student artefacts including assessment tasks. These will be analysed and mapped against the curriculum. It is understood that the assessment tasks will need to be analysed sometime after the *Depth Study* and I can complete that work off site any time after the observation period. If digital copies are the preferred mode of dissemination to me, I will de-identify all names and the school prior to secure storage.

ARE THERE ANY RISKS/INCONVENIENCE?

Yes, there is some inconvenience which will be kept to a minimum. There is some time commitment outside of class time in being a part of this study. The impact on the Year 11 classes that are observed in this study will be minimal since the methods of observation are unobtrusive and students will not be identified in this study. Any artefacts or documents reviewed during the study will be de-identified and confidentiality will be maintained at all times.

Since the focus of the study is to identify good teacher practices, it is not anticipated that practices that are not effective will become a focus of the study. Rather than there being any risk to your reputation, it is more likely that the process will be an affirming and a positive experience. You will be able to gain benefit by reflecting on your own practices.

You may also decide to be identified in any papers that are written during and after the case study and the school may permit images or you to be used for that purpose. This will only be done with your permission and the permission of your principal. Hence, participating in the research could be a positive experience for you and your school. Student images will not be used for the purposes of this study.

DO I GET PAID FOR PARTICIPATION?

No. Participation is voluntary. However, if there are any expenses incurred due to the research study, they will be reimbursed by the researcher.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. 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 Deborah de Ridder (researcher) at

Deborah.LdeRidder@student.uts.edu.au or A/Prof Matthew Kearney at Matthew.Kearney@uts.edu.au or ph: +61 29514 5165

If you withdraw from the study during the interview, all your audio recording and transcripts will be destroyed.

However, it should be noted, that it may not be possible to withdraw your data from the study results if these have already had your identifying details removed during data processing. School and case study data can be removed after the case study if required. Any transcribed data may be viewed at any time for approval.

CONFIDENTIALITY

By signing the consent form you consent to the researcher collecting and using information about you for the research project. All this information will be treated confidentially and your name and the organisation at which you work will be coded and de-identified.

We would like to store your information for future use in research projects that are an extension of this research project. In all instances your stored information will remain de-identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact me on Deborah.L.deRidder@student.uts.edu.au or my supervisor A/Prof Matthew Kearney (supervisor) at Matthew.Kearney@uts.edu.au or

You will be given a copy of this form to keep.

NOTE:

This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, 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. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Expert Teacher Consent Form

I ____________________ *[name]* agree to participate in the research project "Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context" being conducted by Deborah de Ridder, University of Technology, Sydney.

I have read the Participant Information Sheet or someone has read it to me in a 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.

I understand that I will be given a signed copy of this document to keep.

I agree to participate in

☐ Semi-structured interview

☐ Lesson observations

☐ Informal discussion

☐ Making curriculum documents and student works available for analysis

☐ I agree that the researcher must not be left alone with students that are in my care

I agree that the research data gathered from this project may be published in a form that:

☐ Does not identify me in any way

☐ May be used for future research purposes

I am aware that I can contact Deborah de Ridder at Deborah.L.deRidder@student.uts.edu.au if I have any concerns about the research.

____ ____/____/____

Name and Signature [participant] Date

____ ____/____/____

Name and Signature [researcher or delegate] Date

Appendix E

Student Information Sheet and Consent

Student Participant Information Sheet- Parent Information

Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context.

WHO IS DOING THE RESEARCH?

My name is Deborah de Ridder and I am a student at UTS. My supervisor is A/Prof Matthew Kearney.

WHAT IS THIS RESEARCH ABOUT?

The aim of this research is to investigate current teacher beliefs and good teacher practices about inquirybased learning (IBL) in Years 11 and 12 Science. In order to do that, the perceptions of students and their learning experiences in the classroom are required to inform the research about teachers' good practices. The research aims to use those findings to develop a model of best practice for the Year 11 and 12 inquiry-based learning which focuses on the curriculum requirement of the Stage 6 *Depth Study.* Hence, the participation to students in the research is important in the development of the model. This research is an important step in promoting IBL practices in Year 11 and 12 Science both in Australian and internationally.

There are three phases to this investigation which include semi-structured interviews of education leaders, case studies and model development. The research utilises qualitative data sources through semi-structured interviews, lesson observation, document analysis, analysis of student samples of work, student focus groups and teacher evaluation, during the three phases of study. The data will be processed and analysed to provide a picture of good teacher practice that will be used to inform the development of a model that can be applied to senior secondary science in Australia and internationally to improve inquiry-based learning in science education.

WHY HAVE I BEEN ASKED?

Your child's teacher has been asked and has agreed to participate in this research study that involves the observation of exemplary teacher's practices in IBL in the classroom. Parental consent is required for your child to participate in this study.

IF I SAY YES, WHAT WILL IT INVOLVE?

Class observations will occur via Zoom with the researcher recording observations off-site. The teacher may ask students to speak to the researcher during the session if they have provided consent. The researcher may attend fieldwork sessions and will remain 1.5m away from the students for any sessions outside of the classroom.

If your child decides to participate, they may be asked to be included in a Focus Group at the end of the study to evaluate the *Depth Study* component of the Year 11 Science course. The area of interest in this research is the *Depth Study* which emphasises inquiry-based learning. The focus group will include 4-6 students who will discuss with the researcher those aspects of the *Depth Study* that they found helpful and those aspects that they found challenging. This will be conducted over 30 minutes at lunch time, while they eat lunch, and will both inform the research and provide the teacher with valuable feedback. A Zoom link will be sent to the teacher and the focus group will be supervised at the school by a staff member. Students will be in a classroom and the laptop will be connected to a data projector screen. I will be using video and audio during the session and will be recording the session. The recording will be saved as an audio only file, securely stored and once transcribed after the interview, the file will be deleted.

While the lesson observations are largely centred on the teacher, there may be times when students are observed unobtrusively while they are working. This includes some informal conversations with the students. However, every attempt will be made not to interrupt their work, hence, informal conversations will only take place at appropriate times.

Students who volunteer to participate in the research will be identified by a name tag which all students will wear during any direct observations so that the researcher can identify them.

Permission is also sought for the researcher to analyse student work such as the assessment tasks during the period of the research. Work samples will be viewed outside of the classroom and will not be graded or judged for achievement. In all analysis, the student or their school will not be identified in this research. The analysis will be based on curriculum outcomes and the variety of student approaches to the *Depth Study*.

ARE THERE ANY RISKS/INCONVENIENCE?

Observations in the classroom will be based on how the teacher teaches and how the students learn. The impact and risks will be minimal as the researcher will be observing via Zoom from the back of the classroom. The teacher or the class will not be recorded during class lessons and observation data will be recorded by the researcher by hand. The time impact of conversations between Year 11 students and the researcher will be kept to a minimum by conducting them only at appropriate times that are convenient to the students and the teacher and keeping them short and relevant.

The focus group session with students will be held at lunch at the end of the *Depth Study* and students will not miss lesson time by participating in the focus group discussion. Arrangements will be made for them to eat lunch either during or prior to the session.

Students, teachers and schools are not identified in this study and the confidentiality of the collected data will be a priority. Focus group interviews will be conducted via Zoom and audio recorded for transcription so that an accurate record of the data can be used for analysis. No students will be identifiable from the recordings.

DO I GET PAID FOR PARTICIPATION?

No. Participation is voluntary.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part and you can choose to participate in either or both the class observations and/or the focus group. Both you and your Parent/Guardian must complete the consent form to allow for your participation.

WHAT WILL HAPPEN IF I SAY NO?

Students who say no will carry on with their learning in the classroom as normal. All students will be treated with the same respect and only students who have agreed to the study will talk to the researcher about their work or allow their work to be viewed.

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. 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 Deborah de Ridder (researcher) Deborah.LdeRidder@student.uts.edu.au or A/Prof Matthew Kearney (supervisor) at Matthew.Kearney@uts.edu.au or ph: +61 29514 5165

If you decide to withdraw from the study during the study period I will make every attempt to identify and remove any data that has been collected of you. If you decide to withdraw after the research period, it might not be possible to locate de-identified and confidential data to remove it.

CONFIDENTIALITY

By signing the consent form you consent to the researcher collecting and using personal information about you for the research project. All this information will be treated confidentially and your name and your schools will be coded and de-identified.

We would like to store your information for future use in research projects that are an extension of this research project. In all instances your stored information will remain de-identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact me on Deborah.L.deRidder@student.uts.edu.au or my supervisor Matthew Kearney (supervisor) at Matthew.Kearney@uts.edu.au

You will be given a copy of this form to keep.

NOTE:

This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, 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. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

STUDENT PARTICIPANT AND PARENTALCONSENT FORM

I ____________________ *[student's name]* agree to participate in the research project "Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context" being conducted by Deborah de Ridder, University of Technology, Sydney.

We have read the Participant Information Sheet or someone has read it to us in a language that we understand.

We 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.

I understand that I will be given a signed copy of this document to keep.

I agree to participate in:

☐ Focus group discussion

☐ Allow the researcher to observe my work in class

☐ Allow the researcher to analyse my assessment tasks and classwork

I agree that the research data gathered from this project may be published in a form that:

☐ Does not identify me in any way

☐ May be used for future research purposes

I am aware that I can contact Deborah de Ridder at Deborah.L.deRidder@uts.edu.au if I have any concerns about the research.

____ ____/____/____

Name and Signature [student participant] Date

____ ____/____/____

Name and Signature [parent/guardian] Date

____ ____/____/____

Name and Signature [researcher or delegate] Date

Appendix F

School Principal Information Sheet and Consent

a. **SCHOOL PRINCIPAL PARTICIPANT INFORMATION SHEET**

Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context.

WHO IS DOING THE RESEARCH?

My name is Deborah de Ridder and I am a student at UTS. My supervisor is A/Prof Matthew Kearney.

WHAT IS THIS RESEARCH ABOUT?

This aim of this research is to investigate current teacher beliefs and good teacher practices about inquiry-based learning (IBL) in Years 11 and 12 Science. The research aims to use those findings to develop a model of practice for the Year 11 and 12 IBL which focuses on the NSW curriculum requirement of the *Depth Study.* This research is an important step in promoting IBL practices in Year 11 and 12 Science both in Australian and internationally.

There are three phases to this investigation which include semi-structured interviews of education leaders, case studies and model development. The research utilises qualitative data sources through semi-structured interviews, lesson observation, document analysis, analysis of student artefacts, student focus groups and teacher evaluation, during three phases of study. Data will be triangulated to gain a picture of good teacher practice. The data will be used to inform the development of a model that can be applied to secondary science in Australia and internationally to improve inquiry-based learning in science education.

WHY HAVE I BEEN ASKED?

Your staff member <name> has been identified as being an exemplar teacher who engages with student inquiry in the Years 11 and 12 Science classroom through the NSW curriculum requirement of the *Depth Study* and it is requested that they become a part of this important study. It is requested that at least one Year 11 class be observed for a one/two week period while they are completing a *Depth Study* in class.

IF I SAY YES, WHAT WILL IT INVOLVE?

By allowing your school to be a case study school for the purposes of this study, it will largely involve observing teacher and classroom practices and should have minimal impact on the Year 11 students. The collection of data in the classroom will involve unobtrusive methods of lesson observation and the impact of regular classroom activity should not be significant. The teacher will engage with semi-structured interviews, lesson observations, and I request permission to analyse units of work relevant to the course observed and student artefacts including assessment tasks, provided that student permission is granted. In detail, I seek your permission and support to undertake the following activities:

1.
Semi-structured interview

Initially, I will invite the teacher to a semi-structured interview of approximately 30 minutes at a place and time that is mutually agreed prior to the case study. The interview will focus on teacher beliefs and practices of inquiry-based learning and will be audio-recorded and transcribed after the interview. The teacher will have the opportunity to read the transcription prior to secure storage.

2.
Lesson Observations

The case study follows the interview and will include at least one of the teachers Year 11 Science classes who are engaging in a *Depth Study*. This will include observation of the class during the duration of the *Depth Study*. Observations in the classroom will occur on Zoom and observations in the field, outside of the classroom, may occur face to face with appropriate social distancing if permitted by the school and with respect to public health orders at the time of the fieldwork. The commencement date and completion dates will be nominated by you and it is expected that at least 7 sessions of unobtrusive observation will be included.

Recording of the data from the observations will be written using a hand-written journal and will not be audio or visually recorded. The purpose of the observations is to observe the practices that you include to facilitate a *Depth Study*. Students will not be closely observed, although if they agree to be observed and have returned consent forms I may speak to them briefly. I will endeavour to conduct this research in an unobtrusive manner to avoid any interruptions to teaching and learning.

The teacher will be asked to distribute student information sheets and permission forms and collect them prior to the study. The students have a choice whether they will be a part of the study and should not be coerced.

It should be noted that the researcher is not to be left alone in the classroom at any time during the research.

3.

<u>Student focus groups</u>

At the end of the case study, 4-6 students who have provided consent to participate, from each class, will be invited to a focus group of approximately 30 minutes in duration which could be organised at lunch to provide an evaluation of the *Depth Study*. I will randomly select these students if more than 4-6 students have returned consent forms and be present at the focus group meeting via Zoom to facilitate the session. The students will be asked questions about what they found helpful and challenging about the Depth Studies. A staff member who is not the class teacher is requested to be present during the focus group meeting and use a staff members'/school computer device in a classroom rather than a student device for the interview. The conversation will be audio recorded. Recordings will be stored securely and deleted once they are transcribed. The focus group could occur during lunch while the students are eating to avoid time away from class.

4.

<u>Work samples and document analysis</u>

During the case study I will also require access to units of work which include the *Depth Study* and any student work samples including assessment tasks. These will be analysed and mapped against the curriculum. It is realised that the assessment tasks will need to be analysed some time after the *Depth Study* and I can complete that work off-site any time after the observation period. I will de-identify all names and the school prior to secure storage. Students and their parents must provide consent for any student works to be analysed.

ARE THERE ANY RISKS/INCONVENIENCE?

There should be minimal inconvenience to the students in the class.

Students, teachers and the school are de-identified in this study and at no time will student names be recorded in any collection of analysis of data. Confidentiality will be paramount at all times.

There will be a small inconvenience of time to students participating in the focus group at the end of the study. However, students should find the work interesting and learn about the processes involved in research studies if they choose to be involved. There is a minor risk of embarrassment in the focus group although the nature of the questions are not of a sensitive nature and if students decide to withdraw at any time, they will be able to without question.

There is also inconvenience to the teacher which will be managed throughout the study. The teachers' reputation will be managed by ensuring that all data remains confidential. Overall, it is aimed that this study should be an affirming experience for the teacher.

The teacher may also choose to withdraw at any time.

DOES ANYONE GET PAID FOR PARTICIPATION?

No. Participation is voluntary. The school recognises that the study will contribute to improved teacher practice both in the school and throughout Australia.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to allow your teacher to take part. Students and teachers are able to withdraw at any time.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. 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 Deborah de Ridder (researcher) or A/Prof Matthew Kearney (supervisor)

It should be noted that if students, teachers or schools withdraw from the study after the completion of data collection, it might not be possible to locate the de-identified data and be able to remove it.

CONFIDENTIALITY

By signing the consent form you consent to the researcher collecting and using personal information about your teacher for the research project. All this information will be treated confidentially and the teachers name, student's names and the school will not be recorded for this research.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact me on Deborah.L.deRidder@student.uts.edu.au or my supervisor A/Prof Matthew Kearney (supervisor) at Matthew.Kearney@uts.edu.au or

You will be given a copy of this form to keep.

NOTE:

This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, 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. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

School Principal Consent Form

I _________________________________ [Principals name] agree to participate in the research project "Conceptualising a model of practice for inquiry-based learning in senior secondary science in the Australian context" being conducted by Deborah de Ridder, University of Technology, Sydney.

I have read the Participant Information Sheet or someone has read it to me in a 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.

I understand that I will be given a signed copy of this document to keep.

I agree to participate in

☐ School/teacher case study

☐ Semi-structured interview of the teacher

☐ Lesson observations of the selected class of students

☐ Informal discussions with students

☐ Making curriculum documents available for researcher analysis

☐ Analysis of student work

☐ Student focus group

I agree that the research data gathered from this project may be published in a form that:

☐ Does not identify the school in any way

☐ May be used for future research purposes

I am aware that I can contact Deborah de Ridder at Deborah.L.deridder@uts.edu.au if I have any concerns about the research.

____ ____/____/____

Name and Signature [participant] Date

____ ____/____/____

Appendix G

Phase B Observation Schedule

Expert Teacher Observation Schedule

School	Teacher	Number of students	Date/time
Cockatoo High School (11 hours)	Robin and Elle (co-teaching)	36	27 April 2021 (7 hours)
	Elle	23	28 April 2021 (1 hour)(AM)
	Robin	13	28 April 2021 (1 hour) AM
	Robin	13	30 April 2021 (1 hour)
	Elle	23	30 April 2021 (2 hours)
	Elle	23	5 May 2021 (1 hour)
Lorikeet High School	Megan	14	16 April 2021 (2 hours)
(11 hours)	Megan	14	20 April 2021 (1 hour)
	Megan	15	21 April 2021 (2 hours)
	Megan	14	26 April 2021 (1 hour)
	Megan	15	28 April 2021 (1 hour) (PM)
	Megan	15	3 May 2021 (1 hour)
	Megan	15	4 May 2021 (2 hours)
	Megan	15	5 May 2021 (1 hour)
Currawong High School	Erin	19	9 June 2021 (1 hour)
(11 hours)	Erin	19	10 June 2021 (1 hour)
	Kate/Erin	16	10 June 2021 (1 hour)
	Christine/ Erin	13	10 June 2021 (1 hour)
	Brad/ Erin	14	10 June 2021 (1 hour)
	Amanda/ Erin	16	10 June 2021 (1 hour)
	Amanda/ Erin	16	11 June 2021 (1 hour)
	Brad/ Erin	14	11 June 2021 (1 hour)
	Christine/ Erin	13	11 June 2021 (1 hour)
	Erin	19	11 June 2021 (1 hour)
	Kate/ Erin	16	11 June 2021 (1 hour)

Note: Field notes were collected for each observation session.

Appendix H

Introductory Script Student Focus Groups

Introductory Script Student Focus Groups

Thank you for participating in the focus group today, I consider student voice a valuable part of any educational research and I value your input.

We call this aspect of research, a “focus group”. Focus groups are often used in qualitative research to provide further research evidence. The purpose of this focus group is to find out the things that worked well for you during your *Depth Study* and those aspects that you found as being challenging. We will use a series of questions to guide our discussion today (provided) and during the discussion I will also be writing notes in my journal to capture the main aspects of the conversation. You will not be identified in this research using your name or schools and the content of our discussion will not be repeated in this school to anyone apart from your teacher. Your teacher might be able to gain some valuable feedback from the discussion today, however, he/she will not participate in the discussion. You are reminded that you can withdraw from the discussion at any time.

I’d like to set some protocols for the discussion today:

1. Respect the comments of others even if you disagree with them
2. There are no right or wrong answers to the questions and you will not be judged for your answers
3. Allow each person in the room to speak freely without interruption
4. Respect the privacy of others and do not repeat conversations that might be sensitive

Appendix I

Ethics Approvals

UTS Human Research Ethics approval number: ETH194039

Date of approvals and COVID19 amendments	Type of approval	Data collection range
23 March 2020- 23 March 2025	Ethics approval for Phases A, B and C by UTS Human Research and Ethics Committee.	Phase A May-August 2020
20 October 2020	COVID19 Amendment to conduct remote observations for Case study schools (Approved by HREC)	Observations delayed
8 April 2021	As per original approval	Semi-structured interviews and document collection: 15 February 2021- 16 September 2021.
	COVID 19 Amendment Permission to revert to on-site observation prior to the start of Phase B observations. (Approved by HREC) UTS COVID-Safe Research Activity Risk Assessment approved.(Approved by UTS FASS)	Onsite observations, informal interviews and student focus groups: 16 April 2021-12 June 2021.
8 September 2021	COVID19 Amendment Permission to conduct student focus group remotely (Currawong High School) Approved by HREC.	14 September 2021.

Appendix J

Open, Axial and Selective coding

Open codes	Axial codes	Selective codes
Understanding and regard for IBL, IBL topics, levels of inquiry, open inquiry, guided inquiry, classroom management, classroom facilitation, benefits of IBL, inconsistent teacher practice, teacher and student discomfort, teacher confidence, teacher expertise.	Benefits and constraints of Inquiry-Based Learning Choosing open and guided approaches Teacher developed topics Supporting students to develop their own Inquiry questions The changing role of the teacher	**The role of the teacher in inquiry-based learning**
External examination, compulsory curriculum, time pressure, completing curriculum content	Managing impacts of formal assessment Balancing completion of curriculum content with IBL	**Curriculum impacts**
Teacher collaboration, meetings, discussion, team teaching, resource planning, Laboratory equipment, teacher, laboratory staff, paper resources, booklet, digital resources, student management systems, Teacher planning, programming, scaffolding, laboratory resources, excursion planning, laboratory staff, marking rubrics, assessment resources.	Collaborative planning Teacher developed topics Developing student resources	**Planning practices**
Lesson intentions, lesson goals, milestones, planning topics and sequence. Lesson goals and intentions, checkpoints of student work.	Sequence of pedagogical practice Transitions between instructional phases	**Instructional phases**
Group work, student collaboration, practical skills, demonstrations, just-in-time teaching, knowledge of the concepts, Scaffolding, safety, feedback, dialogic and monologic talk practices, questioning, direct and explicit instruction, use of the classroom space, student independence, student learning, peer feedback, multimodal resources, flexibility, subject knowledge, facilitating, practical demonstrations, secondary sources.	Guidance within phased instruction: Differentiated guidance Adapting practices Lesson intentions Learning environment Regulation practices Levels of guidance Use of multimodal resources	**Instructional practice**
Feedback, peer feedback, marking, check points, discussion, questioning, rubrics, discussion, reflection	Evaluative practice of teaching practice Summative assessment Student evaluation	Evaluative practices (throughout planning and instructional practices)