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Cognitive Demands of Science Curricula:

A Case Study of Alignment Between Intention and Practice

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Abstract

The cognitive demands of curricula guide students' knowledge development and the cognitive skills they use to demonstrate their learning. As official curriculum documents are translated into textbooks and classroom teaching, the cognitive demands of knowledge may change, potentially impacting students' opportunity to learn content to its intended depth. This study investigated the alignment of cognitive demands between science syllabus objectives (the prescribed curriculum), textbooks (the de facto curriculum), and classroom instructions (the enacted curriculum). Taxonomies of educational objectives can provide a common language and classification framework when determining alignment. This study classified cognitive skills based on the six cognitive levels of Marzano and Kendall's (2007) New Taxonomy of Educational Objectives: retrieval, comprehension, analysis, knowledge utilisation, metacognition, and self-system thinking.

Data were collected in the context of a senior secondary curriculum reform in Queensland, Australia, using a collective case study design. Specifically, document analysis was used to determine the cognitive demands of syllabus learning objectives and textbook questions in Year 11 and Year 12 physics, chemistry, and biology. Data on the cognitive demands of classroom teaching were collected with a modified version of the Florida Taxonomy of Cognitive Behaviour (Brown et al., 1968) during the repeated lesson observations of 18 teachers in seven schools. Following this, curriculum alignment was quantified with Porter's (2002) alignment index.

Results show that the reformed senior science syllabi place greater emphasis on retrieval and comprehension than on higher-order cognitive skills such as analysis and knowledge utilisation. Metacognition and self-system thinking are implicit rather than explicit learning goals of each syllabus. Textbooks examined through this research were found to focus on a narrow range of cognitive skills and provide comparatively little opportunity for knowledge utilisation or metacognitive reflection. In these textbooks, facts are valued over processes, linguistic responses over symbolic responses, and deductive reasoning over inductive reasoning. Observed teachers' classroom instructions, in turn, showed that the enacted curriculum provides students with frequent and balanced opportunities to practise lower- as well as higher-order cognitive skills. However, higher-order tasks were dominated by theoretical analysis at the cost of contextualised or student-centred knowledge utilisation. Teachers' choices for instructional strategies showed little variety, and teacher-centred activities, such as individually answering practice questions, dominated the enacted curriculum.

Alignment between the cognitive demands of the enacted curriculum and prescribed curriculum was low, mainly due to insufficient comprehension and knowledge utilisation tasks in lessons. Therefore, classroom practice did not align with the intended cognitive demands of science curricula. The de facto curriculum in textbooks was only moderately aligned with syllabus learning objectives. Classroom teaching aligned most with textbook questions, with both curriculum components placing more emphasis on analysis than the syllabus objectives.

This study's findings highlight the difficulties of aligning enacted curricula with standardised learning objectives or national goals and the need for more critical awareness of science textbooks' influence on teaching practice. The discussion of findings explores the challenge of science curricula, which must strike a balance between educating future scientists with a strong foundational knowledge and cultivating scientifically literate citizens. It also considers the potential impact that the cognitive demands of science curricula and current instructional approaches have on student engagement with STEM subjects. Furthermore, this research carries practical implications for the design of teachers' education, to ensure teachers intentionally use educational taxonomies and effective pedagogies that equip students with the cognitive skills necessary for life in the 21st century.

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List of Acronyms

ACARA	Australian Curriculum, Assessment and Reporting Authority
ATAR	Australian Tertiary Admission Rank
ICSEA	Index of Community Socio-Educational Advantage
OP	Overall Position
QCAA	Queensland Curriculum and Assessment Authority
QCE	Queensland Certificate of Education
QTAC	Queensland Tertiary Admissions Centre
STEM	Science, Technology, Engineering, and Mathematics

Chapter 1. Introduction

The cognitive demands of learning can be conceptualised as the level of thinking required to successfully engage with a learning task (Stein et al., 2009). Scientific thinking, which is often described as a form of problem solving or reasoning (Holyoak & Morrison, 2012), requires a particular range of cognitive skills such as questioning, investigating, analysing, evaluating, and decision making (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2014). Effectively teaching these cognitive skills, and thus developing scientifically literate citizens, is a core purpose of science education (Rennie et al., 2001).

This study investigated the cognitive demands of the senior science curriculum in Queensland, Australia and appraised the alignment of cognitive skills in the prescribed learning objectives, textbooks, and classroom teaching. Learning objectives have two dimensions: the content knowledge students should construct and the cognitive skills students should use to demonstrate their learning. Content knowledge is likely to be interpreted and implemented more consistently than cognitive skills when learning objectives of a prescribed curriculum are translated into the de facto curriculum (teaching resources), and into the enacted curriculum taught in classrooms (Atuhurra & Kaffenberger, 2022; Blumberg, 2009; Boesen et al., 2014; Contino, 2013; El Hassan & Baassiri, 2019; Liu & Fulmer, 2008; Resnick et al., 2004; Webb, 1999; Ziebell & Clarke, 2018). While content matter outlined in learning objectives tends to match content matter in lessons, the lessons emphasise different cognitive skills or teach only a limited range of cognitive skills outlined by the learning objectives. The result is a change in the cognitive demands of knowledge as the curriculum is implemented.

Such findings suggest a problematic phenomenon that is about the nature of the relationship between intended and enacted curricula in the context of cognitive demand. The phenomenon is of concern due to the potential misalignment between the cognitive demands of teaching practice, teaching resources and the expectations set forth by curriculum developers. It is probable that the cognitive skills students are guided to develop are inconsistent among schools within the same education system. Consequently, not all students may be afforded the learning experiences essential to attain the prescribed learning. There is a need for a more profound understanding of how cognitive skills evolve during the curriculum implementation process and whether there are discernible patterns in changes to cognitive demands that can be effectively addressed across jurisdictions.

Alignment studies can quantify the differences in cognitive demands between various curriculum components. Thereby, they stimulate discussion on the appropriateness of emphasising certain cognitive skills in learning objectives, textbooks, and classroom teaching, which can improve the quality of instructional practice (Porter, 2002). Studying curriculum alignment is particularly important for evaluating whether introduced changes are interpreted and enacted consistently during the transition to a new curriculum after educational reform (Edwards, 2010). High curriculum alignment indicates that policy intentions in official curriculum documents are coherent with what is practised in the classroom, whereas low alignment calls for improved communication of the curriculum developers' vision, for example via teacher professional development and the design of aligned teaching resources. Therefore, alignment studies conducted during a change process, such as this research, can probe factors influencing the implementation of a new curriculum and improve decision making during reform efforts.

By focusing on the alignment of cognitive skills, this research has the potential to support teachers in deliberately developing their students' thinking skills at all levels of cognition and to stimulate dialogue about the cognitive demands of curricula in professional learning communities. In this manner, this research can create knowledge about ways to provide educators with agency to evaluate and purposefully increase curriculum alignment. Without teachers' explicit focus on cognitive skills, students may not develop their thinking skills to their fullest potential or they may have limited success with assessment tasks requiring higher-order thinking (Marzano & Kendall, 2007). A systematic literature review conducted as part of this research project showed that the cognitive demands of science lessons in Australian secondary classrooms are not well known. Without such knowledge, it remains unclear whether the aims of science curriculum writers have been achieved.

This chapter outlines why the alignment of a curriculum's cognitive demands requires empirical investigation and describes the context in which this case study collected data on curriculum alignment after a major educational reform. It introduces operational definitions of key terminology used to analyse and interpret data, and provides a summary of the research objectives and their assumptions. The chapter ends with a synopsis of the thesis.

1.1. The Investigated Problem

The following hypothetical example best illustrates the problem investigated in this study. Let us assume that an official curriculum document prescribes Year 12 physics students to achieve the following learning objective: *Students solve problems involving projectile motion*. The intention is for students to apply their knowledge of multiple algorithms and vector analysis to formulate solutions to authentic situations, such as predicting the motion of a student trying to jump the school's staircase on a bike. Expert physics educators will develop teaching resources that address the learning objective. They may write textbook practice questions for students, such as:

> A stunt rider attempts a 5 m wide jump. The take-off platform is 2.5 m higher than the landing platform [diagram provided]. Calculate the minimum horizontal speed that must be achieved to complete the jump successfully, disregarding the effect of air resistance.

Students are expected to select the appropriate algorithms and substitute values from the diagram to find the answer. In the classroom, a physics teacher may implement a lesson addressing the learning objective by reviewing relevant formulas for projectile motion and modelling several worked examples of textbook questions. Students are then provided with similar problems to solve independently by following the teacher's instructional steps. With sufficient repetition, students will master the procedure and the teacher may introduce more complex variations of the problem.

Examined independently, there is no problem with either step in the curriculum implementation. The learning objective, the textbook question, and the teacher's instructional approach can successfully engage students in the learning of the same required knowledge. However, when examined together, it becomes evident that the cognitive demand of the knowledge changes. While the curriculum document envisions students will use their knowledge of projectile motion to overcome a potentially unfamiliar problem and formulate a creative solution, the textbook question requires students to analyse a theoretical situation with clear parameters and limited correct solutions. The teacher's instructional approach, in turn, helps students retrieve and apply the steps of a procedure that can be used to solve certain types of projectile motion problems—a highly useful skill for physics examinations. Therefore, prescribed learning objectives, learning resources, and classroom teaching only align superficially. In this example, a gap exists between the cognitive demands of the prescribed learning objective and classroom teaching, potentially leading to an even larger gap between the cognitive demands required for learning science at school and practising science in other settings.

1.2. Study Context

In 2019, the Australian state of Queensland underwent a major senior curriculum reform. Key features of the reformed system are redeveloped syllabi for all senior subjects, new standardised assessment tasks including external examinations in subjects leading to tertiary study pathways, and the replacement of the Overall Position (OP) score with the Australian Tertiary Admission Rank (ATAR, see Department of Education, 2018). The new external examinations contribute 50% towards students' final subject results in the sciences and are thus considered high stakes. The ATAR is a percentile rank score that allows for the comparison of student achievement between subjects, state or territory systems, and years (McCurry, 2013). This rank score replaced the OP system to ensure greater transparency and rigour in Queensland's tertiary entrance system and improve the allocation of applicants to appropriate tertiary courses (Matters, 2015).

The implementation of the reformed Queensland Certificate of Education (QCE) aims to enhance the validity of evidence gathered about students' learning (Matters & Masters, 2014). Queensland's OP system was designed over 20 years ago and its effectiveness had not been formally reviewed since (Matters & Masters, 2014). Considering the fast-moving changes in educational agendas, tertiary or vocational study pathways, and workforce requirements over the past two decades, a redesign of the system was proposed. The reformed system addresses 23 recommendations outlined in *Redesigning the Secondary-Tertiary Interface: Queensland Review of Senior Assessment and Tertiary Entrance* (Matters & Masters, 2014, p. 59), which identified a list of "shortcomings in the current OP system." The Queensland Government's response to the review led to key recommendations about senior assessment, tertiary entrance, and implementation of a new senior system (Department of Education, Training and Employment, 2014). Responses to the recommendations were developed by a committee consisting of 22 subject working groups with representatives from state, private, and independent schools, universities, and unions. Thereafter, solutions were implemented by the Senior Secondary Assessment Taskforce established by the Minister of Education in 2016.

The resulting changes encompass a shift in curricular priorities in terms of knowledge and skills taught (Matters & Masters, 2014). Syllabus documents now have more specifically defined content descriptors to ensure the commonality of content knowledge around the state. Furthermore, concerns regarding a limited range of cognitive skills tested on former senior assessment have been addressed. The Queensland Curriculum and Assessment Authority (QCAA, 2019, para. 1), "a statutory body of the Queensland Government" charged with "a critical role in the design and delivery of education in Queensland," has prioritised Marzano and Kendall's (2007) New Taxonomy of Educational Objectives as the framework for their reformed senior syllabi. Each syllabus's learning objectives are prefaced by a cognitive verb based on the New Taxonomy. Cognitive verbs describe the depth to which students are required to understand and demonstrate their knowledge during assessment (QCAA, 2018e) and thus indicate the cognitive demand of the learning objective. For example, according to the New Taxonomy, *compare* is a Level 3: Analysis cognitive verb, thus the objective *compare mitosis and meiosis* requires teachers to provide students with opportunities to analyse the processes of mitosis and meiosis.

The importance of cognitive skills is emphasised throughout the reformed senior science syllabi. For example, the Teaching and Learning section of the physics, chemistry, and biology syllabi states that "students are required to use a range of cognitive processes in order to demonstrate and meet the syllabus objectives" (QCAA, 2018b, p. 5) and the first summative piece of assessment also requires the focus "on the application of a range of cognitions to multiple provided items" (QCAA, 2018b, p. 42). Moreover, the QCAA's (2018e, p. 1) *Cognitive Verb Toolkit*, a teaching resource accompanying the release of the reformed syllabi, states that "students explicitly taught the skills and processes of the cognitive verbs are better equipped to meet syllabus objectives and demonstrate their learning through assessment." All reformed syllabi include a Science as a Human Endeavour subject matter which aims to link theoretical science concepts to real-world social, economic, cultural, and ethical contexts. As such, the reformed senior syllabi resemble the current Prep to Year 10 Australian Curriculum by prioritising the development and assessment of student attributes that are considered necessary for life in knowledge societies of the 21st century (Matters & Masters, 2014).

A growing proportion of occupations in today's knowledge societies require skills in Science, Technology, Engineering, and Mathematics (STEM) subjects. Skill shortages in Australia create an impetus for the reformed senior science syllabi to align with Australia's aims for STEM education, such as increasing all students' foundational science knowledge and inspiring a larger proportion of students to pursue further study in STEM fields (Education Council, 2015; Tytler, 2007a). To achieve these aims, the *National STEM School Education Strategy 2016–2026* recommends that science education in classrooms focuses on contextualising learning experiences that resemble scientists' work life, and challenges students to make decisions while participating in open-ended tasks (Education Council, 2015). This requires students to confidently use complex cognitive skills beyond the more traditional manipulation or application of abstract knowledge in theoretical scenarios. Apart from the cognitive domain, quality science education should address students' affective domain. This can be achieved by creating interest in the natural world and motivation to engage in critical public discourse about scientific matters, making evidence-based decisions about one's own life (Rennie et al., 2001), or creating an increased awareness of commercial opportunities that result from the application of modern science (Tytler & Symington, 2006). Furthermore, STEM employers encourage schools to develop people skills like teamwork and communication in their future workforce (Tytler & Symington, 2006). Arguably, student-centred teaching strategies are more conducive to achieving these aims than a content-centred transmission pedagogy (Goodrum & Rennie, 2007; McBain et al., 2020).

The changes introduced by Queensland's senior curriculum reform in 2019 combined with Australia's national goals for science education provided a unique context for this research study. Data collected in the first two years of the reform's implementation allow for reflection on issues arising during the initial enactment of reformed syllabi. This, in turn, can shed light on how to improve educational policy and practice.

1.3. Operational Definitions

Literature on curriculum alignment does not use consistent terminology to describe the curriculum components analysed in this study (Remillard & Heck, 2014). To avoid misinterpretations, the following section discusses this study's choice of terminology for curriculum components. Furthermore, specialised terminology derived from the study's theoretical framework is defined.

1.3.1. Curriculum Components

Learning objectives in syllabus documents or standards written by an educational authority for use in schools are referred to as the *prescribed curriculum* (Ross, 2017). Alternative labels of this curriculum component in the literature include the *intended curriculum* (Porter, 2002), the *official curriculum* (Remillard & Heck, 2014), the *planned curriculum* (Marsh, 2010), or the *mandated curriculum* (Ziebell & Clarke, 2018). However, many of these terms are too broad. For example, the intended curriculum and planned curriculum seem to extend past formal curricular aims and include implicit instructional or pedagogical philosophies of teachers, while the official curriculum may also entail prepared learning resources and assessment tasks. The term mandated curriculum may have a negative connotation for some readers, implying that mandated content restricts teachers' agency or decision making. Hence, the term *prescribed curriculum* has been chosen as it most clearly focuses on the explicit written learning goals in official curriculum documents and because it has been used in Australian context in the past (e.g., Ross, 2017).

Teachers' classroom instructions and pedagogical choices to achieve the prescribed curriculum are termed the *enacted curriculum* (Remillard & Heck, 2014). Again, a variety of other terms are used in the literature to describe this curriculum component, including the *operational curriculum* (Phaeton & Stears, 2016; Remillard & Heck, 2014), the *implemented curriculum* (Törnroos, 2005), the *performed curriculum* (Ziebell et al., 2017), or the *experienced curriculum* (Marsh, 2010). This study opts for *enacted curriculum* as it seems to be the most widely used term in alignment studies and because it excludes teachers' intentions for instructions (e.g., unit and lesson plans). Thus, the enacted curriculum focuses on actual classroom learning opportunities provided to students and reflects teachers' professional judgements about how the prescribed curriculum should be implemented.

The final curriculum component examined in this study is the curriculum presented in textbooks, specifically in textbook tasks and questions. There are fewer terms in the literature naming this curriculum component and used terminology tends to include other lesson resources, such as online resources or resources developed by the school's science department. Törnroos (2005) describes the role of the textbook as *potentially implemented curriculum* to highlight its intermediate stage between the prescribed and enacted curriculum. However, this study uses the term *de facto curriculum* (Harwood, 2017) to acknowledge the influence of textbooks, which can replace the prescribed curriculum as a primary source of guidance for lesson planning (Usiskin, 2013).

There are further curriculum components that are beyond the scope of this research project. These include the knowledge and skills students have acquired as the *attained curriculum* (International Bureau of Education, 2022; Törnroos, 2005), the values and beliefs of the *hidden curriculum* (Gordon, 1982), and the knowledge and skills students are required to demonstrate in the *assessed curriculum* (Porter, 2004). These curriculum components are not explicitly or intentionally examined in this study, even though the seemingly strong influence of the assessed curriculum on the enacted curriculum is acknowledged (see Section 8.2.3.) and aspects of the hidden curriculum in science lessons are considered (see Sections 4.3.3. and 8.2.4.).

1.3.2. Cognitive Skills as Criterion for Curriculum Alignment

Literally speaking, curriculum alignment means that all curriculum components are arranged in a line, or complement each other. Starting with the prescribed curriculum, all explicit and implicit knowledge, skills, beliefs, and priorities of each curriculum component are similar and coherent (Näsström, 2008). Different methods for measuring curriculum alignment have been proposed (e.g., Porter, 2002; Resnick et al., 2004; Webb, 1999) without reaching a consensus on the criteria that should be used to evaluate the degree of alignment. Common criteria include the overlap of curriculum components in terms of content topics, the cognitive complexity or depth of knowledge, the breadth of knowledge, and the emphasis on particular content knowledge. Evaluations of common alignment models conclude that the choice of alignment criteria should depend on the goals of the analysis and the aims of the analysed curriculum (Cizek et al., 2018; Martone & Sireci, 2009).

This research focuses on cognitive skills as an alignment criterion for two reasons: firstly, the teaching and assessment of a wide range of cognitive skills have been prioritised in Queensland's reformed senior syllabi (QCAA, 2018e); and secondly, there is mounting evidence that cognitive skills frequently and significantly contribute to the misalignment of curricula (Atuhurra & Kaffenberger, 2022; Blumberg, 2009; Boesen et al., 2014; Contino, 2013; El Hassan & Baassiri, 2019; Liu & Fulmer, 2008; Resnick et al., 2004a; Webb, 1999; Yu et al., 2022; Ziebell & Clarke, 2018). The QCAA (2018g, p. 1) defines cognitive skills as "the mental process of acquiring knowledge and understanding through thought, experience and the senses." They help learners organise and integrate their experiences (Staver, 1998) and are thus an integral part of learning. Cognitive skills stated in syllabus objectives or lesson instructions determine the cognitive demand of the learning activity. For example, the cognitive skill *recall* is less demanding than the cognitive skill *explain* when applied to the same concept.

Educational taxonomies classify cognitive skills based on their demand or complexity. For example, Bloom et al.'s (1956) widely used Taxonomy of Educational Objectives categorises cognitive skills into six hierarchical levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. Since then, research on and discussion about the ideal classification of cognitive skills has led to the development of many more taxonomies. Some well-known taxonomies include the Structure of Observed Learning Outcomes (SOLO) Taxonomy (Biggs & Collis, 1982), the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001), and the New Taxonomy of Educational Objectives (Marzano & Kendall, 2007).

This study uses the classification system suggested by Marzano and Kendall's (2007) New Taxonomy of Educational Objectives to categorise cognitive skills into six levels:

1. retrieval: "the recognition, recall, and execution of basic information and procedures"
2. comprehension: "identifying and symbolizing the critical features of knowledge"
3. analysis: "reasoned extensions of knowledge … [by] matching, classifying, analyzing errors, generating, and specifying"

4. knowledge utilisation: "knowledge is used to accomplish a specific task … [by] decision making, problem solving, experimenting, and investigating"
5. metacognition: "setting and monitoring goals … [by] specifying goals, process monitoring, monitoring clarity, and monitoring accuracy"
6. self-system thinking: "addressing attitudes, beliefs, and behaviors that control motivation … [by] examining importance, examining efficacy, examining emotional responses, and examining overall motivation" (Marzano & Kendall, 2008, pp. 6–7).

While retrieval and comprehension of existing knowledge are considered lower-order cognitive skills, analysis and knowledge utilisation are classified as higher-order cognitive skills because they require students to extend existing knowledge. However, the cognitive levels in the New Taxonomy are thought to be non-hierarchical, which means that mastery of lower levels is not a prerequisite to higher levels. Metacognition and self-system thinking—also termed the metacognitive system and self-system, and henceforth referred to as the metacognitive and self-system—influence and direct thinking at the first four levels (Marzano & Kendall, 2007). The terminology and structure of the New Taxonomy underpin learning objectives and assessment tasks in the reformed Queensland senior syllabi (QCAA, 2017b), which is why it was selected as the most appropriate framework for this study's curriculum analysis.

1.4. Research Objectives and Assumptions

This study aims to investigate and quantify the cognitive demands of the prescribed, de facto, and enacted senior science curriculum. Further, the analysis of the enacted curriculum aims to shed light on pedagogical practices or typical learning tasks used to teach senior science in Queensland, Australia. Finally, the study aims to determine the degree of alignment between the three curriculum components to assess the extent to which intention has been translated into practice. The research questions chosen to achieve these research objectives were derived from a systematic literature review and are outlined at the end of Chapter 2.

The above research objectives rely on several assumptions made during the design of this study's methodology. For example, this study assumed that an analysis of the syllabus documents can uncover the type of cognitive skills that are valued by an educational reform. In other words, a syllabus analysis would provide insight into the type of thinking that is expected and preferred in the reformed Queensland senior science syllabi. It was also assumed that an examination of teaching resources, specifically textbook questions prepared for the implementation of the reformed curriculum, could indicate the cognitive skills students would practise when instructed to use their textbooks. Moreover, based on Porter's (2004) recommendation, the study assumed that lesson observations are a reliable and valid method to investigate the enactment of the reformed curriculum in classrooms and can highlight senior science teachers' preferred instructional approaches.

The methodology for this research project followed a case study approach and data were collected across seven schools in Far North Queensland. The remoteness of the region and the resulting low-density population, combined with a shortage of secondary science teachers (Bureau of Transport and Regional Economics, 2006) resulted in reduced opportunities for teacher collaboration or face-to-face professional development, thus increasing the challenge of implementing a reformed senior system. It was therefore assumed that research evaluating reform efforts, curriculum alignment, and teaching practice in such a context has the potential to uncover problematic aspects of curriculum enactment after reforms that may be less pronounced in other regions of Australia. Finally, the study assumed that an educational taxonomy is a valid categorisation framework for the cognitive demands of curricula on the basis that the use of educational taxonomies has shown acceptable reliability (Coleman, 2017) and that educational taxonomies are commonly used in curriculum alignment studies (Näsström & Henriksson, 2017).

1.5. Synopsis of the Thesis

Following this introduction to the study, Chapter 2 reports on the systematic literature review synthesising past research on curriculum alignment, with a focus on cognitive skills in the prescribed, de facto, and enacted curriculum. Search methods, which followed the PRISMA model (Moher et al., 2009), resulted in 132 relevant articles for the qualitative synthesis. The review highlights the significance of curriculum alignment and showed that alignment after educational reforms is typically low. In terms of each examined curriculum component, the review shows how the use of educational taxonomies in prescribed curricula can support alignment and encourage the explicit teaching of cognitive skills. It also indicates that textbooks often act as filters and conduits between the prescribed curriculum and classroom teaching. Finally, the review describes how recent changes in assessment and recommended pedagogies for science teachers emphasise the development of students' cognitive abilities, which has been linked to improved student outcomes. In light of these findings, the chapter outlines considerations for teachers in Queensland and concludes that research is needed on the enacted cognitive skills curriculum in Queensland and its alignment with the de facto curriculum and the reformed prescribed curriculum. This systematic review has been published in the *Australian Journal for Teacher Education* (Johnson et al., 2020).

Chapter 3 describes and justifies the study's methodology. A post-positivist research perspective and a collective case study approach were chosen to answer the research questions. The instrumental cases representing the senior science curriculum were the three subject areas: physics, chemistry, and biology. Cognitive demands of the prescribed, de facto, and enacted curriculum were analysed through the lens of Porter's (2002) alignment model and Marzano and Kendall's (2007) New Taxonomy of Educational Objectives. An initial pilot study shaped the final methods for the multi-method data collection and analysis. The document analysis of the prescribed curriculum and de facto curriculum involved the classification of 570 learning objectives in three syllabi as well as 8070 questions across nine textbooks. The syllabus documents were also analysed qualitatively for references to the metacognitive and self-system. Maximum variation sampling of teachers was used to gather quantitative and qualitative data on the enacted curriculum, which resulted in 82 lesson observations of 18 teachers in seven schools of the Far North Queensland school district. Curriculum alignment was calculated using Porter's (2002) alignment index. The chapter ends with a discussion of the research design quality and ethical considerations.

Chapter 4 presents findings on the cognitive demands of the prescribed physics, chemistry, and biology curriculum. Results showed that cognitive demands of learning objectives are skewed towards lower-order thinking skills in all three sciences. Further, comparisons with the replaced syllabi (i.e., the syllabi replaced in Queensland's 2019 senior curriculum reform) confirmed a reduced emphasis on analysis and knowledge utilisation. Teaching metacognition and self-system thinking were found to be implicit rather than explicit objectives of the reformed syllabi. The chapter's main conclusion is that there may be a mismatch between the policy goals of science education in Australia and the cognitive demands emphasised in the reformed syllabi, fuelling the debate about an appropriate balance of lower-order and higher-order cognitive skills in secondary science. These findings have been published in the journal *Research in Science Education* (Johnson et al., 2022).

Chapter 5 examines the cognitive demands of the de facto curriculum in nine senior science textbooks written for the reformed curriculum in Queensland, Australia. Results show that textbook questions emphasise lower-order cognitive skills, such as retrieval and comprehension, over real-world application of knowledge, metacognitive thinking, or reflection on beliefs and emotions. Textbook questions seem to value the learning of facts over processes, linguistic over symbolic responses, and deductive over inductive reasoning. A focus on a narrow range of cognitive skills in science textbooks may give students a false impression of the nature of scientific knowledge and practice beyond school. Based on these results, the chapter discusses the challenge for science educators to critically select high-quality teaching resources at a time of continuously increasing choice to ensure that students are able to meet the diverse cognitive, affective, and ethical demands of a globally changing milieu. The findings presented in this chapter have been published in the book *Challenges in Science Education* (Johnson & Boon, 2023).

Chapter 6 investigates the cognitive demands of the enacted curriculum based on 82 lesson observations in the 2020 school year. Year 11 and Year 12 physics, chemistry, and biology students were exposed to learning tasks with a range of cognitive demands. The findings indicate that 53% of teacher instructions fostered students' higher-order cognitive skills. However, higher-order thinking tasks rarely involved authentic knowledge utilisation or self-system thinking, which could decrease students' perception of the subject matters' relevance, and subsequently, their engagement. Lower-order thinking tasks seemed to value knowledge breadth over depth. Further, teachers' preferred instructional strategies were content-focused, prioritising individual over cooperative work and lacking variety. Spoken and written teacher questioning was frequently observed to foster thinking at every cognitive level. The discussion of these findings considers implications for increasing the engagement of Australian students with science learning in high school and beyond. This chapter's findings were presented at the 2023 Australian Science Education Research Association Conference in Cairns.

Chapter 7 quantifies and discusses the alignment of the prescribed, de facto, and enacted senior science curriculum. The alignment between the prescribed and enacted curriculum was low as retrieval and analysis tasks were overemphasised in the classroom, meaning that the aims of the recent senior curriculum reform were not yet fully implemented by teachers. The chapter's discussion suggests possible reasons for the misalignment of the prescribed and enacted curriculum and reiterates the need for higher alignment in a socially just curriculum. A second key finding is that the de facto curriculum found in textbooks is only moderately aligned with the prescribed curriculum and more strongly aligned with the enacted curriculum. Since the de facto and enacted curriculum both overemphasise analysis tasks over knowledge utilisation tasks when compared to syllabus learning objectives, it is likely that textbooks influence the cognitive demands of teachers' instructions in this study. The chapter makes the argument that more frequent inquiry learning may reduce this influence.

Chapter 8 provides a conclusion to the study by summarising the main research findings presented in Chapter 4 to Chapter 7 and by discussing the findings' significance. This includes a reflection on the balance between lower- and higher-order cognitive skills in science curricula, the strong influence of textbooks in the form of the de facto curriculum, and difficulties in aligning curriculum components after educational reforms as well as aligning curriculum with Australia's goals for science education. Implications of findings for the study of curriculum alignment are also outlined in the chapter; that is, the costs and benefits of increasing alignment through standardisation of curricula and the impact of a study's choice of educational taxonomy on research findings. Furthermore, implications for the implementation of curriculum reforms, for teacher education programs, and for effective science pedagogy are considered and discussed. This discussion centres around the significance of providing empirical evidence and practical tools for teaching cognitive skills to educators. Lastly, the limitations of this study are outlined, including recommendations for the design of future research studies that may address these limitations.

The appendices include the results of the pilot study based on nine lesson observations of two senior science teachers and subsequent teacher interviews. These preliminary results were presented at the 2019 Australian Association for Research in Education Conference in Brisbane. Appendices also document the search keywords generated for the qualitative syllabus analysis, participant information and informed consent forms, the lesson observation instrument, and research approvals from a university ethics board and two educational departments.

Chapter 2. Systematic Literature Review

A systematic review of relevant literature was conducted to rationalise the knowledge contribution of this study. This chapter outlines the methods of the systematic literature search and synthesises the findings from existing theoretical frameworks and empirical research on cognitive skills in secondary science curricula. Initially, three questions derived from the research aims guided the review:

1. How do prescribed science curricula embed and categorise cognitive skills? (Section 2.2.1. Cognitive Skills in the Prescribed Curriculum)
2. How can cognitive skills be taught effectively in the enacted curriculum and what are the current paradigms for teaching cognitive skills in science? (Section 2.2.2. Cognitive Skills in the Enacted Curriculum)
3. How is the curriculum alignment of cognitive skills studied and how do reform efforts affect curriculum alignment? (Section 2.2.3. Alignment of Cognitive Skills in the Prescribed and Enacted Curriculum)

Guiding Question 1 addresses literature on the intentions of curriculum developers, Guiding Question 2 addresses literature on classroom practice, while Guiding Question 3 addresses literature on the alignment between intention and practice. This initial systematic review highlighted the salient role of textbooks in determining which cognitive skills are taught as part of the curriculum. Thus, a fourth guiding question was added to guide the systematic literature search:

4. What role do textbooks play in science curricula and what can research conclude about cognitive skills in textbooks? (Section 2.2.4. The De Facto Curriculum in Textbooks)

The literature review aimed to apply findings to the senior secondary curriculum reform in Queensland, to propose considerations for practice, and to provide a rationale for the present study. It concludes by presenting this study's four research questions and their sub-questions.

2.1. Systematic Literature Search

2.1.1. Search Methods

Search methods employed to identify and evaluate relevant literature followed the PRISMA model (Moher et al., 2009). The online database Scopus was used to identify literature as it is the largest multidisciplinary database of peer-reviewed literature in terms of coverage (Bosman et al., 2006) and journal range (Falagas et al., 2008). The following search words were derived from the research aims and a thesaurus: cognit*, "thinking skill," "cognitive verb," curriculum, alignment, reform, enacted, intended, prescribed, objective, taxonomy, pedagogy, teach*, "high school," secondary, and science. To extend the search to literature on cognitive skills in textbooks, additional searches with the following search words were added: textbook, question, task, cognit*, and science. Searches were limited to peer-reviewed literature published in the past 20 years, which considered fast-changing educational paradigms and policies. Similarly, searches were limited to studies published in English in the subject areas of psychology, social science, arts and humanities, multidisciplinary, or undefined. All searches were conducted between 29 August and 17 November 2018, and again in July 2019. Search alerts were set for each search word combination to include literature published after July 2019. Additional articles were identified via reference lists of literature located through the Scopus search, websites of government or educational organisations, and resources gathered during the researcher's professional development workshops in 2018 and 2019.

2.1.2. Search Results

A total of 1163 articles were located. These articles' titles and abstracts were screened for relevance to the aims of the review. Studies were excluded if they did not satisfy the following inclusion criteria:

1. mainstream education
2. Prep to Year 12 education
3. face-to-face classroom education
4. cognitive skills relevant to science education

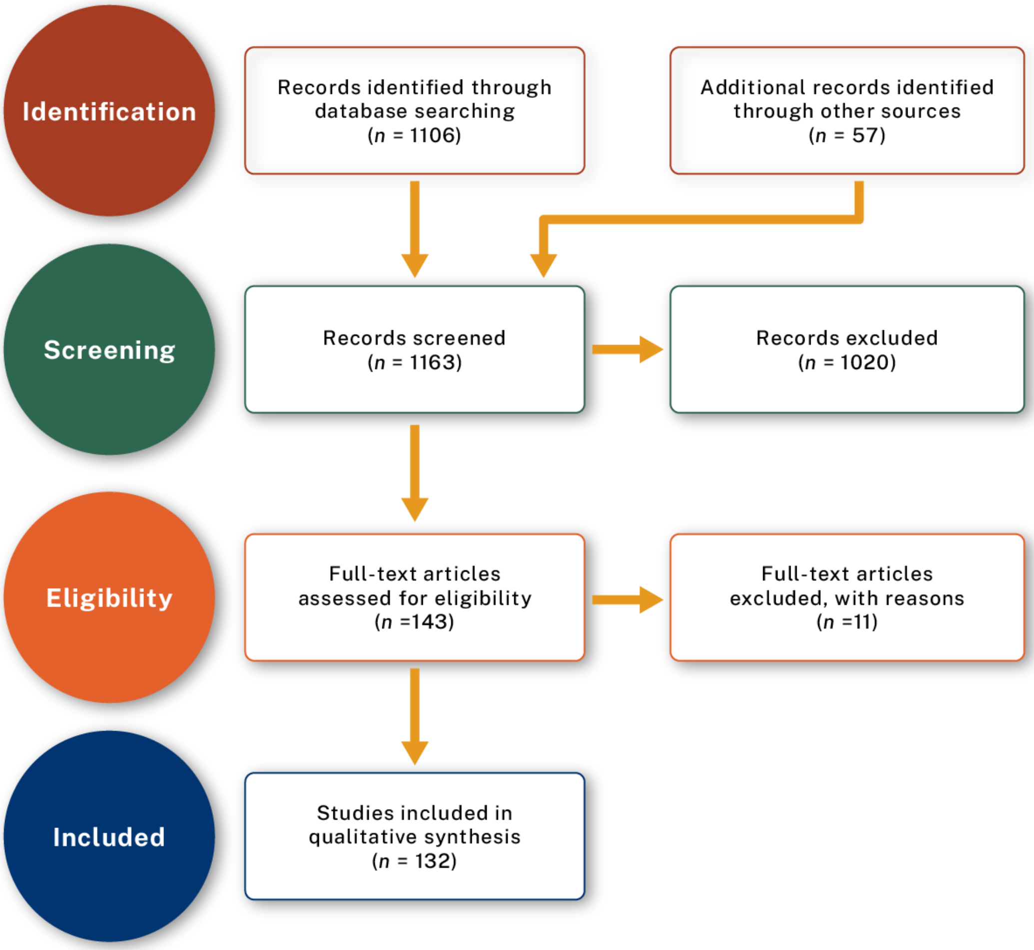
Since psychology was included as a subject area in each search, studies focusing on mental illness, psychiatric disorders, or cognitions in animals appeared in search results and were excluded from the screening process. Similarly, duplicates of studies already identified in previous searches using different keywords were also excluded.

Screening resulted in 143 studies that were read in full and assessed for eligibility. Articles read in full were excluded from the review if they (a) did not report or review empirical data, (b) focused on teacher training, or (c) investigated a very narrow pedagogical technique to promote cognitive skills (e.g., visuals in PowerPoint presentations). This process resulted in the inclusion and qualitative synthesis of 132 articles. Figure 2.1 illustrates the steps taken in conducting the literature search and the number of articles included in the review.

This review draws conclusions from an exhaustive search and situates its findings in the context of the included articles. However, these findings are partial because it is unlikely that all studies on the topic have been located, considering that searches were limited to the English language and one large database (Booth et al., 2016). Search results may also be limited by publication bias. For example, studies identifying low curriculum alignment are potentially more likely to be published than studies that have found adequate or high curriculum alignment, since low curriculum alignment indicates a problem that needs attention from teacher educators or policy writers.

Figure 2.1

Literature Search Process



2.2. Systematic Review Findings

The review's findings are organised thematically in order of the four guiding questions. First, the review explains how educational taxonomies are used to embed cognitive skills in the prescribed curriculum's learning objectives. The evolution, uses, and limitations of relevant taxonomies are also analysed. Second, trends in explicitly teaching cognitive skills in the enacted curriculum are outlined, including effective pedagogies and the benefits of teaching cognitive skills. Third, methodologies to study curriculum alignment and trends in curriculum alignment after educational reforms are discussed. Last, the review examines the influence of textbooks on teachers' pedagogical choices and research on typical science textbooks' learning tasks. At the end of each section, findings are applied to Queensland's context and recommendations are made for teaching practice.

2.2.1. Cognitive Skills in the Prescribed Curriculum

2.2.1.1. Educational Objectives. Educational objectives, sometimes called aims, goals, success criteria, or curriculum standards, are explicit statements describing what students are expected to learn during a course or subject (Bloom et al., 1956; Marzano & Kendall, 2007). Effective educational objectives should identify observable student behaviour and the context in which the behaviour should be demonstrated (Anderson & Krathwohl, 2001; Bloom et al., 1956). Practically speaking, objectives should contain a verb describing the intended cognitive skill, plus an object describing the knowledge students are expected to construct. For example, students should describe (cognitive skill) how temperature can affect an enzyme's activity (knowledge). Well-written objectives allow teachers to design effective learning activities and assessment tasks (Blumberg, 2009), choose appropriate learning resources, and set measurable goals for students (Yamanaka & Wu, 2014).

Educational objectives can be organised using taxonomies. Taxonomies classify components of a larger system based on similarities and differences, and can provide organising frameworks which improve precision in communication and understanding of the classified topic (Anderson & Krathwohl, 2001). In Biology, for example, taxonomies group organisms based on shared characteristics. In education, taxonomies have been developed to classify the goals of education systems and provide a universally understood language (Bloom et al., 1956). Taxonomies in education are therefore useful for improving educators' communication about curriculum and assessment, increasing comparability of educational objectives, and supporting new curriculum design. Furthermore, a common vocabulary for curriculum objectives referring to clear behavioural criteria supports teachers in planning instructions and designing assessments that align with curriculum objectives (Anderson & Krathwohl, 2001; Bertucio, 2017; Bümen, 2007).

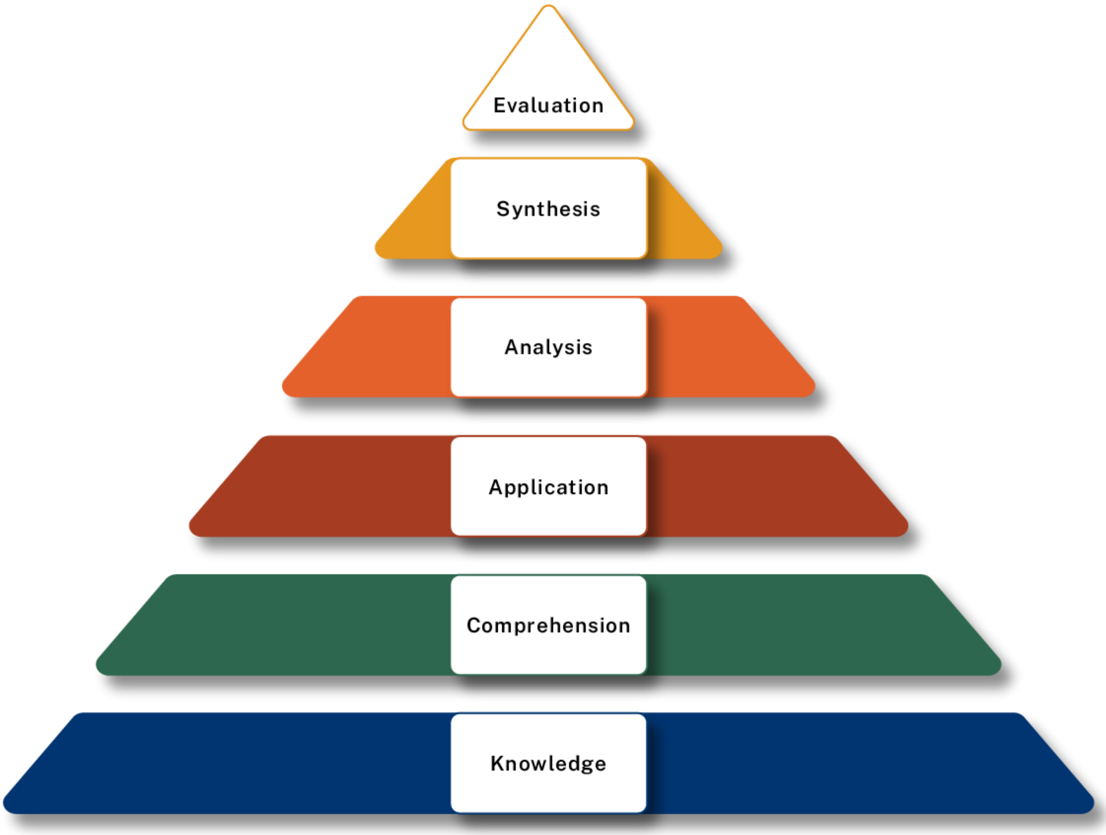
There is a long list of currently used educational taxonomies that apply varying theoretical frameworks for cognitive skills (see de Kock et al., 2004; Irvine, 2017; and Moseley et al., 2005 for a comprehensive review). Biggs and Collis's (1982) Structure of Observed Learning Outcomes (SOLO) Taxonomy, for example, is popular in the Prep to Year 12 and tertiary context (e.g., Bijsterbosch et al., 2017; Fensham & Bellocchi, 2013; Rembach & Dison, 2016). Other notable taxonomies include Fink's Taxonomy of Significant Learning (Fink, 2013) and Wiggins and McTighe's (2005) Facets of Understanding. Anderson and Krathwohl (2001) recommend that, ideally, each discipline should have a taxonomy of objectives described in its own language. The following section elaborates on Marzano and Kendall's (2007) New Taxonomy of Educational Objectives and taxonomies that influenced its development because the New Taxonomy underpins cognitive skills in the suite of Queensland's reformed senior secondary syllabi.

2.2.1.2. The Evolution of Taxonomies for Educational Objectives. The idea for a taxonomy of educational objectives first originated in the 1940s among tertiary education examiners who wanted to improve the exchange of examination materials and stimulate research on examination. After several annual meetings, a committee of American college and university examiners published the *Taxonomy of Educational Objectives, Handbook 1: Cognitive Domain* (Bloom et al., 1956). This first handbook classified educational objectives that aimed to develop students' cognitive skills and knowledge. However, the working group theorised that learning comprises cognitive as well as affective and psychomotor domains. The group's long-term aim was to develop a comprehensive taxonomy that includes all objectives of education without casting judgement on their value (Bloom et al., 1956). Handbooks for the affective and psychomotor domains were published in subsequent years (Harrow, 1972; Krathwohl et al., 1964), but never reached the same popularity, widespread use, or impact on curriculum as the first handbook (Irvine, 2017). This is possibly due to educational objectives tending to be biased towards cognitive knowledge-processing goals rather than goals that develop students' attitudes or physical skills (Pekdağ & Erol, 2013).

Bloom et al.'s (1956) cognitive domain is organised into six levels to help educators analyse learning systematically. The levels are considered hierarchical based on difficulty with cognitive skills in higher levels building on cognitive skills in the preceding levels (Bloom et al., 1956). For example, questions requiring synthesis are considered more difficult than questions requiring comprehension, and the effective application of a concept is considered a prerequisite for its evaluation. Knowledge, the first level of the taxonomy, is positioned as the basis for all purposes of education (Bloom et al., 1956). Figure 2.2 depicts the six cognitive levels of Bloom's Taxonomy and their hierarchy.

Figure 2.2

Cognitive Levels of Bloom's Taxonomy



Note. Adapted from *Taxonomy of educational objectives, Handbook I: Cognitive domain*, by B. S. Bloom, M. D. Engelhart, E. J. Furst, W.H Hill and D. R. Krathwohl, 1956, Longman Group LTD. Copyright 1956 by Longman Group LTD.

As understanding of cognitive skills developed and student-centred approaches to learning increased in popularity, Bloom's original taxonomy was revised. Anderson and Krathwohl's (2001) Revised Taxonomy was developed by a group of cognitive psychologists, curriculum theorists, instructional researchers, and assessment experts. It is two-dimensional with six types of cognitive skills on one dimension acting on four types of knowledge on the other dimension (see Figure 2.3). The structure of the Revised Taxonomy is less strictly hierarchical than Bloom's Taxonomy. For example, the Revised Taxonomy acknowledges that some subcategories of lower cognitive levels can be more complex than subcategories of the bordering higher cognitive level. Executing (Level 3) may sometimes be easier for students than explaining (Level 2; Anderson & Krathwohl, 2001). Similarly, lower-level cognitive skills are no longer considered prerequisites of higher-level cognitive skills (Edwards, 2010). A student can, for example, determine acceleration using Newton's second law before being able to explain that acceleration occurs due to unbalanced forces. So, the student applied knowledge (Level 3) before fully understanding it (Level 2). Moreover, changes have been made to terminology: the names of cognitive levels have been converted from nouns to active verbs to help educators formulate measurable learning objectives and instructions. Further, *comprehension* has been relabelled as *understand* and *synthesis* as *create*, which has been moved to the top of the hierarchy. The most significant change was arguably the addition of metacognition as part of the knowledge domain, which recognised the importance of students' motivation, learning goals, and learning strategies. Finally, the purpose of the taxonomy changed from a taxonomy for the construction of test items in tertiary education to a taxonomy for the alignment of curriculum, instruction, and assessment at all year levels (Anderson & Krathwohl, 2001). The focus has thus shifted from student performance to student learning. Overall, the Revised Taxonomy is considered superior to Bloom's Taxonomy in its application to learning in secondary school (Bümen, 2007).

Figure 2.3

Cognitive Skills and Knowledge Dimensions of the Revised Taxonomy

The Knowledge Dimension	1. *Remember*	2. *Understand*	3. *Apply*	4. *Analyze*	5. *Evaluate*	6. *Create*
A. *Factual Knowledge*						
B. *Conceptual Knowledge*						
C. *Procedural Knowledge*						
D. *Metacognitive Knowledge*						

Note. From *A Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. Abridged Edition*, by Lorin. W. Anderson and David. R. Krathwohl (Eds.), 2001, New York, NY: Longman. Copyright 2001 by Longman. Reprinted with permission.

Research and discussion about the ideal classification of cognitive skills and knowledge continued. Scholars began to consider how students decide whether to engage in a new learning task and how information is processed after the decision is made (Marzano & Kendall, 2007). With this broader view, Marzano and Kendall published the New Taxonomy of Educational Objectives. Like the Revised Taxonomy (Anderson & Krathwohl, 2001), the New Taxonomy separates knowledge (the objects) from cognitive skills (the process). It describes three types of knowledge:

1. information, including details, terms, facts, principles, or generalisations
2. mental procedures, including processes like writing and reading, following rules, tactics, or solving algorithms
3. psychomotor procedures, including physical procedures like movement, manual dexterity, speed, or strength

Cognitive skills used to learn all three forms of knowledge are organised into four levels, which together comprise the cognitive system:

1. retrieval: activation of knowledge by recognising and recalling information
2. comprehension: storing knowledge in permanent memory by integrating and symbolising information
3. analysis: reasoned extension of knowledge by matching, classifying, analysing errors, generalising, or specifying
4. knowledge utilisation: accomplishing a task by decision making, problem solving, experimenting, or investigating

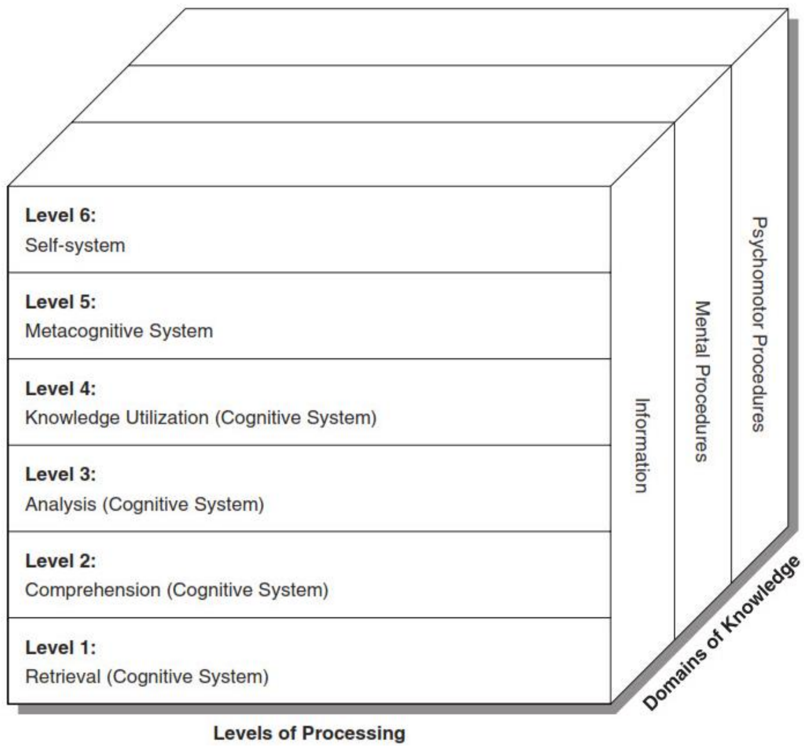
Retrieval and comprehension are considered lower-order cognitive skills as they relate to accessing existing knowledge, whereas analysis and knowledge utilisation are classified as higher-order cognitive skills because they require students to create and apply new knowledge. Higher cognitive levels also require greater intentionality of thinking than lower levels (Toledo & Dubas, 2016). Decision making, for instance, requires more conscious thought and awareness than recalling information, which is often executed automatically (Marzano & Kendall, 2007). Notably, problem solving has been added to the New Taxonomy. This seems to be a valuable addition, given problem solving has been shown to substantially increase student achievement (Hattie, 2008). Finally, Moseley et al. (2005) criticise the omission of reasoning and creative thinking as cognitive skills in the New Taxonomy. However, this intentional omission may be justified since critical and creative thinking involves several distinct cognitive skills, such as analysing and evaluating (Anderson & Krathwohl, 2001).

Marzano and Kendall (2007) argue that learning is a function of more than just cognitive skills and knowledge. They recognised the influence of a student's *self* intentionally choosing to learn and control the learning process. In other words, learning is not conceptualised as purely rational and the role of learners' attitude and motivation is recognised. Thus, in the New Taxonomy, the cognitive system is influenced by two further systems: the metacognitive system and the self-system (see Figure 2.4). The metacognitive system describes students' learning goals and students' strategies to accomplish those goals by monitoring their progress, accuracy, and clarity of understanding. The role of metacognition in the New Taxonomy is different to the Revised Taxonomy. In the New Taxonomy, the metacognitive system is not a subcategory of knowledge. Instead, it is a critical requirement for effective engagement with cognitive skills (Irvine, 2017). Teaching metacognition seems to be effective at enhancing students' cognitive skills long-term and frequently across subject disciplines (Beyer, 2008; Sanz de Acedo Lizarraga et al., 2010). Hattie's (2008) synthesis of meta-analyses on factors influencing student achievement also supports the benefits of teaching goal setting (effect size: 0.56) and other metacognitive strategies like self-questioning (effect size: 0.69).

The self-system denotes students' beliefs and emotions about the importance of acquiring knowledge and their own efficacy around this knowledge. It includes students' decision to engage in learning and their motivation. Previously, components of the self-system were a subset of metacognition. The introduction of the self-system as highest level of the New Taxonomy emphasises the need for a learner-centred approach to instructions as well as the primacy of students' self-regulation. The self-system controls students' metacognitive and cognitive skills by determining whether a learning task is worth engaging with. It considers intention an important precursor of learning (Irvine, 2017). The *Australian School Science Education National Action Plan 2008–2012* argues that such a focus on relevance to students' concerns and experiences is a core characteristic of an ideal science curriculum (Goodrum & Rennie, 2007). Similarly, the Australian government initiative *School Innovation in Science* describes contextualisation of content to students' lives and interests as effective science classroom practice (Tytler, 2009).

Figure 2.4

Levels of Processing and Knowledge Domains in the New Taxonomy



Note. From *The New Taxonomy of Educational Objectives* (2nd ed.), by Robert. J. Marzano and John. S. Kendall, 2007, Thousand Oaks, CA: Corwin Press. Copyright 2007 by Corwin Press. Reprinted with permission.

Previous taxonomies stated that cognitive skills can be ordered hierarchically based on complexity (Anderson & Krathwohl, 2001). The New Taxonomy argues that the difficulty of cognitive skills depends on how complex the required cognitive skills are and the familiarity a person has with the process. As familiarity with a cognitive skill increases, the skill becomes quicker and easier to execute (Marzano & Kendall, 2007). Research confirms that examination questions requiring higher level cognitive skills do not necessarily correlate with question difficulty or students' performance on a particular question (Momsen et al., 2013). Question difficulty and cognitive levels are two separate concepts, even though they sometimes correlate positively. Therefore, the New Taxonomy does not attempt to sort cognitive skills hierarchically. Instead, the three systems are ordered based on control; skills of higher systems control the skills of lower systems. For example, the metacognitive system controls the cognitive system as students will not effectively engage in the retrieval, comprehension, or analysis of information unless they first set a goal relating to the learning task and choose strategies to accomplish the learning goal. Table 2.1 summarises the main differences between the three discussed taxonomies of educational objectives.

Table 2.1

Differences Between Bloom's Taxonomy, the Revised Taxonomy, and the New Taxonomy

Characteristic	Taxonomy		
	Bloom's Taxonomy (Bloom et al., 1956)	Revised Taxonomy (Anderson & Krathwohl, 2001)	New Taxonomy (Marzano & Kendall, 2007)
Cognitive levels	Hierarchical cognitive levels based on difficulty; lower levels are prerequisites for higher levels	Hierarchical cognitive levels based on complexity; use of verb forms for cognitive levels	Non-hierarchical cognitive levels; order of levels based on intentionality of thinking, not difficulty
Structure	One-dimensional with knowledge as first cognitive level; separate taxonomies for the affective and psychomotor domain	Two-dimensional (types of knowledge and cognitive skills); inclusion of metacognitive knowledge	Two-dimensional (types of knowledge and cognitive skills); inclusion of the self-system and the metacognitive system
Purpose	Designed to classify university assessment	Designed as framework for objectives, assessment, and classroom instructions for teachers at all year levels	Designed as framework for objectives, assessment, classroom instructions, and a cognitive skills curriculum for teachers at all year levels
Focus	Students' performance on assessment	Students' learning	Students' learning, intentions, and goals

2.2.1.3. Applications of Educational Taxonomies. The New Taxonomy of Educational Objectives has proven useful for the development and classification of state standards, learning objectives, pedagogies, and assessment (Dubas & Toledo, 2015, 2016; Marzano & Kendall, 2007; Moseley et al., 2004). It is predominantly used in US jurisdictions (e.g., Toledo & Dubas, 2016) where its adoption may have been influenced by strong marketing efforts. In Australia, the QCAA has chosen the New Taxonomy as the theoretical framework for the reformed senior syllabi effective in 2019. All syllabus learning objectives begin with a cognitive verb based on the New Taxonomy. Cognitive verbs, categorised by cognitive levels in Figure 2.5, provide a description of the depth that students are required to understand and demonstrate their knowledge (QCAA 2018e). For example, the chemistry learning objective *determine the relative strength of oxidising and reducing agents* requires students to analyse information or data about reagents (Level 3), rather than to recall a memorised answer for a particular set of chemical reactions (Level 1). Classroom learning experiences meeting this syllabus objective should give students the opportunity to practise determining an answer by analysing data.

A single taxonomy was used to frame all objectives of the reformed senior syllabi to align intended learning outcomes, subject matter, and assessment (QCAA, 2018f). Using the same taxonomy for all subject areas ensures consistency of language about cognitive skills. This is important because, as Schnotz (2016) notes, students who are familiar with the language of the cognitive levels can more accurately judge the difficulty level or mental effort required to learn content and are then able to make better decisions about how to study.

Figure 2.5

Categories of Cognitive Verbs in Queensland's Senior Syllabi

	Retrieval and comprehension	Analytical processes	Knowledge utilisation
Category description	the activation and transfer of knowledge from permanent memory to working memory, and the storage of critical features of information in permanent memory	involves the reasoned extension of knowledge	about using knowledge — involves the processes individuals use when they wish to accomplish a specific task
Skills	• recognising • recalling • executing • integrating • symbolising	• matching • classifying • analysing error • generalising • specifying	• decision-making • problem-solving • experimental inquiry • investigating
Cognitive verbs	calculate (e.g. numerical answer; mathematical processes)	analyse	appraise
	clarify	apply	appreciate
	comprehend (meaning)	categorise	argue
	construct (e.g. a diagram)	classify	assess
	define	compare	comment (make a judgment)
	demonstrate	consider	conduct (e.g. investigations)
	describe	contrast	construct (e.g. an argument)
	document	critique	create (e.g. a unique product/ artefact; language texts; meaning)
	execute	deduce	decide/determine
	explain	derive	design (e.g. a methodology, an artefact, a proposal)
	identify	determine	develop (e.g. a strategy, product or process)
	implement (e.g. a plan, proposal)	differentiate	devise
	recall	discriminate	discuss/explore
	recognise (e.g. features)	distinguish	evaluate
	select	identify errors/problems	experiment/test (e.g. ideas, methods)
	sketch	infer/extrapolate	express (e.g. an artistic idea or viewpoint)
	summarise	interpret (e.g. meaning)	generate/test (e.g. hypotheses)
	symbolise (e.g. through diagram, illustration, model)	judge	hypothesise/propose (e.g. arguments, solutions, ideas)
	understand	organise/sequence/structure	investigate/examine (e.g. an argument, concept)
	use	reflect (on)	justify/prove (e.g. an argument, statement or conclusion)
			make decisions
			manipulate (e.g. language texts; skills; technologies)
			modify
			predict (e.g. a result)
			realise/resolve (e.g. artistic works)
			solve (e.g. problems)
			synthesise

Note. From *New and Redeveloped Syllabuses*, by QCAA, 2018, https://www.qcaa.qld.edu.au/downloads/senior-qce/common/snr_categories_cognitive_verbs.pdf . CC BY 4.0.

The cognitive verbs in Figure 2.5 are also used for the design of assessment items. School internal assessment tasks and external examination questions are mapped to each unit's learning objectives, as specified in the syllabus documents and their cognitive verbs. For example, if the syllabus specifies that students should be able to *describe* the structure of a cell (Level 1), the external examination would not include a question asking students to *categorise* cells according to their structures (Level 3). The QCAA also urges all school-based internally designed test items to use cognitive verbs to instruct students on the type of answer required. For example, a test item would ask students to *compare eukaryotes and prokaryotes* instead of asking *what is the difference between eukaryotes and prokaryotes* to indicate that an analytical and reasoned response is required rather than a description of each cell's structure. In this manner, cognitive verbs indicate the cognitive demands of test questions. By using a variety of cognitive verbs in assessment instruments, the reformed senior system aims to assess a broad array of cognitive skills in the sciences.

A renewed application of the New Taxonomy uses the cognitive system as a basis for the design of an explicit cognitive skills curriculum (Marzano & Kendall, 2007). Research has shown that actively teaching skills such as retrieving, analysing, or investigating knowledge can lead to the faster and more effective execution of these processes (Marzano & Kendall, 2007). The need to teach cognitive skills has been voiced since the 1980s (Marzano & Kendall, 2007) and, to this end, the reformed Queensland senior syllabi place emphasis on the explicit teaching of cognitive verbs (QCAA, 2018e). The QCAA (2018f, p. 3) recommends teachers "build communities of practice … to discuss curriculum, assessment and pedagogy, including the use of cognitive verbs in syllabuses" and "provide opportunities for students in lower year levels to engage with the cognitive verbs in general syllabuses." The QCAA has also released a Cognitive Verb Toolkit to support teachers with the explicit teaching of cognitive skills language (QCAA, 2018e). Teachers are now called upon to make cognitive skills a part of their explicit curriculum by integrating them into their lesson content, and by using cognitive verbs when constructing assessment tasks.

Further, educational taxonomies can increase precision in the evaluation of alignment by providing a classification framework for objectives, instruction, and assessment (Anderson, 2005; Bümen, 2007; Edwards, 2010). While commenting on the tertiary education context, as opposed to the senior secondary school context discussed herein, Blumberg (2009) notes that cognitive skills found in the objectives of university courses are often set at a higher level than the cognitive skills required of students during learning activities or assessment tasks. Blumberg therefore suggests the use of cognitive levels in educational taxonomies to assess alignment in university courses and thus improve course design. In Australia, the Australian Qualifications Framework (AQF) has established regulations for learning objectives at different course levels to make the cognitive skills required for each level explicit (Australian Qualifications Framework Council, 2013). Similarly, taxonomies can scaffold the analysis of the scope of an existing course (Mathumbu et al., 2014) or the scope of an assessment (Motlhabane, 2017), and support teachers in their interpretation of course objectives (Bümen, 2007) or even in differentiating teaching techniques (Dettmer, 2005). Most studies pertaining to cognitive skills curricula—that were reviewed during this study's systematic review in 2018 and 2019—reveal the use of Bloom's Taxonomy (Bloom et al., 1956) or the Revised Taxonomy (Anderson & Krathwohl, 2001) to investigate the alignment between assessment and teaching of cognitive skills or assessment and cognitive skills in learning objectives. To date, no research has been located that uses the New Taxonomy for a similar alignment study.

2.2.1.4. Limitations of Educational Taxonomies. Applications of educational taxonomies have limitations, regardless of the particular taxonomy used. When classifying instructions or assessments, educators must make assumptions about the prior learning students were exposed to as the cognitive level of tasks also depends on factors other than the wording of a question (FitzPatrick et al., 2015). For example, an unknown situation is needed for a student to truly apply knowledge. If the context is familiar, a student may solve an application question by recalling the solution (Radmehr & Drake, 2018). Furthermore, two students may solve the same problem in two different ways, using two different cognitive skills (Bloom et al., 1956) and educational taxonomies cannot always predict which cognitive skills students will use to answer questions. For example, Gierl (1997) classified middle school maths test questions using Bloom's Taxonomy and then analysed students' thinking process with think-aloud protocols. The expected and observed cognitive level only matched 53.7% of the time. Notably, high-achieving students had more matches, which could indicate that high achievers were better able to recognise the cognitive skill needed to successfully solve the question.

In addition, the difficulty level of a question is not solely decided by the cognitive skill it requires for a correct solution, but also by other factors like the time required to find the solution and the complexity of the question content (Lemons & Lemons, 2013). Liou and Bulut (2020) analysed almost 3000 test question responses from middle school students in Taiwan and criticised the hierarchical order of Bloom's cognitive domain as students scored higher on questions classified as more difficult.

Some educational researchers criticise educational taxonomies because they predominantly value intellectual activities that lead to observable changes in students' behaviour (Bertucio, 2017). Most taxonomies seem to dismiss the importance of internal sympathetic changes like wonder and appreciation, or covert learning outcomes like changes in learners' values and perceptions (Ulmer, 2005). A common assumption implicit in taxonomies of educational objectives is that students have only learned knowledge if they can demonstrate it through an activity, and the evaluation of instructional effectiveness is solely based on measurable observations. The fact that the original taxonomy of the affective domain (Handbook II) was not as influential as Bloom et al.'s (1956) handbook of the cognitive domain supports the prevalence of this perspective.

The New Taxonomy positions the self-system, which includes students' beliefs and emotions, as essential to learning. However, the new QCE learning objectives that are demonstrated in the suite of reformed syllabi predominantly draw on the cognitive system. High-stakes external examinations could narrow this focus further. According to Bertucio (2017), a focus on observable cognitive skills to the exclusion of all others may reduce student engagement because learning content is divorced from real meaning. Hence, even though the prescribed curriculum prioritises the cognitive system, one can argue that an effective enacted curriculum needs to address the self-system as well.

2.2.1.5. Summary and Considerations for Teachers in Queensland. The prescribed curriculum communicates which knowledge and cognitive skills students are expected to learn through educational objectives. These objectives can be classified using taxonomies. The most well-known and widely utilised taxonomy for educational objectives is Bloom's Taxonomy, which describes six hierarchical levels of cognitive function (Bloom et al., 1956). As a result of continuing research into learners' cognitive skills and new understandings of the way students process knowledge, Bloom's Taxonomy was revised at the start of the century (Anderson & Krathwohl, 2001) and restructured again in 2007 (Marzano & Kendall, 2007). The most significant changes made to Bloom's original taxonomy are the dynamic rather than hierarchical organisation of cognitive skills; the classification of two-dimensional learning (types of knowledge and cognitive skills); and the increased attention to students' metacognition, goals, and intentions. Despite some limitations in the use of educational taxonomies for assessment and curriculum design (e.g., Bertucio, 2017; Lemons & Lemons, 2013; Moseley et al., 2005), the New Taxonomy of Educational Objectives serves as underlying framework for the development of learning objectives and assessment items in the reformed Queensland senior syllabi. The taxonomy also has the potential to support the implementation of an explicit cognitive skills curriculum (Marzano & Kendall, 2007).

In light of building new capacities, it may be interesting to explore the effect of embedding a stronger focus on curriculum alignment through the use of educational taxonomies in teachers' professional development. If the language used in syllabus documents is not clear to teachers, they are likely to misinterpret the prescribed curriculum, leading to low curriculum alignment (Boesen et al., 2014). Explicitly modelling how to use an educational taxonomy to plan lessons or to reflect on teaching, and continuing to embed such practices in teacher education, may also increase curriculum alignment because educational taxonomies can support the intentional teaching of cognitive skills (Mathumbu et al., 2014).

2.2.2. Cognitive Skills in the Enacted Curriculum

2.2.2.1. Trends in Teaching Cognitive Skills. In many western countries, educational reforms and policies over the last two decades have emphasised the development of students' cognitive skills. This is evident in Ireland (McGuiness, 1999), Israel (Zohar & Cohen, 2016), England, the United States (US), Canada, and Australia (Firn, 2016). Tan's (2007) literature review of pedagogical imperatives throughout time concludes that since the 1990s, effective teaching has started to be characterised by the modelling of learning and thinking processes while communicating content knowledge.

Several well-researched cognitive skills programs have been implemented in Europe, the US, Ireland, and Australia. Some of these are stand-alone programs, such as Feuerstein's Instrumental Enrichment in Ireland, and others are subject-specific interventions, such as Cognitive Acceleration through Science Education and Cognitive Acceleration through Mathematics Education in England and Australia. Some programs are infused with a cognitive skills curriculum embedded across several subjects, such as Philosophy for Children in the USA or Activating Children's Thinking Skills in Ireland. On other occasions, the implementation of a cognitive skills intervention has originated from a government initiative, such as the Thinking Schools, Learning Nation (TSLN) vision launched by Singapore's Ministry of Education in 1997. Three distinct approaches for teaching cognitive skills are apparent in these programs:

1. teaching content knowledge and developing students' cognitive skills as a by-product
2. teaching cognitive skills and developing students' content knowledge as a by-product
3. teaching cognitive skills with an emphasis on transferring cognitive skills to new content (Ulmer, 2005).

In Australia, support for a curricular focus on students' cognitive skills is high. The *Melbourne Declaration on Educational Goals for Young Australians* acknowledges that successful learners "are able to think deeply and logically, and obtain and evaluate evidence in a disciplined way" (Ministerial Council on Education, Employment, Training and Youth Affairs, 2008, p. 8). More recently, Gonski et al. (2018) argue in their *Review to Achieve Educational Excellence in Australian Schools* that the Australian Curriculum's General Capabilities need to be at the core of the curriculum and teaching practice for students to succeed in the 21st century. One of these cross-curricular General Capabilities is critical and creative thinking. In Queensland, most senior science syllabi explicitly list critical thinking as a skill to be developed throughout the course (e.g., QCAA, 2018b) and the QCAA's (2018e) *Cognitive Verb Toolkit* emphasises that explicit teaching of cognitive skills improves students' ability to meet syllabus objectives and respond to assessment.

The above innovations are informed by cognitive psychology and dominated by social constructivist principles in nearly all reviewed studies investigating pedagogies for cognitive skills education (e.g., Adey, 2005; Marušić & Sliško, 2012; McGuiness, 1999; Oliver &

Venville, 2017; Tornero, 2017; Venville & Oliver, 2015; Wilson, 2016). Cognitive psychology introduced the concept of working memory to education and states that learning is strategically regulated by the brain. Its influence on cognitive frameworks in education is so strong that more than half of the frameworks analysed in a systematic literature review of 35 taxonomies for learning have been devised by psychologists rather than educators (Moseley et al., 2005).

Social constructivist pedagogies are based on the premise that students actively construct their knowledge through interactions with their peers, teachers, and parents, and that learning occurs through educational discourse (Staver, 1998). For social constructivists, learning requires students to interact with learning material and re-evaluate their prior knowledge on the topic (Juhary, 2013). The learner is central to the creation of new knowledge and meaning (Biggs, 1996). These principles encourage an inductive teaching approach in which learners have an active role and are provided with carefully scaffolded assistance at an appropriate level of difficulty (McInerney & McInerney, 2010). Teachers should act as facilitators and individualise learning based on students' learning preferences and interests (Juhary, 2013). In other words, teaching should be student centred. However, Beyer's (2008) review of studies on the teaching of cognitive skills reported that both social constructivist and didactic teaching strategies can be effective in the development of cognitive skills. This is relevant for Queensland as the introduction of content-dense syllabi and high-stakes external examinations can result in teachers adopting teacher-centred didactic pedagogies (Krüger et al., 2013).

2.2.2.2. Corresponding Trends in Science Education. Current recommendations for science education in secondary schools parallel the previously discussed trend to teach cognitive skills underpinned by a constructivist philosophy (Chiappetta & Koballa, 2010; Tytler, 2009). Effective science teaching makes authentic links to real-world issues, is context based, is mindful of students' prior knowledge, and is student centred (Chiappetta & Koballa, 2010; Danaia et al., 2013; MacKinnon & Bacon, 2015; Scogin et al., 2018). A study of 10 secondary schools in the US indicates that schools with low-performing science programs place little emphasis on student-teacher relationships or the development of students' scientific thinking skills (Scogin et al., 2018). Hence, it is now recommended that science education moves beyond only teaching scientific knowledge to also developing students' capability for scientific thinking.

Efforts to improve students' cognitive skills in science are enhanced by inquiry-based teaching models (e.g., Laxman, 2013; Marušić & Sliško, 2012; Tan, 2007; Zohar et al., 1998; Zoller, 1999). Inquiry-based learning is a creative process during which students develop an explanation for authentic and potentially self-generated scientific questions (Chiappetta & Koballa, 2010; Fitzgerald et al., 2019). Students then use their new understanding to make predictions or solve a meaningful problem. In this manner, students have greater control over their learning. At the same time, inquiry-based learning creates conditions conducive to the verbalisation of students' ideas, classroom discussions and higher-order thinking (McGregor & Gunter, 2001) as students explore scientific concepts before their teacher provides an explanation. It is important to note that a scientific investigation or practical activity does not automatically result in inquiry-based learning because students may conduct an investigation to reproduce an already known scientific phenomenon.

Firn's (2016) literature review on emergent trends in senior science syllabi concluded that inquiry-based pedagogies are prevalent across the science curricula in Australia, the United Kingdom, Canada, and the United States of America (USA). They are consistently recommended in Australian science education reforms (Fitzgerald et al., 2019) and characterise exemplary science teachers (Sherriff, 2019). Moreover, the Australian Prep to Year 10 science curriculum mandates teachers to develop and assess students' science inquiry skills, next to students' content knowledge (ACARA, 2014). The reformed Queensland senior science syllabi do not openly endorse or recommend an inquiry-based teaching approach, but they prescribe the teaching of science inquiry skills (e.g., QCAA, 2018b).

Benefits of inquiry-based pedagogy range from increased student engagement to greater student understanding and retention (Chiappetta & Koballa, 2010; Cian et al., 2018), higher student satisfaction (Barnea et al., 2010), higher cognitive demands placed on students (Cian et al., 2018; Duran & Dökme, 2016), and increased development of students' metacognitive skills (MacKinnon & Bacon, 2015; Sun et al., 2017). Walker and Molnar's (2013) qualitative study of 119 secondary schools in Canada as well as Barnea et al.'s (2010) synthesis of three separate intervention studies in Israel both conclude that inquiry-based learning leads to positive student outcomes across the cognitive, metacognitive, and affective domain, thus unintentionally addressing all three systems of learning outlined by the New Taxonomy of Educational Objectives (Marzano & Kendall, 2007). However, a large-scale database analysis shows that even though inquiry-based learning has positive effects on student engagement and interest, evidence of positive effects on student achievement is wanting (Furtak et al., 2012).

2.2.2.3. Effective Teaching of Cognitive Skills. The literature provides consensus that cognitive skills and their procedural steps can be taught (Beyer, 2008). Mastery of cognitive skills does not come naturally as a student matures, nor coincidentally as more complex subject content is taught. Instead, this mastery needs to be developed through systematic teaching (Beyer, 2008; Sandi-Urena et al., 2011; Simon & Richardson, 2009) and continuous practice of cognitive skills (Sanz de Acedo Lizarraga et al., 2010). Explicitly teaching skills such as retrieving, analysing, or investigating knowledge can lead to faster and more effective execution of these skills. Even complex cognitive skills can be learned and executed with little conscious effort as a student's familiarity with the process improves (Marzano & Kendall, 2007).

Marzano and Kendall (2007) recommend that students are taught how to use their knowledge-processing skills more efficiently by following a protocol for each cognitive skill. For example, to improve students' ability to retrieve information, students could be taught how to use a mnemonic. A possible protocol for comprehension could involve (a) looking for a pattern and (b) organising the new information using the pattern in a diagram. Empirical evidence also suggests that teaching cognitive skills should not be divorced from teaching content knowledge but integrated with subject content, as learning will be more effective if students perceive an authentic need to use a new cognitive skill (Beyer, 2008; De Corte, 1990; Rickey & Stacy, 2000).

Different cognitive learning objectives require different instructional strategies and resources (Anderson & Krathwohl, 2001; Bietenbeck, 2014). Researchers have attempted to specify pedagogies that produce particular cognitive learning outcomes (Anderson & Krathwohl, 2001), but have not succeeded in providing a universal answer. Nevertheless, evaluation of cognitive skills intervention programs in secondary schools has pointed to a list of pedagogies that seem to be effective at improving students' cognitive skills long-term and frequently across subject disciplines (see Table 2.2).

Table 2.2

Pedagogies Shown to be Effective at Improving Secondary School Students' Cognitive Skills

Pedagogy	Evidence
Metacognition: making cognitive skills explicit by talking about and reflecting on mental processes	Beyer, 2008; Sanz de Acedo Lizarraga et al., 2010; McGregor & Gunter, 2006; McGuiness, 1999
Modelling cognitive skills or thinking aloud	Beyer, 2008; Fairbrother, 2000; McGuiness, 1999; Simon & Richardson, 2009
Using diagrams that visualise the steps of each cognitive skill	Burke & Williams, 2008
Transferring cognitive skills between subject domains and to authentic contexts outside of school	McGregor & Gunter, 2006; McGuiness, 1999; Miri et al., 2007; Sanz de Acedo Lizarraga et al., 2010
Using feedback until students find a solution themselves or develop their ideas	Adey & Shayer, 1990; Sanz de Acedo Lizarraga et al., 2010
Open-ended questions	McGregor & Gunter, 2006; Sanz de Acedo Lizarraga et al., 2010
Collaborative and cooperative learning	Coll et al., 2005; Gillies, 2008; McGregor & Gunter, 2006
Group discussions	Coll et al., 2005; McGregor & Gunter, 2006; Miri et al., 2007; Sherriff, 2019; Simon & Richardson, 2009

These pedagogies include a range of explicit scaffolding strategies, such as modelling (Simon & Richardson, 2009) or using visual diagrams (Burke & Williams, 2008), applications of skills to real-world contexts (McGuiness, 1999), and self-directed group or collaborative learning (McGregor & Gunter, 2006; Sherriff, 2019). Beyer's (2008) review of pedagogical interventions for cognitive skills and De Corte's (1990) review of pedagogies to teach problem solving both confirm that frameworks comprised of (a) modelling the skill, (b) guided student practice of the skill with teacher feedback, (c) independent transfer of the skill to new contexts, and (d) metacognitive reflection on thinking procedures are particularly useful for effective cognitive skills curricula. Minimally guided approaches to teaching cognitive skills have been criticised as less efficient because of the prerequisite knowledge required by learners to effectively discover new knowledge and solve problems in unfamiliar contexts (Hattie, 2008; QCAA, 2016).

Notably, pedagogical strategies recommended for the fostering of cognitive skills tend to be predominantly social. Ikuenobe (2002) argues that certain cognitive skills, especially critical evaluation, cannot be learned fully without interaction between students. A quasi-experimental study in Scotland also affirms that cognitive skills intervention programs have the greatest effect on student performance in collaborative learning conditions, but it should be mentioned that even the individually working group of students engaging with the intervention program made greater gains on the post-test than the control group without any cognitive skills intervention (Burke & Williams, 2008).

Introducing students to the language of thinking is another key component of effectively teaching cognitive skills (Burke & Williams, 2008). Negretti and McGrath (2018) argue that the first step in teaching cognitive skills is to make knowledge processing visible by verbalising it, so students can associate cognitive verbs with the relative cognitive skill. This may be done by consistently using cognitive verbs in classroom instruction. Students who know about and can verbalise cognitive skills are more likely to use them when confronted with different learning tasks (Pintrich, 2002) as a consistent language describing cognitive skills provides students with a cue for retrieving and applying learnt cognitive procedures (Beyer, 2008). A systematic literature review of 178 studies on metacognition also confirms that introducing the language of thinking in the classroom is a successful strategy to enhance cognitive skills (Zohar & Barzilai, 2013). The reviewed empirical evidence on pedagogies that have proven effective in enhancing students' cognitive skills largely draws from sources that are over a decade old, underscoring the necessity for more up-to-date data on teaching strategies for effective cognitive skills curricula.

2.2.2.4. Benefits and Barriers of Explicit Cognitive Skills Curricula. There is ample evidence that teaching cognitive skills correlates with improved student outcomes. The strongest evidence comes from a meta-analysis of 29 studies, which concludes that cognitive skills programs are effective in improving student performance on instruments measuring cognitive skills as well as curricular outcomes measured by conventional assessment (Higgins et al., 2005). Empirical studies, predominantly quasi-experiments with an intervention and a control group, have linked teaching cognitive skills in secondary school with significant cognitive gains (Oliver & Venville, 2017) and positive learning outcomes (McGuiness, 1999). This research includes a study of almost 600 middle school students in Australia (Venville & Oliver, 2015). Even a study with interventions that addressed only one cognitive skill (e.g., scientific reasoning), lead to significantly increased thinking abilities and grades as compared to students who have been taught with a more traditional, content-focused approach (Marušić & Sliško, 2012). A similar picture emerges at the university undergraduate level, where a focus on the teaching of cognitive skills leads to improved exam performance (Stevens & Witkow, 2014), overall grades and course retention rates (Williams, 2017).

The benefits of some cognitive skills intervention programs appear to be long-lasting and transferable. Adey's (2005) longitudinal studies of the Cognitive Acceleration through Science Education program in secondary school concludes that the program caused long-term positive effects on students' achievement during reasoning tests, and a transfer effect on mathematics and English. For one school in the same study, one topic had to be skipped in the intervention lessons of the program, but students still outperformed the control group on the test, even though the concepts tested were never directly taught. This suggests that students have gained skills and knowledge that are transferable to new contexts. However, not all interventions are equally successful and the positive effect of cognitive acceleration programs does not always show in students' overall achievement (Adey & Shayer, 1990), possibly because traditional achievement tests often do not assess a wide range of cognitive skills (Cimer & Cimer, 2010; Fensham & Bellocchi, 2013).

The implementation of an explicit cognitive skills curriculum has many barriers, such as an overcrowded curriculum, limited professional development opportunities for teachers, or resistance from students as teaching cognitive skills contradicts their conditioned expectations (Zoller, 1999). Active implementation of cognitive skills curricula is also likely dependent on the familiarity of the teacher with the curriculum (Abdullah et al., 2016). A study of Israeli physics teachers showed that teachers are frequently uncertain about teaching cognitive skills or do not consider cognitive skills to be an important objective of their lessons (Barak & Dori, 2009). Quantitative research in Israel also showed that secondary school teachers are less likely to actively teach higher-order cognitive skills than primary school teachers, and that teachers with more experience teach cognitive skills less frequently than teachers with less experience (Zohar & Schwartzer, 2005). Although studies report on excellent practice, a majority of Australian teachers may rarely teach cognitive skills explicitly (Venville & Oliver, 2015). The Organisation for Economic Cooperation and Development's (2018) Teaching and Learning International Survey sampled 3573 Australian secondary teachers and concluded that less than 50% use "practices involving student cognitive activation" (i.e., evaluate, apply, or problem solve; p. 2). It seems that empirical evidence concerning the value of teaching cognitive skills does not automatically translate into frequent attempts to explicitly teach such skills in ordinary classrooms.

2.2.2.5. Summary and Considerations for Teachers in Queensland. Current educational reforms, policies and curricula in North America, Europe, some parts of South

East Asia, and Australia emphasise the development of students' cognitive abilities (Firn, 2016). This increased attention to cognitive skills education has resulted in (a) changes to assessment and pedagogy, such as recommendations to teach science with an inquiry-based approach (Firn, 2016; Fitzgerald et al., 2019) and (b) the implementation of a series of secondary school cognitive skills intervention programs. Most of the cognitive skills evident in curricula are underpinned by cognitive psychology and social constructivist teaching principles (McGuiness, 1999; Moseley et al., 2005).

Intervention programs fostering cognitive skills consistently indicate that cognitive skills can be taught and improved with practice (e.g., Beyer, 2008; Sandi-Urena et al., 2011; Sanz de Acedo Lizarraga et al., 2010; Simon & Richardson, 2009). Studies have also identified teaching strategies that seem to be particularly conducive to effective cognitive skills education. Some common themes of these pedagogies are the integration of cognitive skills instruction into subject content, the social interaction of students, explicit modelling, guided practice, the transfer of cognitive skills to new contexts, and metacognitive reflection (De Corte, 1990). Another key component of effective cognitive skills curricula is the development of students' language of thinking; that is, their ability to verbalise their thinking and to understand the meaning of cognitive verbs (Burke & Williams, 2008; Negretti & McGrath, 2018; Pintrich, 2002). There is a plethora of evidence showing that the teaching of cognitive skills is linked to improved student outcomes (e.g., Higgins et al., 2005; Oliver & Venville, 2017; Venville & Oliver, 2015). Some of these benefits are likely to be long lasting and transferable (Adey, 2005).

However, the prevalence and type of cognitive skills taught in Australian classrooms are not well known. For example, this systematic literature review has not found any data on the implementation or evaluation of a cognitive skills curriculum in Queensland. The reformed senior syllabi make such research highly relevant. Currently, it is not clear which cognitive demands are placed on senior science students in Queensland's classrooms and which pedagogies or learning activities are used to teach cognitive skills. The prevalence of enacted cognitive skills curricula in Queensland senior secondary lessons should be researched to evaluate the success of recent reform efforts. Studying the case of Queensland can yield empirical evidence and valuable insights into the strengths and opportunities within contemporary science classroom teaching practices. These findings can then be extrapolated and applied to enhance education systems elsewhere.

In Queensland, the QCAA (2018e) guides teachers' use of cognitive verbs in developing cognitive skills. Infosheets and posters outlining the definitions, cognitive processes, and examples of use for the most common cognitive verbs across senior syllabi have been released, followed by the publication of separate resources on cognitive verbs in the Australian Curriculum for Prep to Year 10 teachers[1]. However, to date there is limited explicit guidance on the skills teachers should be teaching to foster metacognition and self-system thinking, the two levels influencing the cognitive system in the New Taxonomy. The self-system provides students with the necessary motivation to engage with cognitive skills and the metacognitive system allows students to regulate their learning (Marzano & Kendall, 2007). Professional development opportunities for such classroom practice would support the alignment of the enacted curriculum with the aims of the curriculum reform (Fenwick, 2018; Massell & Perrault, 2014).

2.2.3. Alignment of Cognitive Skills in the Prescribed and Enacted Curriculum

2.2.3.1. The Significance of Curriculum Alignment. Curriculum alignment is the coherence between all components of an educational system, particularly between learning objectives in the prescribed curriculum, learning activities of the enacted curriculum, and the

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[1] Available at https://www.qcaa.qld.edu.au/p-10/aciq/version-8/frequently-used-resources/cognitive-verbs.

assessed curriculum (Anderson, 2005). Students have a clear idea of the direction of their learning when learning goals, instructions, and assessment items are consistent (Blumberg, 2009). Hence, it is not surprising that a positive relationship has been reported between curriculum alignment and student achievement (Kurz et al., 2010). High alignment between the prescribed, assessed, and enacted curriculum allows students to learn the cognitive skills and knowledge necessary to succeed. High alignment also provides students with appropriate and sufficient opportunities to meet set standards, therefore improving the validity of assessment tasks and increasing educational accountability (Anderson, 2005; FitzPatrick et al., 2015; Näsström, 2008; Ziebell & Clarke, 2018).

When content or skills of certain learning objectives are omitted in assessment or classroom teaching, a course is misaligned. An imbalance of emphasis given to particular objectives in classroom instructions or the assessment also leads to misalignment (Porter, 2004). Failure to identify low alignment could lead to low student performance when classroom instructions do not match the assessment, or to invalid results when the assessment does not align with learning objectives (Anderson & Krathwohl, 2001). Teacher effectiveness may also be decreased or misjudged if classroom instructions are poorly aligned with national standards or external assessments (Anderson, 2005).

Studying alignment is particularly important during the transition to a new curriculum, such as the transition to the reformed QCE system, to evaluate the coherence between the newly prescribed curriculum and enacted curriculum (Edwards, 2010). However, it needs to be emphasised that alignment does not measure the quality or appropriateness of objectives, teaching activities, and assessment for a particular group of students (Blumberg, 2009) and that high alignment cannot guarantee improved student outcomes (FitzPatrick et al., 2015). For example, a mathematics teacher’s learning objectives, classroom instructions, and school internal assessment may be well aligned but only target the retrieval of procedural knowledge, which may not be appropriate for learning mathematics at school and insufficient for high achievement in the National Assessment Program for mathematics. The appropriateness of a curriculum's knowledge types and cognitive demands therefore needs to be discussed independently from curriculum alignment.

2.2.3.2. Alignment Studies. Studies examining alignment are an extension of educational research evaluating the content validity of assessment (Martone & Sireci, 2009). These studies have been conducted extensively in the United States after the implementation of the No Child Left Behind Act in 2001 and its standard-based accountability system (Ziebell & Clarke, 2018). During this time, various methods of measuring the degree of curriculum alignment have been developed, most notably Webb's (1999, 2002) Alignment Method, the Achieve Method (Resnick et al., 2004b), and Porter's (2002) Survey of Enacted Curriculum. The first two methods focus exclusively on alignment between the prescribed and assessed curriculum, whereas the third method can be used to measure the alignment of teacher instructions. The Survey of Enacted Curriculum has also been used to measure alignment between the prescribed curriculum and textbooks (Polikoff, 2015), between several different prescribed curricula (Jane et al., 2011; Porter et al., 2011), and it could be used to measure a change in curricula over time (Polikoff et al., 2020). For a comprehensive review and evaluation of these curriculum alignment measures please refer to literature written by Martone and Sireci (2009) and Cizek et al. (2018).

To measure curriculum alignment, information in the different curriculum components needs to be coded into a common language to allow for comparison (Ziebell & Clarke, 2018). Frequently, this is done on two dimensions: knowledge and cognitive skills. Knowledge types can be deduced from content matter, while cognitive skills are often categorised using educational taxonomies. To exemplify this, Table 2.3 compares a selection of popular classification frameworks for cognitive skills in alignment studies. The use of a clearly defined common language for categories to describe and classify learning objectives, classroom instructions, and assessment can improve the quality of alignment studies (Porter, 2002). If this common language is too complex, it will prevent shared understanding, but if it is too simplistic, it will overlook distinctions among content (Porter, 2004). No consensus has yet been reached on the ideal classification criteria for quantifying curriculum alignment, or the satisfactory amount of alignment (Martone & Sireci, 2009; Ziebell & Clarke, 2018).

Table 2.3

Categories of Cognitive Skills in Different Classification Frameworks

Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001)	New Taxonomy of Educational Objectives (Marzano & Kendall, 2007)	SOLO Taxonomy (Biggs & Collis, 1982)	Depth of Knowledge Dimensions (Webb, 2007)	Levels of Cognitive Demand (Porter, 2002)
Remember	Retrieval	Pre-structural	Recall	Memorise
Understand	Comprehension	Uni-structural	Skill/concept	Perform procedures
Apply	Analysis	Multi-structural	Strategic thinking	Communicate understanding
Analyse	Knowledge utilisation	Relational	Extended thinking	Conjecture/generalise
Evaluate		Extended abstract		Solve non-routine problems
Create				

Alignment studies have the potential to provide data which can guide the improvement of educational standards, assessment, and instruction. Results from alignment studies can support policymakers in the evaluation of educational programs and educators in making improvements to their planning, teaching, and assessment (Martone & Sireci, 2009; Nässtrȍm, 2008). Alignment studies are particularly useful in the context of reform efforts, such as the implementation of a new syllabus, as they indicate which areas of the enacted curriculum need further changes to match the newly prescribed curriculum and address deficiencies in newly developed assessment or resources (Edwards, 2010). In addition, alignment studies carry inherent benefits to readers and participants of the research as they help educators become more familiar with the details of standards and assessment (Martone & Sireci, 2009). Participation in alignment studies itself increases the degree of alignment between the prescribed and enacted curriculum as participating teachers improved their ability to interpret learning objectives and assessment questions (Ziebell & Clarke, 2018).

2.2.3.3. Curriculum Alignment After Educational Reforms. There is a strong emphasis in the literature on measuring the alignment between the prescribed and assessed curriculum (Çil, 2015; Contino, 2013; Edwards, 2010; El Hassan & Baassiri, 2019; Kara & Cepni, 2011; Liang & Yuan, 2008; Liu & Fulmer, 2008), as opposed to examining the alignment of the enacted curriculum. After educational reforms, the prescribed and assessed curriculum tend to be poorly aligned (Kuiper et al., 2013). It appears that curriculum reforms frequently entail changes to the prescribed curriculum by releasing new policies or curriculum documents, while assessment practices remain the same, leading to inconsistent messages about which knowledge and skills are important. For example, Cullinane and Liston (2016) reported that the range and emphasis on different cognitive skills in Irish biology examinations remained the same as before the implemented syllabus reform; the examinations predominantly assessed the first three cognitive levels of Bloom's Taxonomy.

In the Netherlands, it was found that external examinations were poorly aligned with newly implemented curriculum documents that emphasise a contextualised approach to science and mathematics education (Kuiper et al., 2013). Ensuring the reliability and comparability of those external examinations prevented a comprehensive assessment of all curriculum aims, including the assessment of concepts in new contexts. A similar picture emerged in China; assessment for certain subjects did not include the same range of cognitive or general skills as prescribed by the reformed biology (Lu & Liu, 2012) or mathematics standards (Leung et al., 2014).

In Queensland's reformed QCE, new summative assessment types, including external examinations, embed the same cognitive skills from the New Taxonomy in their criteria and task descriptions as syllabus learning objectives. Year 12 school-internal assessment must be submitted to and endorsed by the QCAA to ensure, amongst other quality criteria, alignment with relevant syllabus objectives. The external examination is written by the QCAA to assess the learning objectives of the final two syllabus units (QCAA, 2020a). Alignment between the prescribed and assessed curriculum may therefore be higher than in the studies reviewed here. Where well-aligned assessment is found, it has the potential to lever curriculum change (Kuiper et al., 2013) and promote new teaching methods that align with the reformed prescribed curriculum (Holme et al., 2010). This means that there is a possibility of significant curriculum alignment in the reformed Queensland senior system.

However, in other contexts, studies show low alignment between the enacted curriculum and prescribed curriculum after educational reforms. Similarly to Queensland, the Swedish mathematics reform included the administration of well-aligned external examinations, yet classroom observations of almost 200 teachers showed that the enacted curriculum often deviated from cognitive skills in the prescribed curriculum (Boesen et al., 2014). This may be because teachers construct their own meaning of curriculum documents, interpret, and then filter the prescribed curriculum to bring it alive in the classroom (Kim-Eng Lee & Mun Ling, 2013). In Western Australia, teacher interviews suggested that diversity in curriculum interpretation after the latest senior secondary curriculum reform was high, even though teachers aimed for high curriculum alignment to prepare students for external exit examinations (Krüger et al., 2013). Furthermore, the introduction of the new English, history, and mathematics syllabi in New South Wales led to the inclusion of new content, but to no initial and significant reform of teaching practices, as teachers felt they were too time-poor to deeply engage with the new conceptual frameworks of the syllabi (O'Sullivan et al., 2008).

These examples show that it is important to investigate the alignment of prescribed and enacted curricula independent of their alignment with the assessed curriculum. Table 2.4 lists relevant findings of all reviewed studies that explicitly researched the alignment of the enacted curriculum with a reformed prescribed curriculum. It is evident that such alignment was low across those studies without exception. Fenwick's (2018) analysis of planned lesson activities in Australia, Nargund-Joshi et al.'s (2011) lesson observations in India, and Orafi and Borg's (2009) lesson observations in Libya showed considerable differences between the prescribed and enacted curriculum. Furthermore, several studies confirmed the previously mentioned trend that cognitive skills contribute more to low alignment than knowledge (Albadi et al., 2019; Boesen et al., 2014; Dolma et al., 2018; Fenwick, 2018).

Table 2.4

Empirical Findings on the Alignment of the Prescribed and Enacted Curriculum After Reform Efforts

Country	Reform aim	Method	Curriculum alignment
Australia	Improve student outcomes through the inclusion of metacognition in literacy	Document analysis (*n* = 4 teachers)	Learning opportunities for metacognition mandated by the newly prescribed curriculum were not created in the enacted curriculum (Fenwick, 2018).[a]
Australia	Critical Inquiry Approach in physical education	Interviews, lesson observations, field notes (*n* = 3 teachers)	Inconclusive; however, the authors conclude that "curriculum and policy are volatile and rarely mobilised as the creator/s intended" (Alfrey et al., 2017, p. 117).
Bhutan	Authentic and constructivist approach to mathematics learning	Qualitative survey (*n* = 72 teachers)	Weak alignment of prescribed and enacted curriculum, particularly for cognitive levels (Dolma et al., 2018).[a]
India	New national curriculum with a constructivist teaching approach in all subjects	Interviews, lesson observations, artefacts (*n* = 2 teachers)	Classroom practices were not aligned with the goals of the curriculum reform (Nargund-Joshi et al., 2011).
Libya	New English language curriculum to include functional language use	Lesson observations, interviews (*n* = 3 teachers)	Misalignment: "The analysis highlights considerable differences between the intentions of the curriculum and instructions observed" (Orafi & Borg, 2009, p. 243).
Saudi Arabia	Student-centred learning in physics (increased emphasis on practical skills and collaboration)	Interviews (*n* = 6 teachers) survey (*n* = 360 students)	Low alignment as most teachers were using the *old style* of teaching (Albadi et al., 2019).
Sweden	National reform of mathematics education to include a range of competency goals	Interviews, lesson observations, online surveys (*n* = 197 teachers)	Only 18% of teachers had functional knowledge of the new competency goals in the reformed curriculum. The authors conclude that "if a curriculum includes content goals, such as arithmetic, then arithmetic is indeed taught, but if the curriculum includes competency goals, such as problem-solving ability, then the effect on teaching may vary significantly" (Boesen et al., 2014, p. 73).
Turkey	Greater emphasis on science process skills and student-centred learning in biology	Survey (*n* = 128)	Lack of coherence between the newly prescribed curriculum and (a) assessment practices; (b) availability of resources, and (c) professional development opportunities for teachers (Öztürk Akar, 2014).
Turkey	Student-centred, constructivist approach to primary science education	Lesson observations, interviews, document analysis survey (*n* = 1)	Enacted classroom assessment activities were misaligned with the prescribed curriculum (Serin, 2015).

[a] Analysis of planned, but not yet implemented, lesson activities such as teachers' lesson plans.

2.2.3.4. Factors Affecting Curriculum Alignment After Reforms. Data in Table 2.4 raise questions about common reasons behind low curriculum alignment after reform efforts. Even if new curriculum materials are developed concurrently with reform implementation by updating textbooks and developing teaching resources, changes in teaching practice may not occur (Albadi et al., 2019; Leat & Lin, 2003). This could be because teachers desire different changes to practice than curriculum developers (Byrne & Prendergast, 2020) or because teachers' opinions of what it means to be capable in a subject do not align with the new syllabus objectives (Doyle et al., 2019). Teachers' prior experience and values play an important role in their interpretation of a newly prescribed curriculum (Dai et al., 2011; Kuiper et al., 2013; Penuel et al., 2009). In addition to these factors, teachers' capabilities and self-efficacy (Orafi & Borg, 2009; Serin, 2015), and the amount and quality of professional development opportunities that teachers are receiving to adequately work with reformed pedagogy or content (Boesen et al., 2014; Öztürk Akar, 2014) may be significant influences on the degree of curriculum alignment. Support by school leadership and colleagues to implement the change is also a noteworthy factor (Alfrey et al., 2017; Orafi & Borg, 2009). Finally, factors that are independent of the direction or philosophy of the reform can lower curriculum alignment, such as perceived time constraints due to overcrowded curricula (Boesen et al., 2014; Öztürk Akar, 2014), pressure to teach to high-stakes assessment (Doyle et al., 2019; Nargund-Joshi et al., 2011), student resistance (Orafi & Borg, 2009), and in the case of India and Saudi Arabia, class size (Albadi et al., 2019; Nargund-Joshi et al., 2011). Table 2.5 summarises these high-alignment obstacles after curriculum reforms.

Table 2.5

Factors Affecting Alignment of the Prescribed and Enacted Curriculum

Factor	Evidence
Teachers' prior experience, beliefs, values, or concerns	Alfrey et al., 2017; Byrne & Prendergast, 2020; Dai et al., 2011; Doyle et al., 2019; Krüger et al., 2013; Kuiper et al., 2013; Orafi & Borg, 2009; Penuel et al., 2009; Wallace & Priestley, 2017
Assessment requirements, particularly requirements of high-stakes examinations	Dai et al., 2011; Doyle et al., 2019; Krüger et al., 2013; Nargund-Joshi et al., 2011; Orafi & Borg, 2009; Öztürk Akar, 2014
Time constraints due to the quantity of content to be covered	Albadi et al., 2019; Boesen et al., 2014; Dai et al., 2011; Nargund-Joshi et al., 2011; Öztürk Akar, 2014; Serin, 2015
Teachers' capabilities, familiarity with pedagogies and self-efficacy	Avargil et al., 2012; Dai et al., 2011; Orafi & Borg, 2009; Öztürk Akar, 2014; Serin, 2015
Lack of teaching resources	Albadi et al., 2019; Boesen et al., 2014; Öztürk Akar, 2014; Penuel et al., 2009
Lack of or insufficient professional development opportunities	Albadi et al., 2019; Boesen et al., 2014; Öztürk Akar, 2014; Serin, 2015
School culture (i.e., insufficient support by leadership, insufficient time to plan and prepare, peer pressure by colleagues)	Alfrey et al., 2017; Lidar et al., 2020; Orafi & Borg, 2009; Penuel et al., 2009
Students' learning habits and/or student resistance	Dai et al., 2011; Orafi & Borg, 2009
Class size	Albadi et al., 2019; Nargund-Joshi et al., 2011

Only two reviewed studies propose factors that can increase curriculum alignment. Firstly, Avargil et al. (2012) emphasise the importance of continuous teacher support in the context of a new chemistry curriculum in Israel. This support particularly includes professional development opportunities focused on pedagogical content knowledge. Secondly, Hume and Coll (2010) examined the alignment of the enacted curriculum 20 years after a curriculum reform in New Zealand, and suggest that collective decision making about classroom practices communicated by departmental guidelines can result in high alignment between the prescribed and enacted curriculum. However, this means that teachers are left with less individual agency over their teaching, thus leading to homogenous approaches to curriculum delivery such as the distribution of pre-written lesson plans and resources, which carries its own disadvantages (Barton et al., 2014).

2.2.3.5. Summary and Considerations for Teachers in Queensland. The reviewed literature highlights that curriculum alignment tends to be low after educational reforms, sometimes even years after their initial implementation. Obstacles to high curriculum alignment after reform efforts range from factors specific to the change the reform aims to achieve (e.g., teachers' or students' opposing beliefs, unfamiliarity with the new philosophy, and school culture), to more general factors (e.g., time constraints, assessment requirements, and lack of teaching resources). The alignment of cognitive skills in the prescribed curriculum and enacted curriculum seems to be particularly problematic.

The QCAA aims to align the reformed syllabus learning objectives and the respective external examination questions by utilising cognitive verbs of comparable levels in both documents (QCAA, 2017b). This begs the question: Will the enacted curriculum also incorporate the same range of cognitive demands? Government authorities and school leadership can improve the chances of high curriculum alignment after reforms by minimising discussed obstacles to the alignment of the enacted curriculum and prescribed curriculum (Table 2.5). Nevertheless, there may be a gap between the expectations of the QCAA and classroom teaching and learning. The development of new curriculum materials for cognitive skills education is not enough for a change in teaching practice to occur (Leat & Lin, 2003).

After analysing the implementation of a new pedagogical approach to health and physical education in Queensland, Alfrey et al. (2017, p. 117) conclude that "curriculum and policy are volatile and rarely mobilised as the creator/s intended." Therefore, research examining the alignment of the enacted Queensland senior secondary curriculum would be instructive, ideally by using longitudinal studies to demonstrate how alignment changes with time after the implementation of the reform. Such research could be more informative if it began soon after the reform as teachers make important decisions about the implementation of change early (Byrne & Prendergast, 2020). Moreover, studies could be designed in a manner that gives the teachers who are implementing reformed curricula a voice, as alignment has been low when teachers are not involved in the change process and if their concerns are not heard (Öztürk Akar, 2014). Participation in alignment research itself could increase curriculum alignment because it improves teachers' understanding of what is intended by the prescribed curriculum (Shalem et al., 2013). Finally, pre-service teachers can play a key role in the implementation of a highly aligned reformed curriculum as they are less likely to have values, beliefs, or ideologies which may form a barrier to curriculum reform (Dinan Thompson, 2001).

Taxonomies for educational objectives can help measure the degree of alignment by providing a classification framework (Anderson & Krathwohl, 2001; Blumberg, 2009). To date, the majority of alignment studies use Bloom's Taxonomy or the Revised Taxonomy to determine the alignment of summative assessment with course objectives in a tertiary education context (e.g., FitzPatrick et al., 2015; Yamanaka & Wu, 2014). Very limited research exists on the alignment between prescribed learning objectives and classroom teaching in senior secondary lessons using the New Taxonomy.

2.2.4. The De Facto Curriculum in Textbooks

2.2.4.1. Significance of Textbooks. In schools, textbooks often act as intermediaries between the prescribed curriculum and enacted curricula by translating policy intentions into sequenced content knowledge and learning activities. This is why the content and tasks in textbooks have been described as the de facto prescribed curriculum (Harwood, 2017) or the potentially implemented curriculum (Törnroos, 2005; Valverde et al., 2002). Textbook content and structure are strongly correlated with the types of questions science teachers ask during lessons and summative assessment (Nakiboğlu & Yildirir, 2011). Textbooks also influence the pedagogical choices of teachers and their prioritisation of subject matter (Reys et al., 2004; Valverde et al., 2002). Usiskin (2013) argues that in the USA, pedagogical practice is more aligned with textbook content than with official curriculum documents. In Asian contexts, alignment between the prescribed curriculum and textbooks is described as the most important indicator of consistency between prescribed and enacted curricula (You et al., 2019; Yu et al., 2022).

The frequency that textbooks are used during science lessons further increases the significance of their influence on the enacted curriculum. Chiappetta et al. (2006) reviewed research on science textbooks in the USA over the past 100 years and reported that textbooks were used to inform and direct lesson activities and homework by 90% of teachers. In Australia, textbooks seem to be used in every or most lessons by the majority of science teachers (McDonald, 2016). Textbooks are likely the most consistently used resource for lesson planning and teaching, despite the increased availability of electronic resources.

Like any teaching resource, textbooks are shaped by culture and are likely designed to reproduce societal values and beliefs (BouJaoude & Noureddine, 2020). In the context of science education, textbooks may guide students' views about the nature of science, including the knowledge and skills that are valued by each scientific discipline (Andersson-Bakken et al., 2020). In this manner, textbooks can define the content and aims of each science subject for students (Valverde et al., 2002), and thus clarify the nature of knowledge and how it is best studied. For instance, Sapountzi and Skoumios (2014) found that Greek physics textbooks present physics content knowledge as unproblematic and true, implying that it needs to be recalled uncritically for students to progress in the subject. This exemplifies how science textbooks can influence the way students process knowledge and, critically, their affective engagement with topics such as In Vitro Fertilisation (IVF), vaccination, carbon sequestration, nuclear power generation, and other issues that engender wide debate in society.

The type of cognitive skills a textbook promotes might ultimately influence student achievement. Studies examining mathematics textbooks have shown that students using textbooks with more questions at higher-order cognitive levels score higher on national summative assessments (Hadar, 2017) and international tests such as the Programme for International Student Assessment (PISA) or the Trends in International Mathematics and Science Study (TIMMS) (Yang & Sianturi, 2017). The more emphasis questions in a textbook place on a particular cognitive skill, the better students using the textbook performed on TIMMS items assessing the same skill (Törnroos, 2005). A possible conclusion is that students' opportunities to learn and practise various cognitive skills is limited by textbook content, particularly textbook questions or tasks. Despite the link between textbook content and student achievement, budget and time considerations prevent many publishers from gathering data regarding the alignment or effectiveness of their textbooks in the classroom (Reys et al., 2004).

2.2.4.2. Past Research on Textbooks. Prior research on science textbooks can be divided into studies analysing the knowledge presented in textbooks and studies analysing textbook learning activities. Vojíř and Rusek's (2019) literature review on science textbook research shows that the majority of studies focus on the knowledge presented in science textbooks, and particularly the breadth of content matter, the integration of concepts, and the non-textual explanations of content. Further popular focus areas for science textbook research include the scale and scope of knowledge (e.g., Boersema et al., 2001), the nature of science (e.g., Chiappetta & Fillman, 2007), or the preparation of students for the 21st century (e.g., BouJaoude & Noureddine, 2020). Only 8% of studies reviewed by Vojíř and Rusek (2019) focus on textbook elements that guide students' learning (e.g., questions), and only 4% of reviewed studies analyse the relationship or alignment between the textbook and the prescribed curriculum.

Research studies analysing science textbook learning activities report a noticeable overemphasis on questions addressing lower-order cognitive skills as compared to higher-order cognitive skills in high school science (e.g., Andersson-Bakken et al., 2020; Kahveci, 2010; Nakiboğlu & Yildirir, 2011). Similar overemphasis has been reported in middle school science (e.g., Pizzini et al., 1992), and at college (e.g., Dávila & Talanquer, 2010; Pappa & Tsaparlis, 2011). Learning activities with low cognitive demands were predominantly closed short-answer questions requiring students to reproduce predetermined declarative knowledge. Pizzini et al. (1992) also noticed that the cognitive demands of questions do not vary as students progress through their textbooks. Several studies remarked on a distinct lack of learning activities that would scaffold scientific inquiry such as experimental design or critical decision making, application of learned knowledge in new contexts, or metacognition (Andersson-Bakken et al., 2020; Dávila & Talanquer, 2010).

To date, the limited number of studies on learning activities in science textbooks indicates a tendency to focus on lower-order cognitive skills. Analyses of textbooks for other subjects reflect this trend. For instance, dominant mathematics textbook tasks tend to be closed questions requiring routine computations as opposed to questions requiring students to solve problems, pose problems, or reflect on their work (Cai & Jiang, 2017; Gracin, 2018). Similarly, tasks requiring lower cognitive demand constitute more than half of all questions in analysed social science textbooks (Tarman & Kuran, 2015), accounting textbooks (Davidson & Baldwin, 2005), and geography textbooks (Yang et al., 2015). Only studies analysing textbooks for English classes seem to report a more balanced occurrence of questions with lower and higher-order cognitive demands (e.g., Assaly & Smadi, 2015; Shuyi & Renandya, 2019).

Finally, studies examining the alignment of textbooks or other teaching resources with the prescribed, enacted, or assessed curriculum are rare. Polikoff's (2015) alignment study of fourth-grade mathematics textbooks in the USA and Qhibi et al.'s (2020) study of seventh- to ninth-grade mathematics textbooks in South Africa represent two instances in which textbooks were relatively well aligned with the prescribed curriculum. However, these textbooks tended to focus on lower-order cognitive skills such as memorisation and the execution of routine procedures. More empirical evidence is needed to examine the alignment of science textbooks with prescribed and enacted curricula to evaluate which skills or knowledge are commonly overlooked.

2.2.4.3. Summary and Considerations for Teachers in Queensland. Simultaneously with the introduction of the reformed Queensland curriculum, three publishers released new senior science textbooks and workbooks. These textbooks were specifically designed for the implementation of the reformed system and are claimed to "perfectly match the new syllabus content" (Cengage Learning Australia, 2022, para. 1). Further publishers followed with new textbook releases within the first two years of the reformed QCE, increasing the choice of available teaching resources. This literature review indicates frequent and consistent use of textbooks by science teachers. Therefore, Queensland's senior science teachers may rely strongly on newly published textbooks for their lesson planning, particularly considering that some learning objectives in the reformed syllabi may be unfamiliar to teachers. Hence, textbooks may influence the cognitive demands of teacher instructions and thus, the alignment of cognitive skills between the prescribed and enacted curriculum.

This literature review also shows that science textbooks often fail to include higher-order thinking tasks to the same extent as envisioned by the prescribed curriculum. By limiting students' learning opportunities, textbooks have the potential to negatively impact student achievement (van den Ham & Heinze, 2018). It would be of value for teachers to examine the cognitive demands of available senior science textbooks and their alignment with the prescribed curriculum, to enable informed decisions about the effective use of this teaching resource. A systematic analysis of cognitive skills in Queensland's senior science textbooks may also inform changes in future textbook editions.

2.3. The Need for the Present Study and its Research Questions

This systematic literature review shows how the prescribed curriculum embeds cognitive skills in learning objectives using cognitive verbs (e.g., describe, analyse, justify, etc.) Those learning objectives can be classified into distinct cognitive levels using educational taxonomies. Building on Bloom's Taxonomy (Bloom et al., 1956) and the Revised Bloom's Taxonomy (Anderson & Krathwohl, 2001), Marzano and Kendall's (2007) New Taxonomy of Educational Objectives has been chosen to underpin all reformed senior secondary syllabi in Queensland. It can be used by educators to analyse syllabus content matter, develop valid assessment, plan relevant lessons, or teach cognitive skills explicitly. Australia's educational policies strongly reflect such teaching of cognitive skills in the enacted curriculum (e.g., Gonski et al., 2018; Ministerial Council on Education, Employment, Training and Youth Affairs, 2008; QCAA, 2018e). Research has identified effective pedagogies to teach cognitive skills, including but not limited to modelling, guided practice, metacognitive reflection, and cooperative learning. However, the alignment of cognitive skills in learning objectives and learning activities is often low after curriculum reforms.

The transition to a new senior curriculum in Queensland highlights the relevance of evaluating such alignment between the prescribed and enacted cognitive skills curriculum. Compared to the USA and many Asian countries, comprehensive research on curriculum alignment in Australian secondary education is scarce. It seems prudent that such alignment studies use the New Taxonomy as a classification framework for cognitive skills because it is considered to support the advancement of curriculum and assessment in Queensland.

In secondary science subjects, textbooks can have a significant influence on teachers' instructions and, in turn, students' opportunities to practise various cognitive skills in the classroom. However, there is no data on the cognitive demands of presently available science textbooks in Queensland. Moreover, it is currently not clear which cognitive skills are modelled and emphasised in Queensland's classrooms and which pedagogies are used to teach them. The lack of such research undermines current educational imperatives which emphasise the development of students' cognitive abilities and the 21st Century Skills outlined in each reformed senior science syllabus (e.g., QCAA, 2018b, p. 9). In light of Queensland's senior curriculum reform and the reviewed literature on cognitive skills, the following research questions guide this study:

1. What are the cognitive demands of the reformed Queensland physics, chemistry, and biology syllabus?
    a. Which cognitive levels are emphasised by learning objectives in the reformed syllabi?
    b. How are the metacognitive and self-system embedded in the reformed syllabi?
    c. What changes were introduced by the recent senior curriculum reform to the cognitive demands of learning objectives?

2. What are the cognitive demands of the de facto curriculum presented in senior physics, chemistry, and biology textbooks?
    a. Which cognitive levels are emphasised by senior science textbooks that are prepared for the reformed syllabi?
    b. Do cognitive demands of senior science textbooks differ between subject areas?
3. What are the cognitive demands of the enacted Queensland physics, chemistry, and biology curriculum?
    a. How many explicit opportunities do students have to actively practise cognitive skills during senior science lessons?
    b. What are the cognitive levels of teacher instructions during lessons?
    c. Which instructional strategies dominate the enacted senior science curriculum?
4. How aligned are the cognitive demands of the prescribed, de facto, and enacted Queensland physics, chemistry, and biology curriculum?
    a. Do the cognitive demands of textbook questions align with the cognitive demands of syllabus learning objectives?
    b. Do the cognitive demands of teacher instructions during lessons align with the cognitive demands of syllabus learning objectives?
    c. Do the cognitive demands of teacher instructions during lessons align with the cognitive demands of textbook questions?

The approach taken to answer these research questions is described in Chapter 3.

Chapter 3. Methodology

This chapter describes and justifies the methodology chosen to address the study's research questions. First, the post-positivist research perspective of this collective case study is discussed. Second, the study design is introduced, including its modifications following a pilot study. Thereafter, the chapter describes the timeline for data collection and explains how data on each examined curriculum component were collected and analysed. The chapter concludes with an evaluation of the study's research design quality and an outline of ethical considerations.

3.1. Research Approach

3.1.1. A Post-Positivist Research Perspective

Most methodologies are closely tied to a specific philosophical perspective (Creswell, 2012). Quantitative experimental designs in the natural sciences, for example, assume a positivist worldview in which the researcher tries to describe an objective reality that is independent of the observer. In contrast to this, most anthropological ethnographies adopt a qualitative relativist perspective which assumes that reality is dependent on and co-created by the researcher. They argue that there is no single objective reality (Ormston et al., 2014).

Case studies are versatile and not necessarily associated with a singular epistemological school of thought (Harrison et al., 2017), giving the researcher the freedom to adopt the most suitable research perspective. Some case studies address both quantitative and qualitative research questions, providing a bridge between both paradigms (Harrison et al., 2017). Such multi-method case studies have been described to have their own philosophical approach, namely pragmatism: the willingness to use any methods that can help understand the research problem (Creswell, 2012) or advance the field of study by providing practical solutions to problems (Henderson, 2011). Often, these case studies have an eclectic philosophy between positivism and relativism.

In this study, the researcher adopts a post-positivist philosophy. This perspective sees case studies as a form of empirical inquiry (Lincoln et al., 2011) with the following characteristics:

- The researcher believes that there is an objective reality, such as an objective amount of misalignment between policy intentions and classroom practice, and attempts to measure this reality while acknowledging that measurements are imperfect. Reality may never be understood fully as social knowledge is constructed differently by different people in different contexts. Social interactions in classrooms have many hidden variables and do not follow universal laws like natural sciences. A physical quantity (e.g., the mass of an object) does not change depending on context, but variables measured in social sciences (e.g., the suitability of a certain pedagogy) vary depending on context, resulting in non-uniformity of knowledge constructed by research results (Erickson, 2011; Panhwar et al., 2017). However, the researcher believes that incomplete data on curriculum alignment which approximates reality can still provide valid opportunities to inform decision making and recommendations.
- Because of the assumption that reality cannot be measured perfectly, it is acknowledged that all methods have limitations. Nevertheless, phenomena can be studied with multiple methods and from multiple perspectives to reduce those limitations and approximate reality more accurately. Hence this study used a multi-method approach in seven different school settings to collect data. In this manner, this study values pluralism rather than an inflexible dualistic representation of opposing research philosophies (Henderson, 2011; Panhwar et al., 2017).
- The researcher strives for objectivity during data collection and data are analysed with an acceptance that all researchers are inherently biased. Strategies, such as standardised inquiry protocols, are put into place to minimise those biases (see Section

3.4. for further strategies), but the values of the researcher are not openly included in the analysis or interpretations of findings as the researcher attempts to separate her values from researched facts. For instance, the researcher completed reflective journal entries after each lesson observation, but these reflections were not included in the analysis of this study.

- The methods follow a systematic approach to data collection and analysis (see Section 3.3.) with scrutiny of research from blinded peer reviewers and participants to ensure the validity of results and rigour of data collection.
- While the research approach allows for issues to be studied in context-dependent natural settings (i.e., classrooms), interactions with participants are minimised. Instead of actively participating in lessons alongside participants, the researcher acts as a passive observer and informer of findings.

3.1.2. Research Through Case Studies

Case studies have been defined and implemented in a variety of ways across a range of disciplines, particularly anthropology, social science, education, business, law, and health (Erickson, 2011; Yin, 2009). Examples of case studies date back to the 19th century with biographies of scientists like Charles Darwin (Harrison et al., 2017). The modern version of a case study has its origin in ethnographic studies of secluded cultures in the first half of the 20th century (Erickson, 2011). Educational research adopted case studies in the 1970s to evaluate curriculum and measure the impact of educational programs (Harrison et al., 2017). Case studies are an effective tool for evaluation and are said to be very suitable for the investigation of processes, such as reform efforts or innovation, because they report on interactions between investigated variables (Merriam, 1998; Yin & Davis, 2007). They are also a preferred methodological approach when the context of a study is distinctive (Yin, 2012), as is the case with this study, which involves collecting data in the first year that students graduate with the reformed QCE. The reform brought about a sudden and significant shift from the previous system, introducing high-stakes external examinations and standardised learning objectives to Queensland teachers and students for the first time in nearly five decades.

The use of case studies in a diverse range of subject areas has made the approach versatile and has prevented a uniform application of the methodology. It is important then to define a case study as it is used to answer this study's research questions. After reflection on the conceptualisation of case studies by three prominent methodologists—namely, Robert Yin, Robert Stake, and Sharan Merriam—this study adopted Yin's (2009) definition as it aligns most closely with the researchers' post-positivist philosophy. In addition, as opposed to Stake and Merriam, Yin does not try to distinguish between quantitative and qualitative case study methods, but pragmatically focuses on common tools that both research traditions can contribute to the design of case studies (Yazan, 2015; Yin, 2012). This pragmatic perspective aligns with the multi-method design of this study.

Yin (2009, p. 17) defines a case study as "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." In the context of this case study, the *contemporary phenomenon* is the alignment of intended cognitive demands in senior science curricula with classroom practice and the *real-life context* is classroom teaching during the transition to a new senior system. Data collection in the real-life context makes case studies particularly valuable for social sciences as their theory is rarely context-independent like in the natural sciences (Flyvbjerg, 2011). In situations without universal predictive theories, deep knowledge of individual cases with all their variables becomes valuable. Case studies lend themselves well to topics that are shaped by human behaviour and social interactions, so they are very suitable for school-based research. Case studies are also highly suitable for uncovering the impact of context on the investigated issue (Flyvbjerg, 2011). In this study, the transition to reformed senior syllabi in a regional and diverse part of Queensland is unique and will most likely influence results.

A case study, as defined in this research, has several unique characteristics. As opposed to experimental studies like randomised controlled trials, the researcher has little or no control over investigated events because research questions are investigated in real-world settings (e.g., classrooms). This makes case studies suitable for situations influenced by many factors and without clear boundaries between the issue investigated and the context. Classroom learning is a prime example of such a situation as a long list of factors impacts curriculum implementation and students' learning. As a consequence of having to consider many factors, multiple sources of evidence with several methods for data collection are used to answer the research questions. Indeed, each research question outlined in Section 2.3. has its own data collection and analysis methods.

The value of case studies has been criticised based on its frequent inability to generalise results (Flyvbjerg, 2011; Harrison et al., 2017). However, knowledge is transferable between cases, just as students can generate knowledge from examples provided in class and apply this knowledge to new contexts. Knowledge constructed through case studies can therefore be used to make theoretical propositions (Yin, 2009). Case studies are often vital during the first stages of theoretical development as this type of research decomposes the case into variables that are then further investigated (Flyvbjerg, 2011). A broad aim of this case study is to expand on existing theory about cognitive skills in science curricula and about curriculum alignment after reform. Findings can help to determine which questions would be important to ask about these topics in the future.

3.1.3. Classification of This Case Study

Three purposes of case studies have been described in the literature: exploration, description and explanation (Yin, 2009). As this study investigates clearly defined factors based on educational theory, it is not an exploratory case study. Instead, the purpose of analysing the cognitive demands of various curriculum components is descriptive. An empirical investigation of factors explaining descriptive results exceeds the scope of this study. Nevertheless, the discussion of findings includes justified hypotheses about known filters to the enacted curriculum that can lead to low curriculum alignment, such as teachers' beliefs and values, assessment requirements, time constraints, available professional development opportunities, and school culture.

Case studies also differ in purpose and structure. Yin (2009) classifies case studies based on the number of cases investigated, (i.e., single- vs. multiple-case designs). This case study does not tell the individual story of each sampled school but aims for a holistic analysis of findings across schools and teachers. Sampled schools or teachers are not treated as separate cases. The study is instead interested in differences between the three analysed subject areas, and subject areas were treated as three separate cases, resulting in a multiple-case design.

Finally, Stake (2013) classifies case studies based on the reason a case or multiple cases are chosen. A case study is intrinsic if the study aims to understand the particularities of the chosen case above the individual variables or problems that are investigated. The case with its unique circumstances is of interest rather than the issues it entails. On the other hand, a case study is instrumental if a case is chosen strategically to give better insights into a particular problem, to generalise or create theory about the issue. The case and its circumstances are of secondary interest and are only used to facilitate the understanding of the researched issue. If a researcher chooses to study multiple instrumental cases, the case study is classified as collective. In such a design, conclusions can be drawn based on how like or unlike individual cases are to each other. The methodology of this research follows a collective case study approach with three instrumental cases. Three different subject areas, namely physics, chemistry, and biology, are investigated to uncover common or diverging findings about the cognitive demands of the senior science curricula.

3.2. Study Design

3.2.1. Investigated Factors

Most methods for analysing curriculum alignment are designed to measure the alignment between learning objectives and assessment (Martone & Sireci, 2009), with the assumption that classroom instructions must be aligned if the prescribed curriculum and assessment align. This study analysed data using Porter's (2002) curriculum alignment model as it has been used to measure alignment between syllabus objectives, assessment, and classroom instructions (e.g., Edwards, 2010; Porter, 2002, 2004). A second advantage of Porter's alignment model, as compared to other frameworks for measuring alignment, is that it produces a single number as a measure for the degree of alignment, allowing for comparison of alignment (a) in different contexts, such as between subjects, schools, or regions; (b) over time, such as changes of alignment in consecutive years after reform efforts; and (c) across other educational variables, such as between textbooks or professional development programs (Martone & Sireci, 2009). The versatility of Porter's alignment model allows for a direct comparison of multiple curriculum components.

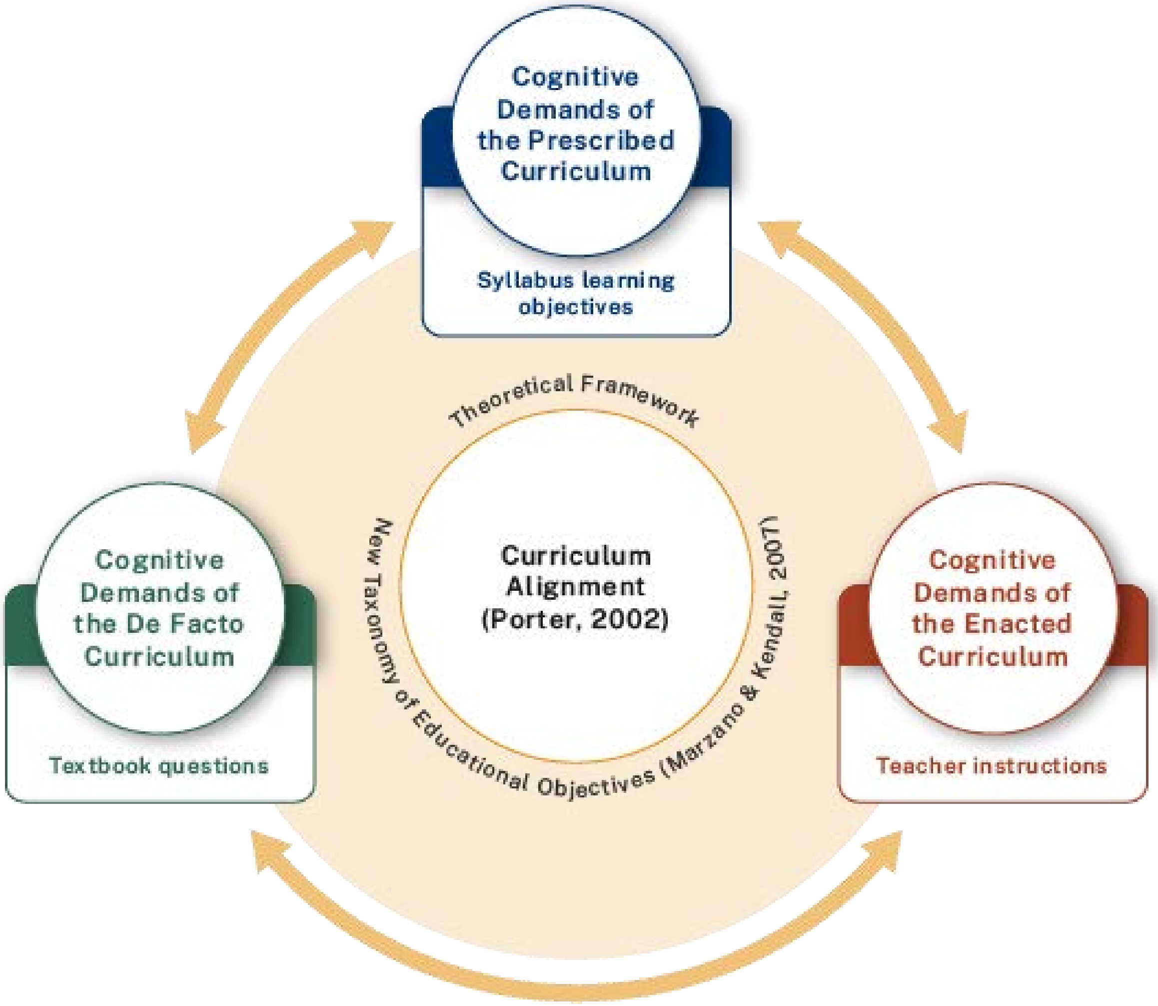
This study applied Porter's (2002) alignment model to the prescribed, de facto, and enacted curriculum with syllabus learning objectives representing the prescribed curriculum, teacher instructions representing the enacted curriculum and textbook questions representing the de facto curriculum. As outlined in Section 2.2.3.1., the concept of alignment refers to the coherence of curriculum content across all aspects of an educational system (Anderson, 2005). According to Porter (2004), curriculum content includes not just the topics that are potentially taught, but also the cognitive demand of learning each topic. Therefore, an analysis of curriculum alignment needs to compare the cognitive demands of content between any examined curriculum components.

Levels of cognitive demands are conceptualised differently in different educational taxonomies. This study classified cognitive demands based on the six levels of the New Taxonomy of Educational Objectives discussed in Section 2.2.1.2: retrieval, comprehension, analysis, knowledge utilisation, metacognition, and self-system thinking (Marzano & Kendall, 2007). The difference between the levels is theorised to be a function of the complexity of the thinking process at each level. For instance, categorising knowledge (analysis) requires more mental steps than recognising knowledge (retrieval) and is therefore considered more complex (Marzano & Kendall, 2007). Therefore, this study assessed the mental complexity of each analysed learning objective, textbook question and teacher instruction to classify it within a specific cognitive level. Further, levels of cognitive demand can be organised based on the degree of influence certain processes exert on the functioning of other processes. Metacognitive thinking, for example, controls how effective a student engages with an analytical task (Marzano & Kendall, 2007). In this study, instances of self-system thinking could be identified by influencing instances of metacognitive thinking and metacognitive thinking could be recognised through its impact on knowledge utilisation.

It is important to note that this study measured alignment on the cognitive dimension only, while the alignment of content knowledge by topic was not analysed. The conclusions of this study need to be read within the boundaries of the investigated factors shown in Figure 3.1 and their underlying theoretical framework.

Figure 3.1

Investigated Factors



3.2.2. Multi-Method Design

To examine the cognitive demands of the three investigated curriculum components, quantitative and qualitative data were collected through document analysis of syllabi and textbooks and through lesson observations. Multi-method case study designs with multiple data sources ensure a comprehensive exploration of investigated factors (Harrison et al., 2017) and can increase the validity of collected data (Kawulich, 2005). Moreover, Yin and Davis (2007) argue that evaluations of reform efforts likely require quantitative and qualitative evidence. In the context of the senior curriculum reform in Queensland, quantitative data can measure the frequency of cognitive skills at each level in each curriculum component and determine the degree of curriculum alignment, while qualitative data can examine implicit learning goals at different cognitive levels communicated throughout the syllabi and document teachers' pedagogical choices in the classroom. Hence, a multi-method design was adopted with the rationale that neither quantitative nor qualitative data alone would capture all trends and explanations of the research problem, but that quantitative and qualitative data could complement each other. Ritchie and Ormston (2014) conclude that despite great differences in methodological and philosophical origins, quantitative and qualitative research approaches can be effectively blended. Quantitative and qualitative results were integrated when answering the research questions and discussing findings, which allowed for higher-quality inferences.

3.2.3. Case Selection

Case studies are not defined by their chosen data collection methods, but by the demarcation of a case with specific and clearly established boundaries (Flyvbjerg, 2011). There is no uniform method for selecting cases to be studied, but certain guidelines can be followed. Flyvbjerg (2011) advises against selecting a random or even typical case, as these cases do not produce the richest data. Similarly, Stake (2013) does not recommend selecting cases based on trying to sample a range of attributes, but instead selecting cases that promise the most results. Cases should be chosen based on the information they can provide (Flyvbjerg, 2011). For instance, extreme cases which are particularly problematic or which exemplify outstanding practice help generate variables and ultimately new theory by documenting a variety of human experiences that may be missed by statistical analysis of random samples (Merriam, 1998). A selection of cases aiming for maximum variation, on the other hand, helps to investigate the significance of context and allows for comparison between different contexts. Alternatively, multiple cases could be purposefully chosen to produce contrasting results to generate theory, or cases that promise to produce similar results could be chosen to support the generalisation of findings (Harrison et al., 2017). Ultimately, the selection of a case and its context depends on the research objectives.

The main object of this case study is the cognitive demands of the reformed senior science curriculum in Far North Queensland. The location of Far North Queensland can be classified as an atypical or extreme context. Implementing the reformed QCE was likely more difficult in the Far North than other regions of Queensland, considering the region's geographical isolation and thus reduced access to professional development opportunities for teachers, its low-density population and hence lower collaboration between schools of the same district, its high student diversity, and its shortage of secondary science teachers (Bureau of Transport and Regional Economics, 2006). If this case study of Far North Queensland indicates a low alignment of the senior science curriculum's cognitive demands, stakeholders can be made aware that increased efforts are required to support teachers and schools in regional districts. Therefore, more can be learned from an atypical context.

The three subjects, physics, chemistry, and biology, were selected as instrumental cases because they were the three senior sciences with the highest student enrolment in Queensland and were offered at most high schools across the school district at the time (QCAA, 2020c). The physics, chemistry, and biology syllabi are based on the same teaching and learning framework and have similar summative assessment pieces (see Section 4.2.1.), suggesting that findings may converge. At the same time, the three subject areas differ in content knowledge and often in perceived difficulty (Lyons, 2006), which may lead to some contrasting findings. In summary, this case study is a collective case study bounded by its geographical location. It investigates the cognitive demands of three reformed senior science curricula in the context of their implementation in Far North Queensland.

3.2.4. Piloting

To test and improve the study design, a pilot study was conducted in Term 4 of 2019 at a small non-government Prep to Year 12 school in Far North Queensland with a 10% Indigenous student population and an Index of Community Socio-Educational Advantage (ICSEA) value of 1050[2]. The researcher was employed at this school as biology teacher; thus, data collection was limited to two subjects only (physics and chemistry). Since Year 12 students were still following the replaced Queensland senior syllabi in 2019, only Year 11 classes were observed. The two participating teachers were part of the intended target population but were not part of the study's sample. At the time of the pilot study, both teachers had over 17 years of teaching experience, a scientific undergraduate degree, and were teaching their subjects to Year 11 and Year 12. The chemistry teacher was also the Head of Department and the physics teacher was a QCAA endorser in the reformed QCE system. Both teachers identified as QCAA confirmers for their subject area and were panel members in the previous QCE system.

The data collection followed the protocol of the main study with an added qualitative element: teacher interviews. First, learning objectives in each subject's syllabus were analysed using the New Taxonomy of Educational Objectives (Marzano & Kendall, 2007) to classify cognitive verbs in subject matter content descriptors. Then, each participant was observed for three 50-minute lessons using the observation instrument designed for the main study and was interviewed once. The purpose of the semi-structured, open-ended interview was to probe for factors that may need to be added to the study's conceptual framework if they appear to affect the alignment of cognitive skills between different curriculum

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[2] The ICSEA is a scale of socio-educational advantage. ICSEA values range from approximately 500 (representing schools with extremely disadvantaged student backgrounds) to approximately 1300 (representing schools with extremely advantaged student backgrounds).

components. Porter's (2002) alignment index was calculated for both subjects together as there were insufficient data points for a separate analysis; lessons from one unit only per subject were observed. Results of the pilot study were presented at the *2019 Australian Association for Research in Education* conference in Brisbane and are summarised in Appendix A.

The analysis of the pilot study results led to several modifications of the research design and data collection procedures. Firstly, it became clear that the timing of observations had a strong influence on results. For example, the cognitive demands of teacher instructions during assignment work lessons were distinctly different to regular lessons during which students learned or practised new syllabus objectives, and so could bias the overall results. Therefore, the researcher decided not to observe lessons during which students are given time to work on their summative assignments (e.g., a student experiment and a research report), even if the lesson incorporated a teacher-directed component. Secondly, a qualitative analysis of how each syllabus embeds the metacognitive system and the self-system was added to the data collection methods. In the pilot study, both systems were evident in observed teacher instructions, even though they are not explicitly referred to in syllabus objectives or subject matter content descriptors. Thirdly, participants would be asked about their teaching experience and educational background (e.g., whether they have studied the subject area they are teaching at a tertiary level), as qualitative results of the pilot study suggest that teachers who are more confident with content matter are able to spend more time considering cognitive skills in their planning and teaching. Finally, both teachers interviewed in the pilot study emphasised their textbooks' influence on their planning and the cognitive demands of their teaching. So a comprehensive analysis of the cognitive demands of published textbooks for the reformed syllabi was added to the study's aims and methodology, in line with the recommendation that case studies should follow an emerging design as the investigated problem is progressively clarified (Yazan, 2015). The following section provides an explanation of and a justification for the methods used to collect and analyse data in the main study.

3.3. Methods for Data Collection and Analysis

Data collection followed a strictly standardised inquiry protocol for each of the three school subjects. This section outlines the timeline for data collection, followed by a detailed description of the inquiry protocols for each examined curriculum component in the order of the study's four research questions: (1) a document analysis of syllabi to analyse the prescribed curriculum, (2) a document analysis of textbooks to analyse the de facto curriculum, (3) lesson observations to analyse the enacted curriculum, and (4) the use of Porter's (2002) alignment index to analyse curriculum alignment.

3.3.1. Timeline

The document analysis of the syllabi was conducted from November 2019 to January 2020. Lesson observations started in January 2020, stopped during school closures due to the COVID-19 pandemic, and resumed at the end of June 2020. The observation schedule was adapted to ensure lesson observations did not occur during class tests, independent assignment work time, or out-of-class activities. All observations were completed by December 2020. It was important to observe teachers throughout the entire school year because instructions can look different early in the year, when teachers may focus on establishing classroom expectations, routines, or relationships, as compared to later in the year when teachers may prioritise preparing students for the external examinations (Matsumura et al., 2008). Textbooks were analysed during the pandemic-related break from lesson observations in April through to June 2020.

3.3.2. Analysis of the Prescribed Curriculum

Document analysis involves the critical and systematic examination of an instructional document. This unobtrusive data collection method provides the researcher with information that cannot be observed directly (Yin, 2009). To answer the first research question about the cognitive demands of the prescribed senior science curriculum in Queensland, this study analysed the biology (2019 version 1.2), chemistry (2019 version 1.3), and physics (2019 version 1.2) syllabus. The documents were accessed through the QCAA website (www.qcaa.qld.edu.au/senior/senior-subjects) and read in full to record their structure and components. Thereafter, subject matter content descriptors, the most specific learning objectives, were analysed for their cognitive demands.

The cognitive demands of these learning objectives were categorised as either retrieval, comprehension, analysis, or knowledge utilisation by matching cognitive verbs at the start of each learning objective with a list of cognitive verbs belonging to each cognitive level published by the QCAA (2018d). For example, *recognise the different types of nitrogenous wastes produced by the breakdown of proteins* was classified as Level 1: Retrieval, while *distinguish between absorption and emission spectra* was classified as Level 3: Analysis. The cognitive levels from Marzano and Kendall’s (2007) New Taxonomy of Educational Objectives were employed as the theoretical lens for analysing the cognitive demands of learning objectives. This decision reflected the reformed Queensland senior science syllabi’s adoption of the New Taxonomy’s cognitive verb terminology for learning objectives. Further, the syllabi explicitly detail the taxonomy’s structure and application in the Teaching and Learning section (e.g., QCAA, 2018b). Using the same taxonomy for the analysis of curriculum documents ensures consistency of language about cognitive skills, which enhances communication between educators (Moseley et al., 2004). The use of other well-known educational taxonomies, such as Anderson and Krathwohl’s (2001) Revised Taxonomy or Biggs and Collis’s (1982) Structure of Observed Learning Outcomes (SOLO) Taxonomy, would have been less appropriate for this study because the intentions of syllabus developers may be misinterpreted when cognitive verbs in learning objectives need to be reclassified based on taxonomies other than the one used for writing the objectives. The frequency of learning objectives in the syllabus written at each cognitive level was reported as a percentage of all analysed learning objectives.

Since the analysis of learning objectives did not find any explicit instructions to develop students' metacognition and self-system thinking, the remaining sections of each syllabus were searched for implicit references to these two levels of the New Taxonomy. The analysis entailed (1) identifying, (2) selecting, and (3) appraising text passages to classify syllabus excerpts as references to metacognition or self-system thinking.

1. To identify text passages, a list of keywords that match the metacognitive and self-system was developed with the help of Marzano and Kendall's (2007, 2008) books *The New Taxonomy of Educational Objectives* and *Designing and Assessing Educational Objectives: Applying the New Taxonomy*. The list of keywords was extended using a thesaurus (see Appendix B for the full list). Synonyms of keywords were included in the list if they were not too far removed from the meaning of the relevant concept. For example, for examining *value* of knowledge (= self-system), *merit* was included but *cost* was not included; for checking one's own *understanding* (= metacognitive system), *grasp* was included but *consciousness* was not included.
2. To select text passages, each syllabus (excluding the glossary) was searched for all keywords using a word-search function and sentences containing a keyword were selected if they addressed metacognition or self-system thinking.
3. To appraise text passages, all selected excerpts were read together to check that they match the New Taxonomy's definitions of the metacognitive and self-system. Text passages that were off-topic were deleted.

The results synthesise how these text passages embed the metacognitive and self-system in the reformed science syllabi.

In the chemistry syllabus, 14 subject matter content descriptors use the cognitive verb *appreciate*, which could be interpreted as a reference to developing students' self-system thinking. However, the QCAA's definition of appreciate instructs students to judge the value and implications of a concept, often with reference to society as a whole. Since this definition does not explicitly refer to students examining the extent to which they personally value the content matter, the verb has not been coded as a reference to the self-system. Rather, it is part of knowledge utilisation as suggested by cognitive verb tables published as a syllabus implementation resource by the QCAA (2018d).

Lastly, the replaced physics, chemistry, and biology senior syllabi were analysed using the same methods as outlined above to evaluate changes to the cognitive demands of learning objectives introduced by the reformed system. Even though the replaced syllabi do not explicitly use a taxonomy as classification framework for cognitive demands, their learning objectives were analysed using the New Taxonomy to allow for a direct comparison of the replaced and reformed syllabi. As the replaced syllabi do not specify cognitive verbs in the description of subject matter, the most specific learning objectives available for the analysis of their cognitive demands were the seven general objectives, including their elaborations. The sample units of work in the replaced syllabi sometimes use cognitive verbs in their outline of suggested learning experiences. However, these cognitive verbs were not coded because they constitute a model for teachers rather than a prescriptive component of the syllabus.

3.3.3. Analysis of the De Facto Curriculum

This analysis involved nine Year 12 physics, chemistry, and biology textbooks that were published for the reformed Queensland senior syllabi. All questions in these textbooks were analysed to determine the cognitive demands of the de facto curriculum and answer Research Question 2. For each subject, the three publishers Cengage Learning Australia, Oxford University Press and Pearson Education Australia were selected, resulting in the following textbook sample.

Physics:

- Adamson, S., Alini, O., Champion, N., and Kuhn, T. (2018). *Nelson Qscience Physics Units 3 & 4* (1st ed.). Cengage Learning Australia.
- Walding, R. (2019). *New Century Physics for Queensland Units 3 & 4* (1st ed.). Oxford University Press.
- Baker, M., Allinson, A., Devlin, J., Eddy, S., and Hore, B. (2019). *Pearson Physics Queensland 12 Units 3 & 4 Student Book* (1st ed.). Pearson Education Australia.

Chemistry:

- Stansbie, N., Steeples, B., and Windsor, S. (2019). *Nelson Qscience Chemistry Units 3 & 4* (1st ed.). Cengage Learning Australia.
- Kuipers, K., Devlin, P., Brabec, M., Sharpe, P., and Bloomfield, C. (2019). *Chemistry for Queensland Units 3 & 4* (1st ed.). Oxford University Press.
- Holmes, N., Bruns, E., Commons, C., Commons, P., and Hogendoorn, B. (2019). *Pearson Chemistry Queensland 12 Units 3 & 4 Student Book* (1st ed.). Pearson Education Australia.

Biology:

- Borger, P., Grant, K., Wright, J., and Munro, L. (2018). *Nelson Qscience Biology Units 3 & 4* (1st ed.). Cengage Learning Australia.
- Huxley, L., Walter, M., and Flexman, R. (2019). *Biology for Queensland an Australian Perspective Units 3 & 4* (1st ed.). Oxford University Press.
- Hall, M., Bliss, C., Fesuk, S. Jacobs, J., and Maher, F. (2019). *Pearson Biology Queensland 12 Units 3 & 4 Student Book* (1st ed.). Pearson Education Australia.

The three publishers have a long tradition in science textbook production. Moreover, they were the only available hardcopy textbooks specifically developed for the reformed senior syllabi in 2019, the year the curriculum reform was first implemented. Each textbook in the sample was used by teachers in at least two of the schools that participated in this study.

Questions were located between textbook chapter subheadings, at the end of each chapter, at the end of each unit, on pages outlining practical activities, and occasionally at the end of real-world case studies. Questions with several subcomponents (e.g., a, b, c, etc.) were coded once only, based on the subcomponent with the highest cognitive demand because subcomponents with lower cognitive demands usually had the purpose of scaffolding the higher-order thinking subcomponent. Supplementary online materials or accompanying workbooks released by each publisher were not analysed.

The coding of questions involved a deductive approach, meaning that the analysis was based on previously published knowledge and theories (Elo & Kyngäs, 2008). Consistent with the analysis of the prescribed curriculum, each question was classified as one of the six levels in Marzano and Kendall's (2007) New Taxonomy of Educational Objectives: retrieval, comprehension, analysis, knowledge utilisation, metacognition, or self-system thinking. For example, the question *Define the term vector* was classified as Level 1: Retrieval and the question *Explain why the classification system for organisms needed to be modified following the ability to sequence DNA* was classified as Level 2: Comprehension.

Occasionally, textbooks suggested a classification for their questions by grouping them under headings such as *comprehension* or *analysis*. However, these suggested categories did not always match Marzano and Kendall's (2007) definitions of the level, so they were ignored. For example, textbooks often classified questions asking students to calculate a value as analysis, even though students had to simply follow steps of a pre-given procedure to calculate the answer, which is classified as retrieval in the New Taxonomy.

Furthermore, the analysis considered the context of the questions rather than just the used cognitive verb, as other research studies have indicated a lack of association between a question's prompt word and the corresponding cognitive process (Larsen et al., 2022). For example, multiple-choice questions were often categorised as retrieval because students only have to recognise the correct explanation or term rather than formulate the answer themselves. It also needs to be emphasised that knowledge utilisation does not include using knowledge to answer simple recall questions. Rather, this category requires knowledge to be manipulated and creatively applied in a new context to accomplish a specific task.

The frequency of questions at each cognitive level was coded as a percentage to allow for comparisons between the three subjects. Similar percentages across different publishers and different subjects might indicate norms or conventions for textbook questions in senior science. In the discussion of results, categories were often grouped as lower-order cognitive skills (i.e., retrieval and comprehension) or higher-order cognitive skills (i.e., analysis, knowledge utilisation, metacognition, and self-system thinking) to compare findings with results of studies using classification systems other than the New Taxonomy of Educational Objectives. Lower-order cognitive skills are defined as thinking skills that require students to access existing knowledge, and higher-order cognitive skills are defined as thinking skills that challenge students to apply or create new knowledge (Marzano & Kendall, 2007).

To ensure analysis reliability, questions in the first five chapters of the Cengage Learning Australia biology textbook were coded again three months after the initial coding. The degree of consistency was calculated using Pearson's Correlation Coefficient and was found to be 98.19%. All nine textbooks are publicly available; interested readers can therefore test the reliability of the analysis.

3.3.4. Analysis of the Enacted Curriculum

Lesson observations are effective methods for studies matching intentions against practice (Wragg, 2002). They capture data on how a prescribed curriculum is presented and how teachers change or maintain its cognitive demands (Matsumura et al., 2008). Porter (2002) claims that observations produce highly valid data on the enacted curriculum as long as probability samples are not needed to answer the research questions. As this study does not aim to generalise findings to the population in a quantitative sense, observations were chosen for the data collection to answer the third research question rather than the more commonly used method of self-report surveys, in which teachers are asked to reflect on the content of their lessons at the end of a teaching period (Porter & Smithson, 2002). The resulting lower sample size was accepted as a pragmatic consequence of the chosen strategy.

Participants were recruited after receiving ethics approval from James Cook University's Human Ethics Committee (Application ID: H7823), the Queensland Department of Education, and the Catholic Diocese of Cairns (see Appendix E). To gain access to research sites and participants, Heads of Science Departments in 14 schools in Far North Queensland were contacted by telephone to determine their interest to participate in this study. If the Heads of Department were interested, the physics, chemistry, and biology teachers in the school were contacted via telephone or in person during a department meeting if they met the following two selection criteria:

1. The teacher is timetabled for Year 11 and/or Year 12 physics, chemistry, or biology in 2020.
2. The teacher is willing to be observed on at least three separate occasions.

After positive feedback from teachers, each school principal was emailed to seek formal permission for lesson observations. All teachers and principals received a letter outlining the purpose and potential benefits of the study along with their rights as participants (see Appendix C).

The resulting sample consisted of 18 teachers in seven schools within the Far North Queensland region, four of which were government and three were non-government schools. The size of schools and their students' socioeconomic backgrounds varied. The smallest school had 565 students enrolled in the year of data collection and the largest school had 1788 enrolments. The schools' ICSEA ranged from 875 to 1074 with four schools under the national average of 1000 and three schools over 1000. The reason for purposefully selecting a variety of contrasting school sites was to indicate the diversity of the enacted curriculum within Far North Queensland schools, so findings would uncover shared patterns and have the potential to be applied to a wider range of situations. Thus, a purposefully selected maximum variation sample was considered superior to a random sample because it can represent a wider range of perspectives, approaches, or contexts (Creswell, 2012; Merriam, 2002).

The sample size of a study needs to weigh up the limitations of scope and time versus the quality of collected data (Hamilton & Corbett-Whittier, 2013). Porter (2004) states that samples of eight to 12 lesson observations are acceptable and can yield reliable and valid results on pedagogical practices which are used during most school days. For atypical pedagogies and learning content, a larger sample is needed. In this study, each teacher was observed three to six times in one school term, resulting in 26 to 28 lesson observations per subject area throughout the entire school year and 82 lesson observations in total across Year 11 and Year 12. The lesson length varied between 35 and 50 minutes, depending on the school's timetable. This sample size satisfies Porter's (2004) recommendation, while allowing a single researcher to collect all data within one year. Table 3.1 shows the number of observed lessons for each subject as well as the number of schools and different teachers contributing to each subject's sample.

Table 3.1

Sample Size

Subject	Year 11 lessons	Year 12 lessons	Schools	Teachers
Physics	9	17	6	6
Chemistry	13	15	5	6
Biology	14	14	6	7
Total	36	46	7	18[a]

[a] One teacher was teaching two senior subjects and is part of the biology and chemistry sample.

Participating teachers varied in gender, teaching experience, and qualification (see Table 3.2). Ten participants were male and eight female. Most observed teachers had between five and 20 years of teaching experience. One teacher was in her first year of teaching and three teachers have been teaching for over 20 years. Only one participant was teaching out of his subject area (mathematics), while 12 participants had a science-specific bachelor's or master's degree and five participants had a Bachelor of Education or Master of Education.

Table 3.2

Participant Demographics

Demographic	Variable	*n* (18)
Gender	Male	10
	Female	8
Teaching experience	<5 years	1
	5–10 years	6
	11–20 years	8
	>20 years	3
Qualification	B.Ed.	4
	M.Ed.	1
	B.Sc., Grad.Cert.Ed.	10
	M.Sc., Grad.Cert.Ed.	2
	B.Math., Grad.Cert.Ed.	1

Note. B.Ed. = Bachelor of Education; M.Ed. = Master of Education; B.Sc., Grad.Cert.Ed. = Bachelor of Science, Graduate Certificate in Education; M.Sc., Grad.Cert.Ed. = Master of Science, Graduate Certificate in Education; B.Math., Grad.Cert.Ed. = Bachelor of Mathematics, Graduate Certificate in Education.

Lesson observations in this study focused on the cognitive demands of teacher instructions and used pedagogies, and are therefore selective observations. Other factors possibly influencing students' thinking were not recorded, such as student interactions, classroom layout, the proximity of the teacher and students in the classroom, or the teachers' body language. A modified version of the Florida Taxonomy of Cognitive Behaviour was used as the lesson observation instrument (see Appendix D). The original instrument was developed by Brown et al. (1968) and is based on Bloom's Taxonomy (Bloom et al., 1956). This instrument was used to categorise cognitive levels of teacher instructions observed in five-minute intervals during lessons. Whenever the teacher set a learning task or asked a question, the researcher asked herself which type of thinking was required by students to complete the task and ticked the corresponding box for the present time interval. The box was ticked only once, even if teacher instructions on the same cognitive level were observed multiple times within each five-minute interval. Recorded teacher behaviours included verbal instructions, visuals, or instructions on handouts. Non-verbal tasks and instructions were included in the analysis, as they have been shown to have significantly different cognitive demands than verbal classroom instructions (Zohar et al., 1998). The instrument's construct validity is based on its close association with Bloom's Taxonomy (Ball & Garton, 2005). The internal consistency of items has been reported as $\alpha = 0.87$ (Ulmer & Torres, 2007) and its intra-rater reliability as 0.95 (Canon & Metzger, 1995).

The items of the modified Florida Taxonomy of Cognitive Behaviour were altered to match cognitive levels of the New Taxonomy of Educational Objective, using descriptions of behaviour taken from Marzano and Kendall (2007). In addition, space was added to include learning activities observed each time a box had been ticked. As in the original instrument, the cognitive demands of observed teacher instructions were noted in five-minute intervals by ticking a box next to each item. Teacher instructions, which could not be classified immediately during the observation because they were given to students non-verbally (e.g., via worksheets or textbook questions), were collected or photographed with a timestamp for classification immediately after the observation. Furthermore, the researcher was aware that not all students are always taught the same content or cognitive skills during a lesson as the teacher differentiates for varied student abilities. Data collection focused on instructions and the teachers' behaviour directed at most students. The researcher practised using the instrument with five recorded online lessons (https://online.clickview.com.au/exchange /channels/32366675) which were reassessed one month after the initial rating, resulting in an intra-rater reliability of Pearson's $r = 0.94$.

The presence of an observer in a classroom can influence the behaviour of students and the teacher (Wragg, 2002). It is therefore possible that the teacher's actions are partially skewed towards pleasing the researcher's judgement (Tuckman & Harper, 2012). To reduce this bias, all teachers were observed at least three times and observations were conducted in the most unobtrusive manner possible (i.e., the researcher was sitting quietly on the periphery of the classroom and was not interacting with students, the teacher, or support staff). Following each lesson observation, the researcher wrote a brief reflection on the lesson structure and any subjective opinions and emotions which arose during the observation, such as engagement or boredom. These notes could be used to critique later analysis and interpretation of data (McNaughton Nicholls et al., 2014).

Analysis of lesson observations involved tabulation of the cognitive demands of classroom instructions and pedagogies recorded on the modified Florida Taxonomy of Cognitive Behaviour. For the cognitive demands of teacher instructions, the frequency of ticks at each cognitive level was totalled for each lesson. Then the percentage of teacher instructions at each cognitive level for all teacher instructions was calculated across all three subjects as well as for each subject individually. All five-minute lesson intervals without a tick for any cognitive level were noted to estimate the lesson proportion during which students were not explicitly instructed by the teacher to engage in any type of thinking. Each time an item was ticked on the instrument, the researcher also noted instructional strategies teachers used to identify the most commonly used pedagogies at each cognitive level and qualitatively describe their attributes. In addition, teaching strategies were categorised as individual or collaborative work. Since questioning stood out as a dominant teaching strategy at every cognitive level, the percentage of teachers' spoken versus written questions at each cognitive level was also calculated. To remain within the scope of this study, data on students choosing to engage with cognitive skills independently were not collected.

3.3.5. Analysis of Curriculum Alignment

The degree of alignment between the prescribed, de facto, and enacted curriculum (Research Question 4) was determined by comparing the proportion of syllabus learning objectives at each cognitive level with the proportion of analysed textbook questions and observed classroom instructions at the same cognitive level. Since no explicit syllabus learning objectives addressed the metacognitive or self-system, classroom instructions and textbook questions that were coded as metacognition or self-system thinking were excluded from the curriculum alignment analysis.

The data needed for the calculation of Porter's (2002) alignment index are proportions of each cognitive level in syllabus objectives, textbook questions, and classroom instructions. This data were derived from the previously explained analysis of 570 learning objectives in three syllabi, 8070 questions in nine textbooks, and 82 lessons of 18 teachers. The proportions were displayed in cognitive demand matrices (see Table 3.3). Alignment can be measured by the extent to which proportions in one cognitive demand matrix match the proportions in another matrix. The alignment index is calculated using the formula:

$$Alignment\ index = 1 - \frac{\sum_{i=1}^{n} |Yi - Xi|}{2}$$

Where:

n = the total number of cells in a cognitive demand matrix

i = a specific cell of the cognitive demand matrix, ranging from 1 to n

Yi = the ith cell of the learning objective matrix, values are ratios ranging from 0 to 1

Xi = the ith cell of the classroom instructions matrix, values are ratios ranging from 0 to 1

Table 3.3

Sample Cognitive Demand Matrices for the Calculation of Porter's (2002) Alignment Index

Classroom instructions (X)				
Subject	Retrieval	Comprehension	Analysis	Knowledge utilisation
Physics	0.50	0.32	0.11	0.07
Chemistry	0.33	0.40	0.21	0.06
Biology	0.10	0.17	0.37	0.36
Learning objectives (Y)				
Subject	Retrieval	Comprehension	Analysis	Knowledge utilisation
Physics	0.40	0.32	0.11	0.17
Chemistry	0.23	0.50	0.11	0.16
Biology	0.10	0.27	0.27	0.36

Alignment is high if the proportions of each cognitive level of classroom instructions match the corresponding cell of learning objectives. The discrepancy between the cells in both matrixes is calculated as $|Y_i - X_i|$. The overall discrepancy is calculated by summing the discrepancies of all cells. So the alignment index for the sample cognitive demand matrices in Table 3.3 was calculated as:

$$1 - (|0.4 - 0.5| + |0.32 - 0.32| + |0.11 - 0.11| + |0.17 - 0.07| + |0.23 - 0.33| + |0.5 - 0.4| + |0.11 - 0.21| + |0.16 - 0.06| + |0.1 - 0.1| + |0.27 - 0.17| + |0.27 - 0.37| + |0.36 - 0.36|)/2$$

The values of the alignment index range from 0 (no alignment) to 1.0 (perfect alignment).

Porter's (2002) alignment index does not stipulate how much alignment can be considered sufficient. Even though the alignment index is a quantitative measure, it must be interpreted qualitatively (Atuhurra & Kaffenberger, 2022). Webb (2002) suggests that alignment between assessment items and learning objectives is adequate at ≥ 0.5 because many examinations require students to achieve ≥ 50% of marks to pass. Porter (2004), on the other hand, recommends alignment must be judged as it compares to the results of other alignment calculations with similarly sized matrices. As a point of reference, the curriculum mapping project accompanying the implementation of Australia's national Prep to Year 10 curriculum considered a Porter's alignment index value of above 0.8 as very high, 0.7–0.8 as high, 0.6–0.7 as moderate, 0.5–0.6 as low, and below 0.5 as very low (Jane et al., 2011).

3.4. Quality of the Research Design

The collection and analysis of data are inevitably affected by the researcher's interpretations and background. A post-positivist research perspective attempts to put measures into place that control for biases and provide evidence that interpretations or conclusions are derived from data rather than the researcher's preconceptions (Boblin et al., 2013). The following section describes how this study worked towards generalisability, validity, reliability, and objectivity of results.

3.4.1. Generalisability

Generalisability refers to the extent that this study's results can be applied to other contexts (Yin, 2009). Due to the low sample of 18 physics, chemistry, and biology teachers, the validity of results for the cognitive demands of the enacted curriculum was affected. Even though the researcher attempted to maximise variation in the purposefully selected sample (i.e., diversity of teachers and schools), the recorded cognitive demands of the enacted curriculum and observed pedagogies may have been skewed by participants' teaching styles. In addition, teachers who agreed to be observed are likely to (a) be more confident and better teachers than a random sample of teachers, and (b) have a greater interest in the teaching of cognitive skills in the reformed senior science syllabi or in the cognitive demands of curricula in general, therefore introducing selection bias to the sample. Thereby, the external generalisability of results is limited. Nevertheless, this study aims to provide sufficient detail about the context of the investigated cases for readers to decide if findings can be transferred or applied to other relevant settings with similar circumstances.

Empirical generalisability to a larger population is only one of many forms of generalisability (Lewis et al., 2014). This study's findings can be applied analytically by making propositions about theory. The findings can, for example, expand and enrich existing theory regarding curriculum alignment after reform efforts and the cognitive demands of science curricula. Furthermore, the findings can be applied to other situations on the basis of analytical claims, such as the claim that certain pedagogies lead to an enacted curriculum with broader cognitive demands. In this manner, findings can guide teachers' practical choices (Merriam, 1998). Finally, the generalisability of case studies also increases when an overlap of findings with the literature in the field is clearly identified (Yin, 2013), as is evident in the discussion of findings in this study.

3.4.2. Validity and Reliability

Validity describes how much the collected data (e.g., scores on an instrument) represent the factor that is intended to be measured (e.g., cognitive demands of teacher instruction), while reliability refers to the consistency of the data collection method across items of an instrument, across time and, if applicable, across different researchers (Yin, 2009). In qualitative research, reliability can also represent the consistency of data with interpretations and described results (Merriam, 2002). Measures taken to avoid biases that reduce this study's validity and reliability are discussed in the following section.

As the researcher became more proficient in her data collection methods throughout the study, instrumentation bias may have been introduced, lowering the reliability of findings (Tuckman & Harper, 2012). For example, improved lesson observation skills may lead to altered notetaking or scoring, thereby introducing errors into the data. To minimise such instrumentation bias, a strict step-by-step protocol for document analyses and lesson observations was established after the initial pilot study. These procedures were systematically adhered to for each syllabus, textbook, and teacher. The instrument used to collect data during lesson observations (the modified Florida Taxonomy of Cognitive Behaviour) also remained the same for each teacher. In addition, lesson observations focused predominantly on the frequency of observed events, which according to Wragg (2002) is less likely to be biased by the experience of the observer than ratings using a scale.

To increase the accuracy and precision of data collected during lesson observations, this study used a modified version of a lesson observation instrument that has been successfully utilised in peer-reviewed research (e.g., Ball & Garton, 2005; Canon & Metzger, 1995; Ulmer, 2005; Ulmer & Torres, 2007). As the reliability of the modified Florida Taxonomy of Cognitive Behaviour and the quality of collected data depends on the researcher's expertise in using the instrument (Ball & Garton, 2005; Porter, 2004), the researcher trained herself to identify teacher instructions at different cognitive levels by reviewing definitions and examples of questions at each cognitive level in Marzano and Kendall's (2008) book *Designing and Assessing Educational Objectives: Applying the New Taxonomy*. Then, she practised using the instrument with five recorded online lessons (https://online.clickview.com.au/exchange/channels/32366675) and during the six observations of the pilot study.

To reduce bias introduced by participants' knowledge of the study's purpose, written contact with schools and verbal explanation of study objectives and research questions remained identical between research sites. Moreover, the researcher decided against a survey design to collect data on the enacted curriculum. The use of surveys would have significantly increased the sample size, but self-reported pedagogies represent how teachers perceive teaching rather than reporting what actually happens in the classroom, which would lower the validity of results (Tuckman & Harper, 2012; Yin, 2009). The researcher also emailed participants a summary of their lesson observation results to allow teachers' feedback on the accuracy of reported data and to validate the discussion.

The validity of this study's document analyses is likely high, as all syllabus learning objectives and all questions in available textbooks have been examined rather than a sample. This analysis used the same classification framework (the New Taxonomy of Educational Objectives) that has been used for the design of the reformed curricula. Measures were also taken to check the reliability of the document analyses. As part of the pilot study, the chemistry teacher was asked to code the cognitive demands of Unit 1 of the chemistry syllabus using the cognitive verbs published by the QCAA (2018d) as a guide. The teacher's results were compared to the researcher's coding of the same unit and showed only one disagreement over the classification of the cognitive verb appreciate. Moreover, questions in five chapters of one textbook were coded twice by the researcher three months apart and Pearson's Correlation Coefficient showed high consistency of coding ($r = 0.98$).

Finally, the researcher welcomed peer scrutiny by her supervisors, other academics (including peer reviewers of published chapters), and practicing teachers at all stages of the research. The provided feedback was used to reflect on alternative methodological approaches and to probe for personal bias during data collection, analysis, and discussion.

3.4.3. Triangulation

Triangulation in case studies is the consideration of multiple data sources or the collection of data using multiple methods to verify meaning before drawing conclusions about the findings. These efforts can reduce errors and strengthen the validity of findings (Harrison et al., 2017; Stake, 2013; Yin, 2013). This study's methods were not designed to collect overlapping data on the same factors from multiple sources. Instead, three different data sources (i.e., syllabi, textbooks, and lessons) were used to answer different research questions and achieve a fuller and more valid understanding of the researched topic (i.e., the cognitive demands of the curriculum). If conclusions drawn from multiple data sources converge, the researcher can have greater confidence in the validity of results because the findings are consistent (Yin, 2013). For example, the same cognitive levels may dominate the cognitive demands of all three examined curriculum components in this study. Triangulation can also be used to uncover a divergence in results, which may constitute findings in itself (Boblin et al., 2013). For example, if the results in this study differ greatly between the three investigated subject areas, despite their shared general syllabus objectives and the common types of summative assessment, conclusions may be drawn about teachers' different philosophies or practices in different subject areas. Lastly, triangulation can be achieved by collecting similar data from several sites, such as seven different schools. In this manner, the researcher checked for the consistency of findings from different sources. Such site triangulation reduces the influence of local context on the study's conclusions. Furthermore, similar results from different sites increase the conclusions' validity (Shenton, 2004; Yazan, 2015).

3.4.4. The Researcher as Participant Observer

In educational research, it has become increasingly common to collect data as a participant observer (Kawulich, 2005). A participant observer becomes part of the context or community from which data are collected while they observe and record behaviour. The goal is to blend in so participants act naturally. Observations, compared to other methods of data collection in education (e.g., teacher or student surveys), allow for the recording of non-verbal behaviour, social interactions, and observed activity timeframes (McNaughton Nicholls et al., 2014).

Such immersion in this field of study naturally adds subjectivity to collected results, which needs to be openly acknowledged and managed. For instance, researchers may have preconceived ideas about the correct way to teach certain content, or they may selectively observe aspects of learning they are interested in throughout a lesson. A systematic observation procedure that clearly outlines who or what is observed, as well as when and where this observation occurs, can reduce such bias (Kawulich, 2005). This study follows such a systematic procedure (see Section 3.3.4.).

There are several types of participant observers who differ in their active involvement in and interactions with the observed situation. In this study, the researcher was predominantly an observer who gathered information as a passive participant and acted as a neutral bystander in lessons. Participants were aware of the researcher's presence and purpose, but the researcher did not interfere in the observed teaching and learning. In this manner, the researcher remained as objective as possible while being an insider (Angrosino & Rosenberg, 2011). Kawulich (2005) claims that this style of participant observation is the most ethical approach as the researchers are open about their activities, but do not attempt to change or influence observed behaviour.

3.5. Ethical Considerations

As the subjects of this study are human beings, careful ethical considerations have been taken. First and foremost, this research has worthwhile potential implications and did not make unreasonable demands on participating teachers. Contact was made via a telephone call in which all participating teachers were informed of the research aims and procedures. The researcher was open and clear about the purpose and aims of the lesson observations. Participants voluntarily chose to participate in this study and were informed of their right to withdraw at any time without reason. Permission was also sought from each school principal via email (see Appendix C).

All collected data were treated with confidentiality by the researcher and recorded data were deidentified. The data were stored safely in the researcher's locked office and on a password-protected computer that was backed up on the cloud-based app OneDrive. After the study's completion, raw data and signed consent forms were archived on the Research Data JCU Depository. The identity of participants and schools remain anonymous as only group findings were reported in the analysis. Therefore, reported data cannot be used for teacher accountability purposes. The impact on participants' time and the intrusiveness of lesson observations were kept to a minimum, with respect for the increased workload of senior teachers who were implementing the reformed curriculum for the first time in 2020. Finally, the researcher explained all potential benefits resulting from the study and shared her contact details with participants should they require additional information after data had been collected. Teachers were also provided with detailed individual reports for self-reflection, and to demonstrate that data had been recorded and reported accurately.

Additional ethical and safety considerations were added to the data collection methods after the outbreak of the COVID-19 pandemic. During all lesson observations in April to December 2020, the researcher kept 1.5 metres distance from students and school staff, disinfected classroom desks together with students as per each school's policy, and thoroughly washed her hands before each observed lesson to minimise the risk of disease transmission.

3.6. Conclusion

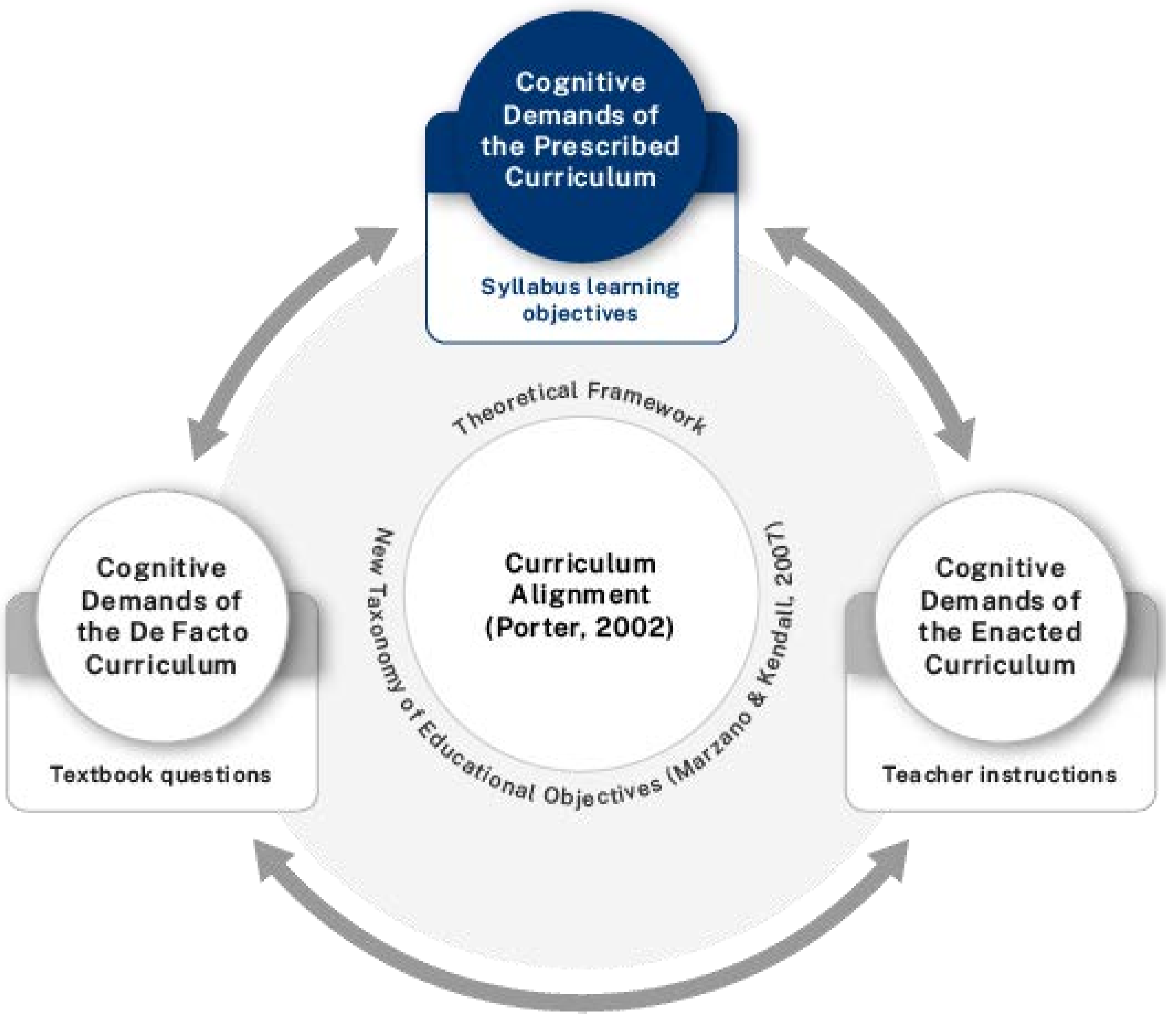
This chapter demonstrates how the study was conducted transparently so results can be regarded as accurate. A collective case study design with multi-method data collection from three sources was chosen because it best answered the research questions. The methodology included provisions for maximising reliability and minimising bias by thoroughly contemplating and justifying decisions about data collection and analysis. The following four chapters present and discuss results derived from the described methodology in order of the four research questions.

Chapter 4. The Prescribed Curriculum

This chapter presents and discusses findings on the cognitive demands of the prescribed senior science curriculum, the first curriculum component examined in this study (see Figure 4.1). It examines all learning objectives in the reformed physics, chemistry, and biology syllabi that are implemented across Queensland since 2019 in Year 11 and since 2020 in Year 12. Results also include a comparison of the reformed prescribed curricula with the replaced curricula. The discussion of findings and their implications is followed by an evaluation of limitations and recommendations for future research.

Figure 4.1

Focus of Chapter 4—The Prescribed Curriculum



4.1. Rationale

The prescribed curriculum tends to be communicated through official documents published by government departments or a statutory educational authority. Some countries develop national and state standards that define core educational objectives for each learning area and inform a standards-based curriculum implementation (e.g., the USA). Other countries list specific learning objectives in syllabus documents for each subject and year level (e.g., Singapore or Australia). Typically, these learning objectives identify content knowledge and a cognitive skill that help learners organise and integrate their experiences. For example, students should evaluate (cognitive skill) the properties and structure of ionic, covalent, and metallic compounds (knowledge). Learning objectives send messages about what is worth learning in a subject and why the subject is taught by communicating which cognitive skills and knowledge students should be taught.

One Australian rationale is to develop learners' skills that promote adaptation to the rapidly changing economic and social circumstances of current times (Gonski et al., 2018). These skills are referred to as General Capabilities in the Australian Curriculum (Prep to Year 10) and Underpinning Factors in the senior syllabi (Year 11 and Year 12). They include higher-order thinking skills like problem solving or critical and creative thinking. Gonski et al. (2018) argue in their *Review to Achieve Educational Excellence in Australian Schools* that capabilities like critical and creative thinking need to be at the core of the curriculum and teaching practice for students to succeed. This view is supported by evidence gathered from a survey of over 500 educators in the USA, which showed that skills like creativity and critical thinking were rated as more important than disciplinary or even interdisciplinary knowledge (Mishra & Mehta, 2017). Such emphasis on skill development is a common feature of recent curriculum reforms in many countries (Gleeson et al., 2020).

Collectively, the message appears to be that higher-order thinking skills should be valued over the teaching of facts and associated lower-order thinking skills. This is reflected in Australian Prep to Year 10 science education. The current Australian Curriculum for science has been shown to have a stronger emphasis on application to problems or novel situations and a lower emphasis on simple recall or retrieval of knowledge than previous state and territory curricula (Jane et al., 2011). Australian senior science syllabus writers are urged to more explicitly identify where and how 21^{st} Century Skills can be incorporated into the curriculum (Firn, 2016). However, the cognitive demands of current Australian science curricula in Year 11 and Year 12 have not yet been analysed. This is a crucial gap in the literature considering Australian science curricula because such an analysis of curriculum policies and documents can expose which cognitive skills are emphasised in each subject area.

This study provides the first in-depth analysis of the recently reformed senior science curriculum in Queensland, Australia. It follows research on the knowledge and cognitive demands of the Australian Curriculum in science up to Year 10 (Jane et al., 2011) and on knowledge and achievement standards expected of Year 12 chemistry and physics students in Australia (Matters & Masters, 2007). International research has analysed the cognitive demands of science curricula in the USA (Liu & Fulmer, 2008), China (Wei, 2020), Singapore and Korea (Lee et al., 2015). These studies supported the alignment of prescribed, assessed, and enacted curricula, and results were used to tailor support and professional development opportunities for teachers. Analysing the cognitive demands of curriculum documents also allows for reflections on the congruence of science curricula with proclaimed goals of science education (e.g., Liang & Yuan, 2008). The analysis of syllabus documents in this study aims to accomplish similar goals, that is, to inform the decision making of curriculum developers and science educators. Results presented in this chapter address the study's first research question and its sub-questions:

1. What are the cognitive demands of the reformed Queensland physics, chemistry, and biology syllabus?
    d. Which cognitive levels are emphasised by learning objectives in the reformed syllabi?
    e. How are the metacognitive and self-system embedded in the reformed syllabi?
    f. What changes were introduced by the recent senior curriculum reform to the cognitive demands of learning objectives?

4.2. Results

To provide context, the results first describe the structure of the analysed syllabi. Thereafter, the cognitive demands of learning objectives are reported for physics, chemistry, and biology combined and separately, as well as the implicit references to the metacognitive and self-system in all three syllabi. Finally, this section presents results on the analysis of the replaced Queensland senior science syllabi to evaluate changes introduced by the reform to the structure and the cognitive demands of the prescribed curriculum.

4.2.1. Syllabus Structure

The reformed physics, chemistry, and biology syllabi are structured identically. The same seven syllabus objectives outline how students are expected to demonstrate knowledge: describe and explain, apply, analyse, interpret, investigate, evaluate, and communicate. Since syllabus objectives are identical between the three subject areas, they do not refer to the subject matter.

Each syllabus's subject matter is divided into four units, with two to three topics per unit. The units are introduced with a description of the knowledge students will learn and seven unit objectives, which are directly derived from the seven syllabus objectives. Syllabus and unit objectives are identical in terms of cognitive skills, but unit objectives state broad subject matter to be learned in each unit (e.g., *describe and explain cells as the basis of life,* *and multicellular organisms*). Thereafter, a comprehensive table with specific subject matter content descriptors and teacher guidance follows. The highly prescriptive content descriptors all begin with a cognitive verb, followed by content knowledge (e.g., *recognise the different types of nitrogenous wastes produced by the breakdown of proteins*). The subject matter content descriptors include all mandatory and suggested practicals that students should experience as part of the course.

This syllabus analysis examined the cognitive demands of the 205 chemistry 207 physics and 158 biology subject matter content descriptors, the most specific learning objectives in the syllabus. Some content descriptors contained more than one cognitive verb; so all verbs were coded to address how students should demonstrate subject knowledge through each listed cognitive skill. Particularly, chemistry subject matter content descriptors frequently require students to demonstrate knowledge at several cognitive levels. A total of 381 cognitive verbs were coded for chemistry, 242 for physics, and 196 for biology. This total was used to calculate the proportions of cognitive levels in each syllabus. Table 4.1 shows examples of learning objectives matched to their cognitive level.

Table 4.1

Examples of Learning Objectives at Each Cognitive Level

Cognitive level	Examples
Retrieval	*Define* the terms genome and gene. (Biology) *Recognise* the electron configuration of Cr and Cu as exceptions. (Chemistry) *Recall* the six types of leptons. (Physics)
Comprehension	*Explain* how non-disjunction leads to aneuploidy. (Biology) *Understand* that the empirical formula expresses the simplest whole number ratio of elements in a compound. (Chemistry) *Describe* and *represent* the forces acting on an object on an inclined plane through the use of free-body diagrams. (Physics)
Analysis	*Interpret* long-term immune response data. (Biology) *Determine* the relative strength of oxidising and reducing agents by comparing standard electrode potentials. (Chemistry) *Compare* and *contrast* elastic and inelastic collisions. (Physics)
Knowledge utilisation	*Make decisions* and *justify* them in regard to best practice for the prevention of disease outbreaks … (Biology) Use appropriate mathematical representation to *solve* problems, including calculating dissociation constants (Ka and Kb) and the concentration of reactants and products. (Chemistry) *Conduct* an experiment to *investigate* the force acting on a conductor in a magnetic field. (Physics)

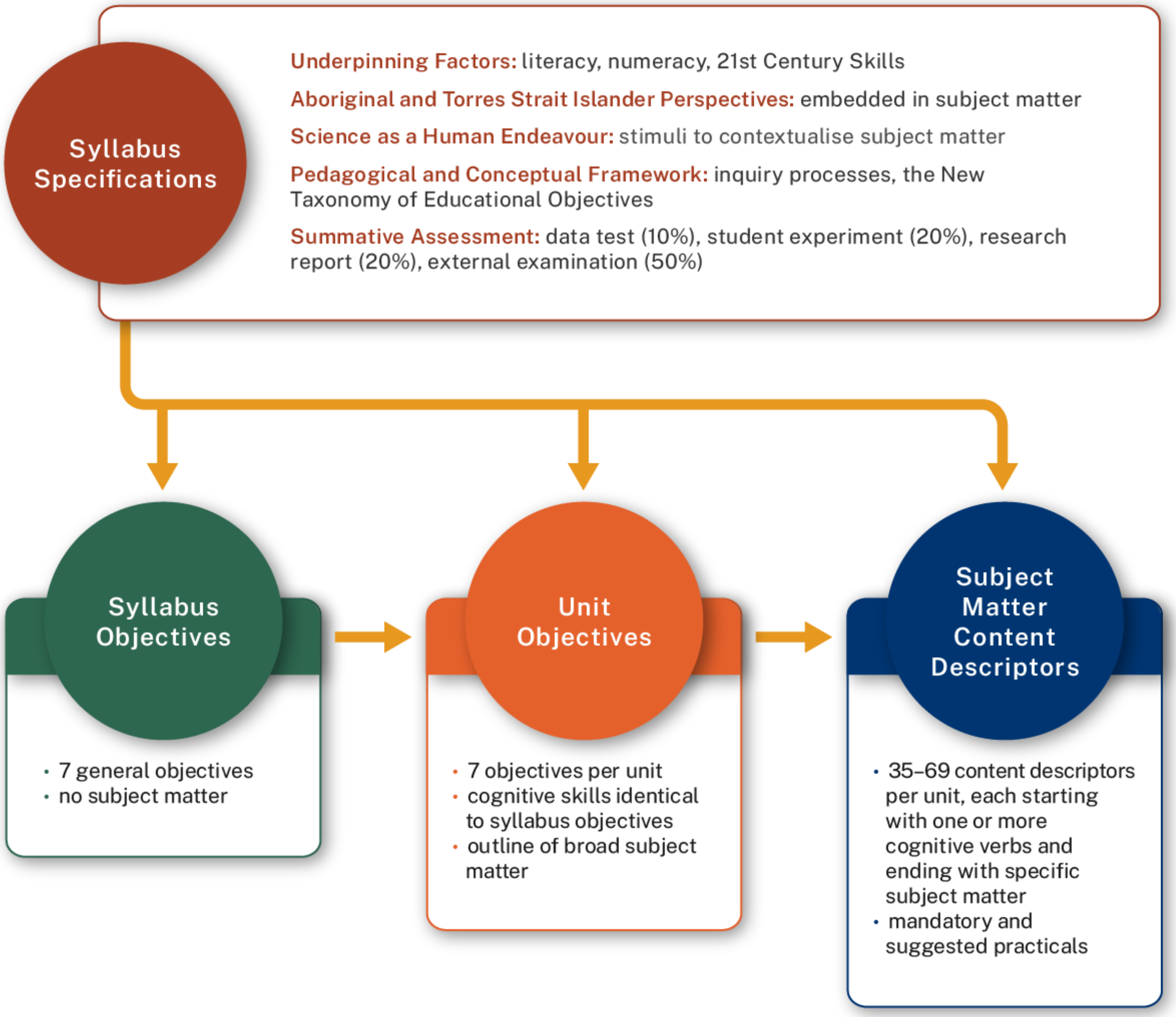
Note. Cognitive verbs used to classify each objective are formatted in italics.

Considering that the QCAA adopted 72 cognitive verbs from the New Taxonomy of Educational Objectives, each science syllabus only utilises a narrow range of verbs. Similar cognitive verbs are thus used repetitively to describe learning objectives at each cognitive level. Define, describe, explain, and solve dominate the physics syllabus; recognise, use, explain, and understand dominate the chemistry syllabus; and identify, recall, recognise, explain, and analyse dominate the biology syllabus.

Whenever appropriate, the learning objectives of each syllabus should be influenced by three Underpinning Factors (numeracy, literacy, and 21st Century Skills) as well as by Aboriginal and Torres Strait Islander perspectives. Teachers also receive guidance on how to include the non-assessed Science as a Human Endeavor subject matter, which aims to support students' understanding of the nature of science and its influences on society. The pedagogical and conceptual framework for the three subject areas is also identical. It elaborates in detail on the inquiry process and inquiry skills. These elaborations aim to guide any pedagogical approach chosen by schools or teachers and are not prescriptive. Finally, the three syllabi outline identical types of formative and summative assessment to be delivered: a data test, student experiment, research report, and an external examination weighted at 50%. The structure of the reformed syllabi is summarised in Figure 4.2.

Figure 4.2

Structure of the Reformed Physics, Chemistry, and Biology Syllabi



4.2.2. Cognitive Demands of Learning Objectives

The percentage and absolute frequency of subject matter content descriptors at each cognitive level of the New Taxonomy of Educational Objectives are shown in Table 4.2. Combined results of the three senior science syllabi show that learning objectives at retrieval level are most common (32%), followed by learning objectives at comprehension level (30%). Eighteen percent of subject matter content descriptors in all syllabi were classified as analysis and 19% as knowledge utilisation. No learning objectives in any subject were coded as metacognition or self-system thinking. More than half (62%) of all examined syllabus learning objectives can be classified as lower-order thinking (see Figure 4.3).

Table 4.2

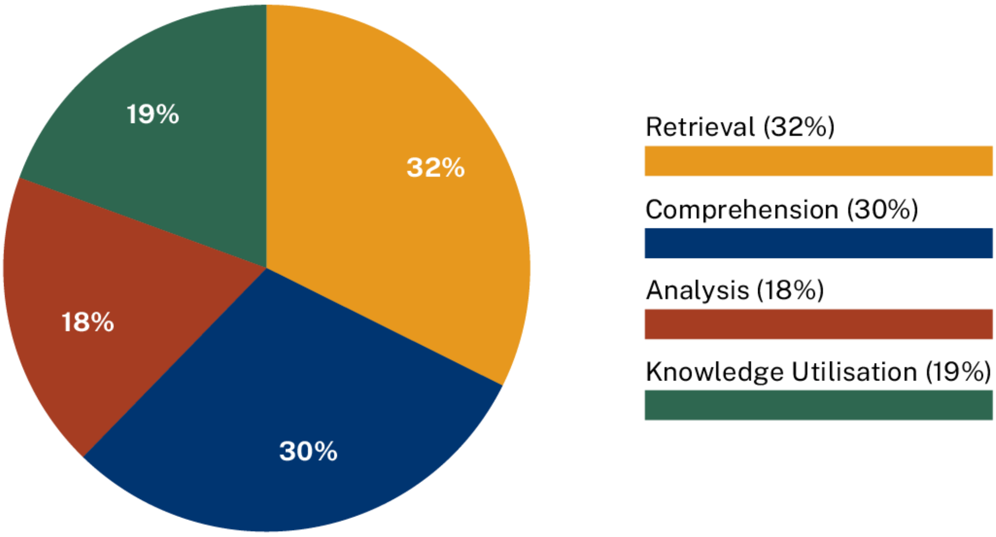
Cognitive Demands of Subject Matter Content Descriptors

Subject	Cognitive level					
	Retrieval	Comprehension	Analysis	Knowledge utilisation	Metacognition	Self-system thinking
Physics	38% (92)	24% (57)	14% (33)	25% (60)	0% (0)	0% (0)
Chemistry	27% (102)	32% (123)	20% (78)	20% (78)	0% (0)	0% (0)
Biology	36% (71)	33% (65)	20% (39)	11% (21)	0% (0)	0% (0)
Total	32% (265)	30% (245)	18% (150)	19% (159)	0% (0)	0% (0)

Note. Percentages are rounded to whole numbers and absolute frequencies are stated in brackets.

Figure 4.3

Cognitive Demands of Subject Matter Content Descriptors Across All Subjects

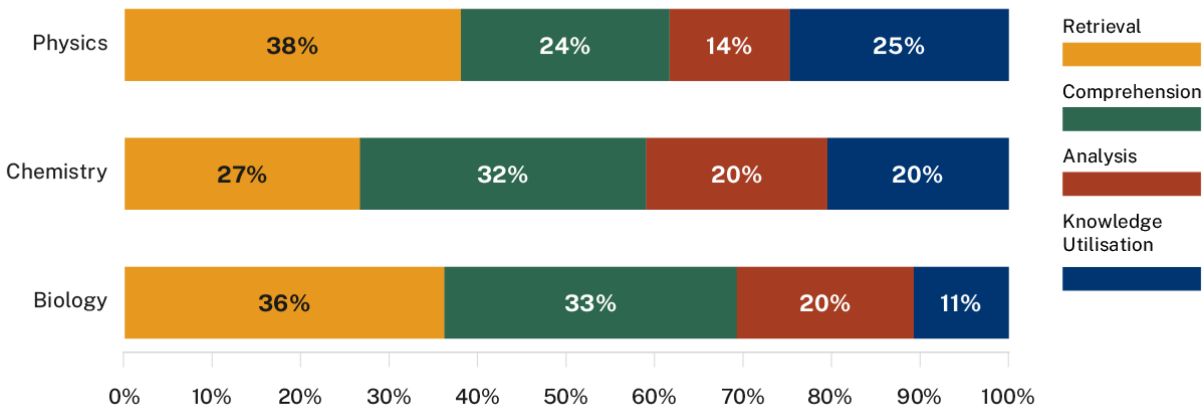


Note. Percentages are rounded to whole numbers.

The analysis of the three subjects separately shows that the cognitive demands of subject matter content descriptors are skewed towards retrieval and comprehension in all three sciences (see Figure 4.4). Thirty-six percent of biology content descriptors ask students to demonstrate knowledge through cognitive skills classified as retrieval, 33% as comprehension, 20% as analysis, and 11% as knowledge utilisation. Less than one third of biology subject matter content descriptors engage students in higher-order thinking. For chemistry, 27% of cognitive verbs in subject matter content descriptors are classified as retrieval, 32% as comprehension, 20% as analysis, and 20% as knowledge utilisation. In physics, there are 38% retrieval subject matter content descriptors, 24% comprehension, 14% analysis, and 25% knowledge utilisation. Physics has the highest emphasis on knowledge utilisation, but also the highest emphasis on retrieval. Even though the proportion of higher-order thinking learning objectives is higher in chemistry and physics than in biology, over half of the cognitive verbs refer to lower-order thinking skills in all three subjects.

Figure 4.4

Cognitive Demands of Subject Matter Content Descriptors



Note. Percentages are rounded to whole numbers.

Table 4.3 and Figure 4.5 show a more in-depth analysis of cognitive demands in each syllabus by examining the proportions of learning objectives at each cognitive level for each content topic. The curriculum mapping project undertaken by the Australian Government to support the development of the Australian Curriculum used topographic graphs like Figure 4.5 to show the extent of content coverage and the emphasis on different cognitive levels for each topic (Jane et al., 2011)[3]. The darker and thicker the lines of the graph, the more cognitive verbs of the relevant cognitive level were found in subject matter content descriptors for that topic (i.e., the stronger the relevant cognitive level was emphasised in this topic).

[3] This type of topographic graph was first published by Porter, A. (2002). Measuring the content of instruction: uses in research and practice. *Educational Researcher*, *31*(7), 3–14.

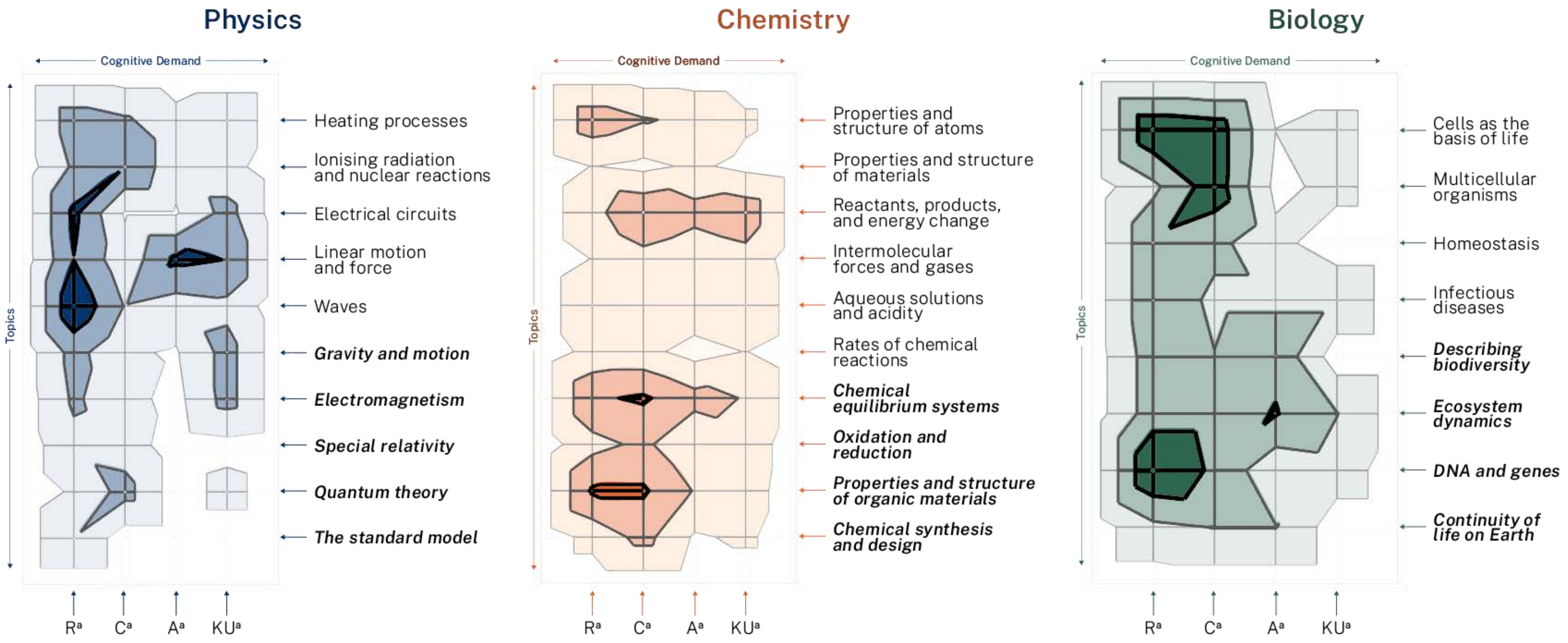
Table 4.3

Cognitive Demands of Learning Objectives by Content Topic

Content topic	Cognitive level			
	Retrieval	Comprehension	Analysis	Knowledge utilisation
Physics				
Heating processes	4.1%	3.3%	1.7%	2.5%
Ionising radiation and nuclear reactions	3.3%	5.0%	1.7%	1.7%
Electrical circuits	5.4%	0.8%	0.8%	3.7%
Linear motion and force	5.0%	1.7%	5.4%	5.0%
Waves	6.6%	2.9%	2.1%	2.5%
Gravity and motion	3.7%	1.2%	0.8%	3.7%
Electromagnetism	3.3%	1.7%	0.4%	3.7%
Special relativity	2.5%	2.1%	0.0%	0.4%
Quantum theory	1.2%	3.7%	0.0%	1.7%
The standard model	2.9%	0.0%	0.0%	0.0%
Chemistry				
Properties and structure of atoms	4.2%	3.1%	2.6%	1.3%
Properties and structure of materials	1.0%	0.5%	1.3%	0.5%
Reactants, products, and energy change	2.4%	4.7%	3.7%	4.2%
Intermolecular forces and gases	1.0%	2.4%	1.6%	2.4%
Aqueous solutions and acidity	2.6%	2.4%	2.4%	2.9%
Rates of chemical reactions	1.6%	1.6%	0.3%	1.0%
Chemical equilibrium systems	4.7%	5.2%	3.7%	2.9%
Oxidation and reduction	2.4%	3.4%	1.3%	2.1%
Properties and structure of organic materials	5.2%	5.2%	2.9%	1.8%
Chemical synthesis and design	1.6%	3.7%	0.8%	1.3%
Biology				
Cells as the basis of life	6.6%	6.1%	1.0%	1.5%
Multicellular organisms	2.6%	6.1%	0.5%	1.5%
Homeostasis	4.6%	3.6%	1.5%	0.0%
Infectious diseases	4.6%	2.6%	2.6%	2.6%
Describing biodiversity	4.1%	3.1%	4.6%	0.0%
Ecosystem dynamics	4.1%	4.1%	5.1%	3.1%
DNA and genes	7.1%	4.6%	1.5%	2.0%
Continuity of life on Earth	2.6%	3.1%	3.1%	0.0%

Figure 4.5

Emphasis on Cognitive Levels Categorised by Content Topic



Note. Bolded topics are assessed on the external examination.
[a] R = Retrieval; C = Comprehension; A = Analysis; KU = Knowledge Utilisation.

In physics, most topics emphasise retrieval or comprehension, while fewer topics emphasise knowledge utilisation or analysis. For example, gravity and motion, electromagnetism, special relativity, quantum theory, and the standard model have few or no subject matter content descriptors at the analysis level. Earlier topics seem to have a greater spread across the four cognitive levels than later topics which are assessed on the external examination. In comparison, chemistry has a more even spread of cognitive levels across the subject matter content descriptors of most topics. This seems to be achieved by requiring students to demonstrate many content matter descriptors at multiple cognitive levels, with the result that chemistry learning objectives have significantly more cognitive verbs than physics or biology learning objectives. However, just like in physics, later chemistry topics that can feature on the external examination focus strongly on retrieval and comprehension (e.g., properties and structure of organic materials and chemical equilibrium systems). In biology, the strong focus on retrieval and comprehension is most notable. Half of the biology topics have very few or no subject matter content descriptors at the analysis or knowledge utilisation levels. By contrast, all topics except infectious diseases have a relatively high proportion of subject matter content descriptors at retrieval and comprehension levels. The distribution of cognitive levels across the subject matter content descriptors in each science subject may explain why some students perceive physics or chemistry as more challenging than biology, and it may contribute to the three sciences being scaled differently for the calculation of students' ATAR (Queensland Tertiary Admissions Centre [QTAC], 2021). Interestingly, while subject matter content descriptors in the three subjects are distributed unequally across the four cognitive levels, the assessment criteria and marking guides of all subjects' internal assessments are identical.

4.2.3. Metacognition and Self-System Thinking in the Syllabi

Subject matter content descriptors directing teachers to engage students with metacognition were not identified. However, there are implicit references to the metacognitive system in other sections of the three syllabi (see Table 4.4). For example, the pedagogical and conceptual framework as well as the Underpinning Factor 21st Century Skills state that physics, chemistry, and biology students should specify goals in the form of plans and research questions; monitor their learning process through self-management and reflection; and monitor the accuracy of the knowledge they are constructing by evaluating ideas, solutions, or evidence. The elaborations of syllabus objectives, one assessment objective and certain unit descriptions also make references to these three components of the metacognitive system. No references were found in the three syllabi relating to students monitoring the clarity of their thinking and understanding.

Similar to the metacognitive system, subject matter content descriptors do not make explicit references to the self-system. Instead, the self-system is an implicit learning goal for students studying the subject. The Underpinning Factor 21st Century Skills and two biology unit descriptions state that students' curiosity, inquisitiveness, emotional responses, and self-awareness of strengths and weaknesses should be developed as part of the course (see Table 4.4). To acquire students' appreciation of the subject matter and its impact, the rationale of each syllabus, several unit descriptions in all subjects, and the non-assessed Science as Human Endeavour subject matter stress that students should develop awareness of how important learned content and skills are to their life outside of the classroom.

Table 4.4

Implicit References to the Metacognitive and Self-System in the Syllabi

Level	Location in syllabus	Examples from syllabi
	The metacognitive system	
Specify goal	Elaboration of syllabus objectives Underpinning Factors (21st Century Skills) Pedagogical and conceptual framework Assessment objectives Unit descriptions	They [students] plan and carry out experimental and/or research activities. Science inquiry involves identifying and posing questions and working to answer them. Personal and social skills—leadership: the ability to use interpersonal skills to … set concrete goals and follow the steps necessary to achieve them.[a]
Monitor process	Underpinning Factors (21st Century Skills) Pedagogical and conceptual framework Unit descriptions	Personal and social skills—self-management: persisting to complete tasks and overcome obstacles; develop organisational skills and identify the resources needed to achieve goals.[a] The progression through the inquiry process requires reflection on the decisions made and any new information that has emerged during the process to inform the next stage. Each stage of the inquiry process is worthy of reflection, the result of which may be the revision of previous stages.
Monitor accuracy	Elaboration of syllabus objectives Underpinning Factors (21st Century Skills) Pedagogical and conceptual framework	Reflecting and evaluating: to … make an appraisal by weighing up or assessing strengths, implications and limitations, make judgments about ideas, works, solutions or methods in relation to selected criteria.[a] When students evaluate claims, they identify the evidence that would be required to support or refute the claim. They scrutinise evidence for bias, conjecture, alternatives, or inaccuracies.
Monitor clarity		No example was identified.

Level	Location in syllabus	Examples from syllabi
		The self-system
Examine importance	Rationale Underpinning Factors (numeracy and literacy) Science as Human Endeavour subject matter Unit descriptions Physics only: Unit 3 suggested practical	It is expected that an appreciation of, and respect for, evidence-based conclusions and the processes required to gather, scrutinise, and use evidence will be carried forward into all aspects of life beyond the classroom. Students could be asked to engage in learning experiences directed by a question that is meaningful to their lives. … provides an opportunity for students to appreciate the use and influence of scientific evidence to make decisions or to contribute to public debate about a claim.
Examine efficacy	Underpinning factors (21st Century Skills)	Personal and social skills—self-awareness: to know yourself or have a clear understanding of your personality, including strengths and weaknesses.[a]
Examine emotional response	Underpinning Factors (21st Century Skills) Unit descriptions	Personal and social skills—self-management: effectively regulating, managing and monitoring emotional responses.[a]
Examine motivation	Underpinning Factors (21st Century Skills)	Creative thinking—curiosity and imagination: the desire to learn or know; inquisitiveness and the action of forming new ideas, images or concepts.[a]

Note. Example references are derived from the three syllabi:

1. Queensland Curriculum and Assessment Authority. (2018). *Biology 2019 v1.2 general senior syllabus*. Queensland Government. https://www.qcaa.qld.edu.au/senior/senior-subjects/sciences/biology
2. Queensland Curriculum and Assessment Authority. (2018). *Chemistry 2019 v1.3 general senior syllabus*. Queensland Government. https://www.qcaa.qld.edu.au/senior/senior-subjects/sciences/chemistry
3. Queensland Curriculum and Assessment Authority. (2018). *Physics 2019 v1.2 general senior syllabus*. Queensland Government. https://www.qcaa.qld.edu.au/senior/senior-subjects/sciences/physics

[a] 21st Century Skills are listed in syllabi without explanations; stated definitions are taken from the QCAA's (2018c) *Capabilities and Skills Frameworks across Senior Curriculum Phases*

4.2.4. Comparison to Replaced Senior Science Syllabi

4.2.4.1. Structure of the Replaced Senior Science Syllabi. Learning objectives and factors underpinning curriculum delivery are structured differently in the replaced physics, chemistry, and biology syllabus than in the reformed syllabi (see Figure 4.6). The replaced syllabi have four broad general objectives with detailed elaborations for each objective. These elaborations use a range of cognitive verbs to communicate what students should be able to demonstrate for each objective. However, no reference to specific subject matter is made. The physics and chemistry general objectives are identical, while the biology general objectives have slight variations. General Objectives 1 to 3 inform the marking criteria of all assessments, and the fourth general objective is not assessed because it addresses affective elements of learning (i.e., attitudes and values).

The subject matter is outlined as a list of key concepts with associated key ideas that indicate the scope and scale of the knowledge to be taught. In other words, subject matter in the replaced syllabi is presented as a list of knowledge statements, with no associated cognitive verbs. Schools then developed six to 12 individualised units of work from the list of key concepts and key ideas. Units of work needed to address at least two key concepts and needed to be approved by the Queensland Studies Authority. Furthermore, at least two units had to be contextualised to the circumstances of the school. This structure resulted in the replaced syllabi being less prescriptive on the exact content knowledge students had to learn and the cognitive skills they had to use to demonstrate their learning of each concept. Depending on their local context, physics, chemistry, and biology students across Queensland potentially studied very different specific subject matter and themes.

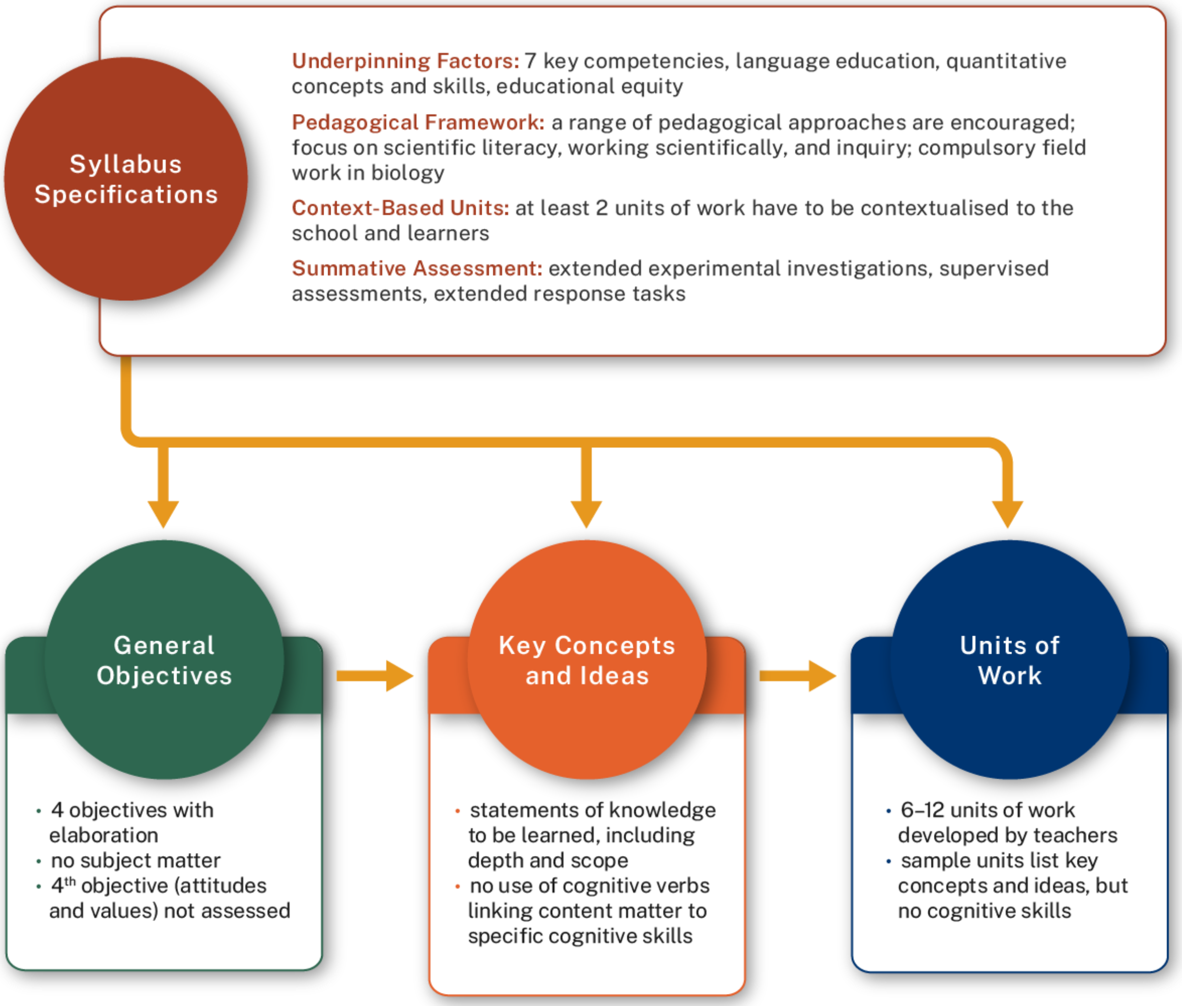
While the sample units in the appendix of each replaced syllabus do not link specific cognitive verbs with each key concept or key idea, it was expected that teachers would choose cognitive skills from the general objectives for students to demonstrate the knowledge they constructed. The replaced physics syllabus states that "the cognitive skills that support the general objectives of this syllabus should be specifically taught and embedded in the learning experiences throughout the course so students may demonstrate what they know and can do" (Queensland Studies Authority, 2007, p. 15). The cognitive skills of the general objectives were also used to develop marking rubrics for summative assessment in the previous QCE system. Therefore, this study uses cognitive verbs in the elaborations of general objectives to code cognitive levels of the replaced syllabi. Notably, the replaced syllabi do not use a specific educational taxonomy as a consistent classification framework for cognitive skills in their learning objectives.

Similar to the reformed syllabi, the replaced syllabi require students' learning across all units to be underpinned by certain key competencies, including language education, quantitative concepts and skills, and educational equity. While these factors have different names than the Underpinning Factors of the reformed syllabi, the content and purpose are very similar. The pedagogical framework of the replaced syllabi is non-prescriptive, encouraging a range of approaches from problem-based learning to guided discovery learning and direct instruction. However, an extended appendix on scientific literacy, ways of working scientifically and the compulsory fieldwork component in biology place an implicit emphasis on various models of inquiry learning and practical work. All summative assessment across the three subjects is school based and students are assessed more frequently than in the reformed system (i.e., up to six pieces of summative assessment per year instead of four). The replaced system's assessment types are supervised examinations, reports on extended experimental investigations, and written extended responses to a stimulus.

Even though the replaced syllabi are not explicitly framed by a classification framework for cognitive skills like the suite of reformed syllabi, there is evidence of existing emphasis on equipping students with a range of cognitive skills. For example, the replaced physics syllabus aims to develop students' "higher-order thinking skills" (Queensland Studies Authority, 2007, p. 44), "creative thinking skills" (p. 1), and challenges students to "apply their knowledge to the more complex real-world situations" (p. 10). The guidelines for learning experiences in all three replaced syllabi instruct teachers to scaffold thinking skills, and in biology, encourage problem-based learning "where thinking and problem-solving skills are naturally developed" (Queensland Studies Authority, 2014, p. 7).

Figure 4.6

Structure of the Replaced Physics, Chemistry, and Biology Syllabi

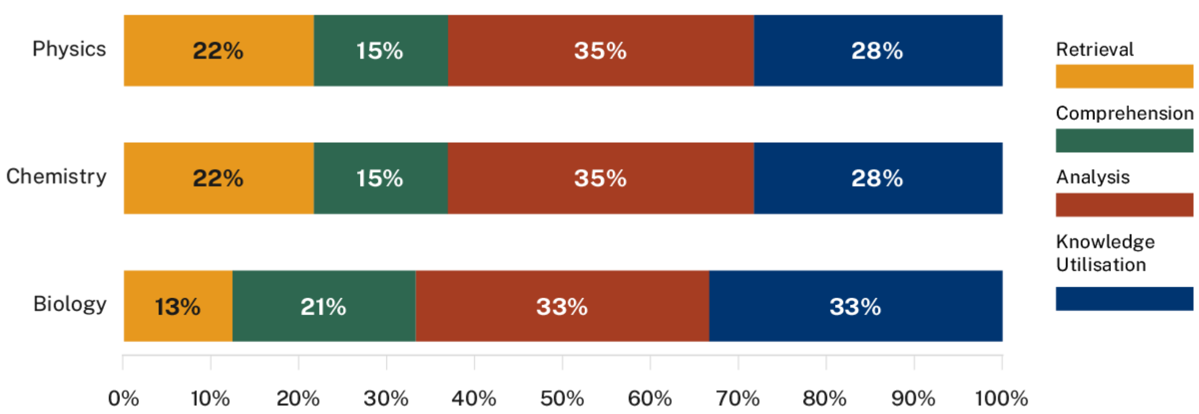


4.2.4.2. Changes to Cognitive Demands. To determine the cognitive demands of learning objectives in the replaced physics, chemistry, and biology syllabi, the research coded 46 cognitive verbs in the elaborations of the physics and chemistry General Objectives 1 to 3, and 24 cognitive verbs in the elaborations of the biology General Objectives 1 to 3. Since these cognitive verbs are not linked to specific subject matter, no topographic graphs could be created to visualise the intended cognitive level for each key concept.

As opposed to the reformed syllabi, the cognitive demands of learning objectives in the replaced syllabi are skewed towards the higher-order thinking skills analysis and knowledge utilisation. In biology, 13% of learning objectives require students to demonstrate knowledge through retrieval, 21% through comprehension, 33% through analysis, and 33% through knowledge utilisation. The distribution of cognitive demands is similar for physics and chemistry: 22% of cognitive verbs in both subjects' learning objectives were coded as retrieval, 15% as comprehension, 35% as analysis, and 28% as knowledge utilisation (see Figure 4.7). Consequently, more than 60% of cognitive verbs refer to higher-order thinking skills, which is almost the exact opposite of the distribution of cognitive levels in the reformed syllabi.

Figure 4.7

Cognitive Demands of General Objectives in Replaced Syllabi

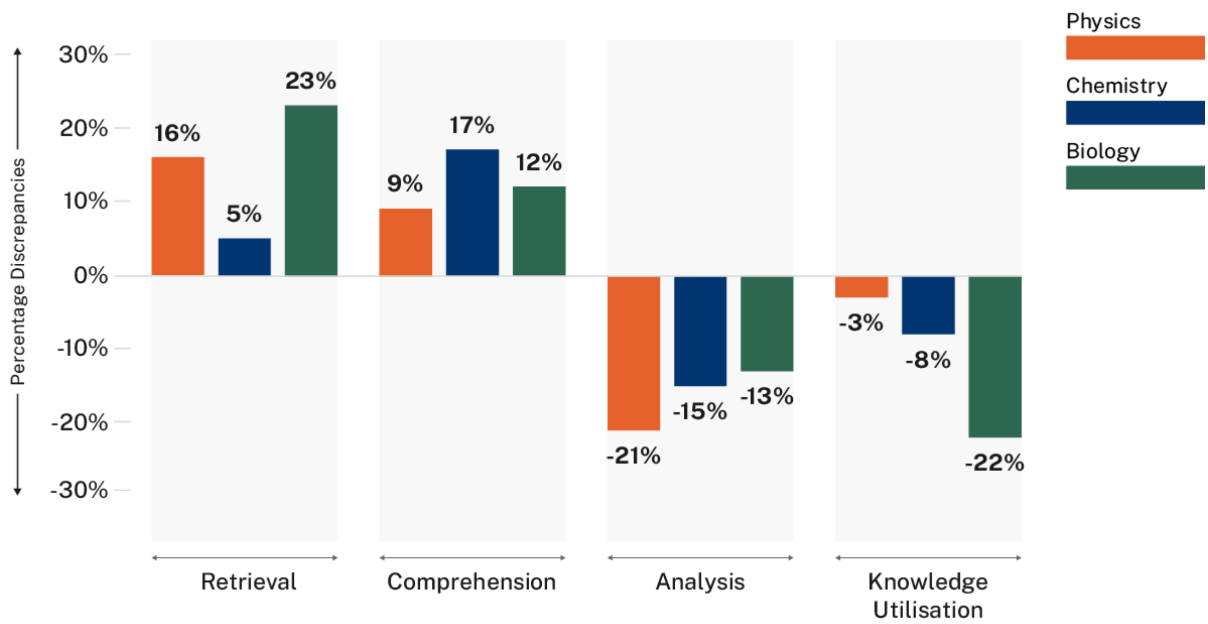


Note. Percentages are rounded to whole numbers.

Figure 4.8 shows the discrepancies in percentages of each cognitive level between the reformed and replaced syllabi. The trend is identical for all three subjects, although its magnitude varies. In physics, the reformed syllabi place greater emphasis on retrieval (+16%) and comprehension (+9%), much less emphasis on analysis (-21%), and slightly less emphasis on knowledge utilisation (-3%). In chemistry, the curriculum reform led to 5% more emphasis on retrieval, 17% more emphasis on comprehension, 15% less emphasis on analysis, and 8% less emphasis on knowledge utilisation. The differences in cognitive demands are most pronounced in biology, with 23% more emphasis on retrieval, 12% more emphasis on comprehension, 13% less emphasis on analysis, and 22% less emphasis on knowledge utilisation in the reformed syllabi.

Figure 4.8

Discrepancies in Cognitive Demands Between the Reformed and Replaced Syllabi



Note. Percentage discrepancy = Reformed syllabi % – Replaced syllabi %. Percentages are rounded to whole numbers.

4.2.4.3. Changes to Metacognition and Self-System Thinking. A noticeable difference between the replaced and reformed system is that the replaced syllabi have a general objective addressing students' affective domain, explicitly instructing teachers to develop students' attitudes and values surrounding their learning in the subject area, while the reformed syllabi do not address these systems in their syllabus objectives. However, the objective addressing students' affective domain was not assessed. The replaced syllabi also list the development of students' attitudes and values through studying the subject area as one of their global aims.

Moreover, the replaced syllabi have implicit references to metacognition and self-system thinking in other syllabus components (see Table 4.5). For example, students are encouraged to:

- define directions for their learning and set themselves goals (= specifying a goal);
- evaluate the effectiveness of their strategies, reflect on their progress, and propose improvements (= monitor process); and
- progress from personal inaccurate constructions to explanations based on accepted theories (= monitor accuracy).

An emphasis on purposeful context for learning across the three subject areas results in students having the opportunity to explore the significance of taught concepts for themselves (= examine importance). Furthermore, the replaced syllabi aim to develop students' self-evaluative expertise (= examine efficacy), their ability to explore feelings or dispositions associated with the subject matter (= examine emotional response), and their thirst for new knowledge in the field (=examine motivation).

The replaced and reformed physics, chemistry, and biology syllabi seem to have a comparable focus on metacognition. They both direct students to specify goals, especially in the context of planning and designing a scientific investigation. Directions for students to monitoring their accuracy of understanding also appear in core components of both syllabi versions (e.g., in the pedagogical framework). Monitoring the learning process seems to be emphasised in the replaced syllabi more than in the reformed syllabi as it is included in both the general objectives and assessment specifications of the replaced syllabi. Neither syllabus suite makes implicit nor explicit references to students monitoring the clarity of their thinking.

As for self-system thinking, both syllabus suites prioritise students examining the importance of learned concepts to their personal lives. However, this theme seems more central in the replaced syllabi as it is referred to in syllabus aims, the general objectives, assessment specifications, and the comprehensive appendix for context-based units of work. Examining one’s motivation is also more directly referred to in the replaced syllabi than in the reformed syllabi (e.g., in the syllabus introductions, the general objectives, and the guidance for learning experiences). Examining self-efficacy only has sparse references in both versions of the syllabi. Finally, there is only one highly implicit reference to students examining their emotional response in the replaced syllabi, without clear guidance on how to implement such a learning goal, while the reformed syllabi direct teachers to teach this skill by developing students’ self-management skills.

Table 4.5

References to the Metacognitive and Self-System in the Replaced Syllabi

Level	Location in syllabus	Examples from syllabi
		The metacognitive system
Specify goal	General objectives, pedagogical framework, key employment competencies/key capabilities, assessment, scientific literacy	Students are encouraged to learn by defining their own directions and setting goals for themselves. What must a student do [for their assessment]: clearly articulate the hypothesis or research question, providing a statement of purpose for the investigation; develop a planned course of action. … students' involvement in specifying the topic, purpose and audience is to be encouraged.
Monitor process	General objectives, learning experiences, assessment, scientific literacy	Ideas for generic learning experiences that may be useful include: … analysing strategies and evaluating effectiveness or improvements; … proposing and/or implementing strategies for improvement. The process of scientific investigation is not a linear one. Rather, it involves a recursive and reflective return to earlier steps, either to monitor progress or to adapt and adjust the questions or hypothesis in relation to new information.
Monitor accuracy	Introduction, general objectives, assessment	One role of science education is to help students move from their personal constructions, which are at times discordant with scientific explanations, towards theories and models accepted by the scientific community. They [students] need to distinguish between a plausible conclusion and one based on pure supposition.
Monitor clarity		No example was identified.

Level	Location in syllabus	Examples from syllabi
		The self-system
Examine importance	Rationale, global aims, general objectives, organisation, assessment, scientific literacy, developing context-based units of work appendix, sample units of work	Students should be given opportunities to develop attitudes and values to: appreciate the contribution of biology to local, national and international issues. Questions to consider when establishing a purposeful context for learning: Does the purposeful context for learning: have the potential to allow students to explore significant concepts and understandings about their world? Provide understandings that are valuable and useful in the world beyond school? Have the potential to really engage and interest students? Global aim: an ability to understand and appreciate the physics encountered in everyday life.
Examine efficacy	Assessment	These instrument-specific criteria sheets are to provide students with the opportunity to develop self-evaluative expertise.
Examine emotional response	General objectives	Attitudes and values: … It refers to the feelings, dispositions and ways of thinking about questions and issues in the field of study.
Examine motivation	Introduction, general objectives, learning experiences organisers, sample units of work, scientific literacy	Investigations use particular ways of thinking and problem solving, and are an effective strategy for: … increasing student involvement in and ownership of the curriculum. Science education should: provide excitement, motivation and empowerment; encourage a thirst for and a willingness to incorporate new and existing knowledge. Students are encouraged to learn through intrinsic and extrinsic motivation.

Note. Example references are derived from the three replaced syllabi:

1. Queensland Studies Authority. (2007). *Senior syllabus physics 2007*. Queensland Government.
2. Queensland Studies Authority. (2014). *Senior syllabus biology 2004 (amended 2006 and 2014)*. Queensland Government.
3. Queensland Studies Authority. (2007). *Senior syllabus chemistry 2007*. Queensland Government.

4.3. Discussion

4.3.1. Highly Prescriptive Learning Objectives

Priestley and Sinnema (2014) argue that many Western curricula over the last decade have moved towards generic content specification, meaning that teachers are free to mould subject matter to their context and individualise it for their learners. The reformed Queensland science syllabi seem to defy this trend. In the replaced syllabi, teachers were given a list of key concepts and key ideas with encouragement and a substantial amount of freedom to contextualise the subject matter by creating their own units and work programs. In contrast to this freedom, the reformed syllabi have pre-written linear units with a detailed list of subject matter to be covered for each concept. The depth that subject matter should be covered is indicated by the cognitive verb at the start of each learning objective. Any learning objective for the final two units may be assessed in the high-stakes external examination at the end of the course, increasing pressure not to deviate from the given template.

Such tight specification of content can benefit the quality and alignment of teachers' lesson planning and formative assessment (Blumberg, 2009). It certainly also addresses the criticism of the replaced Queensland senior system that the level of content coverage or demand of assessment were often not comparable between different schools in the state (Matters & Masters, 2014). However, the flipside of a highly prescriptive syllabus is that individual differences between learners and school contexts cannot be taken into account fully, thereby reducing the potential for curriculum to develop students' self-system thinking (e.g., their emotional response to subject matter, their interest, and motivation). The development of standardised lesson plans for the Australian Curriculum (i.e., Curriculum to Classroom) has also indicated that a *one size fits all* approach to curriculum delivery carries its own problems, such as teachers' increased levels of stress and covert resistance to change (Barton et al., 2014).

4.3.2. Dominance of Retrieval and Comprehension in Learning Objectives

The results of this syllabus analysis are surprising, considering the increased focus on 21st Century Skills in science education internationally and the goals of science education in Australia previously outlined in the introduction and literature review chapters. In all three subjects, more than half of the subject matter content descriptors address lower-order cognitive skills. Moreover, topics that may appear on the external examination have learning objectives that focus stronger on lower-order cognitive skills than on higher-order cognitive skills in all three sciences, potentially demonstrating the alignment of curriculum to the restrictions of the assessment mode (Au, 2007). Research has shown that high stakes external examinations may in some circumstances hinder intentions to focus on higher-order cognitive skills (Fensham & Bellocchi, 2013).

While a focus on retrieval and comprehension in the reformed syllabi seems to contradict the aims of science education in Australia (see Section 4.1.), some scholars would argue that it is a deliberate and positive shift. For instance, Mishra and Mehta (2017) analysed perspectives on 21st Century Skills and argue that domain-specific critical thinking or creativity needs to have a foundation in the discipline's knowledge; such a knowledge base enables the learner to view problems in unique ways. During the development of the reformed syllabi, the QCAA (2016) identified a heavy focus on higher-order thinking at the expense of content knowledge and the vague description of learning objectives as a weakness of the replaced senior science syllabi. The senior system was criticised for failing to develop the knowledge base required for many university courses, particularly in mathematics and the natural sciences (Matters & Masters, 2014). The government responded to this criticism by arguing that students need foundational knowledge and skills before applying their knowledge during inquiry-based assessments. A further argument is that describing retrieval and comprehension as lower-order or lower-level cognitive skills might entail a devaluing connotation. Booker (2007) asserts that Bloom's Taxonomy has been misinterpreted or misused to diminish the importance of knowledge retrieval and comprehension rather than positioning it as a vital component of thinking. This resonates with common arguments expressed in the literature before the turn of the century. For example, the argument that effective problem solving requires strong content knowledge specific to the problem (De Corte, 1990) because problem solving involves automatic retrieval of relevant knowledge (Christensen, 1991).

However, the above arguments contradict the theorised independence of cognitive levels in the New Taxonomy of Educational Objectives, which does not assume that lower-order thinking skills are needed as a foundation to develop effective higher-order thinking skills (Marzano & Kendall, 2007). This is one of the greatest differences to Bloom's original Taxonomy for Educational Objectives, which claims that foundational knowledge precedes higher-order learning (Bloom et al., 1956). Some empirical evidence supports the independence of cognitive levels suggested by the New Taxonomy, showing that building foundational knowledge through lower-order thinking tasks does not affect learners' performance on higher-order thinking tests and, just as importantly, that higher-order thinking practice does not affect performance on lower-order thinking tests. The cognitive complexity of the practised tasks had to match the cognitive level of the test to have a positive effect on student outcomes (Agarwal, 2019).

Internationally, two opposing trends in science curricula are evident. Hollins and Reiss's (2016) analysis of prescribed science curricula in the USA, Australia, Canada, Finland, Japan, Singapore, Hongkong, and Shanghai suggests that the Asian jurisdictions are in the process of reforming their science curricula to focus less on knowledge and more on application and creativity, with increasing references to exploration and a student-centred curriculum. Similarly, China's senior chemistry syllabus, while still dominated by lower-order cognitive skills, has increased the number of higher-order cognitive skills in learning objectives in recent decades (Wei, 2020). In contrast to this, science curricula in Western countries are seemingly becoming more focused on the recall of knowledge (Hollins & Reiss, 2016).

The replaced Queensland senior science syllabi have a heavy focus on higher-order thinking, particularly investigating and evaluating, and arguably less breadth of knowledge (Firn, 2016; QCAA, 2016). To evaluate the shift in cognitive demand towards more retrieval and comprehension of knowledge, further research is needed. This research may address the effect of the increased focus on retrieval and comprehension of knowledge on students' results, their perception of knowledge construction in science, and their creative solutions to unique problems. Comparative studies examining international science curricula (e.g., the International Baccalaureate), would also be instructive.

4.3.3. Metacognition and Self-System Thinking as Implicit Curriculum Component

The exclusion of metacognition and self-system thinking learning objectives from subject matter content descriptors, syllabus objectives, and assessment criteria of the reformed senior science syllabi is not out of the ordinary. Teaching skills such as goal setting or self-regulation positively affect students' achievement (Hattie, 2008) and cognitive development (Bayat & Tarmizi, 2010; Venville & Oliver, 2015). However, these skills are rarely addressed explicitly in learning objectives or seen as worthy of separately allocated lesson time, and are often considered to be less academic than cognitive skills (Kereluik et al., 2013; Marzano & Kendall, 2008). An analysis of 15 different chemistry syllabi in Turkey showed that the cognitive domain dominates learning goals (Pekdağ & Erol, 2013) and more locally, Morris and Burgess (2018) highlight the very limited use of metacognitive knowledge dimensions in the Australian history curriculum as well as the previous New South Wales history curriculum. This could be the case because it is difficult to reach a consensus about the successful mastery of certain metacognitive or affective skills that cannot be observed directly, such as value systems or motivation.

Nevertheless, the qualitative analysis of the reformed senior science syllabi shows that, to a certain extent, metacognition and self-system thinking have become accepted implicit goals of the senior science curriculum. However, their importance seems to have diminished in the reformed syllabi as compared to the replaced syllabi, which had an explicit yet unassessed learning objective addressing students' affective domain and instructing teachers to develop students' attitudes and values surrounding their learning in the subject. The replaced senior science syllabi also mandated the contextualisation of prescribed subject matter in teacher-designed units (e.g., Queensland Studies Authority, 2007), which can foster a student-centred curriculum and self-system thinking. In contrast to this, it seems that the reformed syllabi rely on metacognition and self-system thinking to be taught as part of schools' hidden curriculum, which involves the implicit and unofficial skills, attitudes, and values students learn (Gordon, 1982). For example, the public celebration of students' success in science subjects or the time and resources allocated to the sciences within a school can send messages to students about the importance of subject matter and encourage a positive emotional disposition. Similarly, a classroom culture that values a growth mindset and encourages learning from failure can teach students metacognitive skills about the process of effective learning.

While references to metacognitive and self-system thinking are present in the reformed syllabi, it's worth noting that they are often tucked away in sections of the document that teachers are unlikely to consult for their lesson planning, and perhaps may not even read. Relying on such implicit directions to teach metacognition and self-system thinking may lead to inconsistent or ineffective implementation of this curriculum component. Marzano and Kendall (2008) demonstrate with many examples that curriculum learning objectives at the metacognitive and self-system thinking level can be designed, and they argue that teachers require specific strategies or frameworks for teaching such thinking skills to students. One curriculum reform in the Northern Territory and South Australia aimed to strengthen students' literacy through the inclusion of metacognition, but an analysis of teachers' planning documents showed low alignment of syllabus intentions and classroom teaching, likely due to the lack of explicit instructions for teachers on how to include metacognition in lessons (Fenwick, 2018). It follows that metacognitive and self-system objectives should ideally be stated overtly in a curriculum if educators wish to address content knowledge comprehensively and develop self-regulatory skills in students (Marzano & Kendall, 2007).

Over time, treating metacognition and self-system thinking as an optional curriculum component may result in lower student enrolments in senior science subjects for intrinsic reasons, as opposed to selecting the subject as a means for gaining entry to certain university courses, which was observed in Western Australia after the last syllabus reform (Krüger et al., 2013). Research is needed to explore the potential effects of the reformed syllabi on the engagement of students with the sciences beyond the secondary level.

4.3.4. Implications for Pedagogy

The reformed physics, chemistry, and biology syllabi do not endorse a specific pedagogical approach or philosophy, but the pedagogical frameworks of the three syllabi outline approaches to inquiry learning in great detail. Inquiry-based pedagogies are prevalent across Australian, the United Kingdom, Canadian, and US science curricula (Firn, 2016), and they have been consistently observed in US schools with effective science programs (Scogin et al., 2018). However, it is questionable whether retrieval and comprehension skills, which dominate the reformed syllabi, are commonly taught by inquiry learning. Instead, teachers may choose to adopt a more didactic teaching style and prioritise content knowledge delivery over cognitive skill development when faced with a highly prescriptive curriculum and high-stakes external examinations (Krüger et al., 2013). More prescriptive syllabi also lead to more time constraints for teachers, which is one of the biggest barriers to inquiry learning (Fitzgerald et al., 2019). Again, there seems to be a potential mismatch between policy recommendations in Australia which advocate inquiry learning (Education Council, 2015) and content in the prescribed curriculum.

Independent of the pedagogical approach, teachers could benefit from professional development opportunities focused on best practices for teaching the different cognitive skills, metacognition, and self-system thinking outlined in the science syllabi. As stated in the literature review, effective teaching frameworks (a) model the cognitive skill, (b) guide students' practice of the skill with teacher feedback, (c) encourage students' independent transfer of the skill to new contexts, and (d) facilitate metacognitive reflection on thinking processes (Beyer, 2008; De Corte, 1990).

4.4. Limitations and Recommendations

This study analysed the cognitive demands of syllabus learning objectives using Marzano and Kendall's (2007) New Taxonomy of Educational Objectives as a theoretical framework. While this framework is highly appropriate for the reformed senior science syllabi because the New Taxonomy was used by the QCAA to design learning and assessment objectives, it may have been less valid when classifying the learning objectives of the replaced syllabi. Cognitive verbs in the replaced syllabi that are not easily classified by the New Taxonomy required the researcher to judge the appropriate cognitive level. In such cases, a thesaurus was used to match the cognitive verb with one that is used by the New Taxonomy. However, this may have distorted the meaning and intention of the curriculum writers.

Furthermore, different types of learning objectives were coded to analyse cognitive levels in the reformed and the replaced syllabi. The aim was to analyse the cognitive demands of the most specific learning objectives for each syllabus. While the reformed syllabi state a cognitive verb for each subject matter content descriptor, key concepts and ideas in the replaced syllabi are presented as a list of nouns without verbs, suggesting the cognitive level or depth to which each key concept or idea should be taught. Therefore, the syllabi's general objectives which inform the marking criteria of all summative assessment were analysed instead. Since these objectives are more general and address multiple concepts, it cannot be said for sure whether the intention was to use certain objectives for more concepts than others (e.g., whether objectives with the lower-order cognitive skills were meant to be used on more subject matter while higher-order cognitive skills were meant to refer to fewer concepts or vice versa).

Finally, this syllabus analysis has not taken the sophistication of subject matter into account when analysing the cognitive demands of learning objectives. One could argue that the cognitive level of learning objectives is not solely decided by the mental process required to demonstrate knowledge, but also by the complexity of the content matter (Lemons & Lemons, 2013). For example, *distinguish between a plant and animal cell* is generally considered a less complex question than *distinguish between gene therapy and therapeutic cloning,* despite both objectives using the same cognitive verb.

Nevertheless, an analysis of reformed curricula is important to ensure alignment of the prescribed curriculum with the enacted and assessed curriculum. The release of a newly prescribed curriculum is only the first step in an educational reform. The senior physics, chemistry, and biology syllabus documents are interpreted, reformulated, and enacted by teachers across Queensland. As Shalem et al. (2013) point out, even well-written standards do not dictate appropriate pedagogical practices. Thus, this study also examined the cognitive demands of the enacted curriculum and the pedagogical choices of teachers implementing the reformed syllabi.

It would also be informative to research whether the reformed system has swung from an arguably ‘overly open’ curriculum with a strong focus on higher-order thinking skills and inquiry learning, to an ‘overly inflexible’ curriculum predominantly focusing on lower-order thinking and transmission learning or whether thinking at all cognitive levels is represented sufficiently. In either case, since there is a wealth of research on effectively teaching the newly emphasised retrieval and comprehension skills (e.g., Dunlosky et al., 2013; Rohrer & Pashler, 2010), it is imperative that senior science teachers receive professional development opportunities addressing changes to the cognitive demands of learning objectives in the reformed syllabi.

4.5. Conclusion

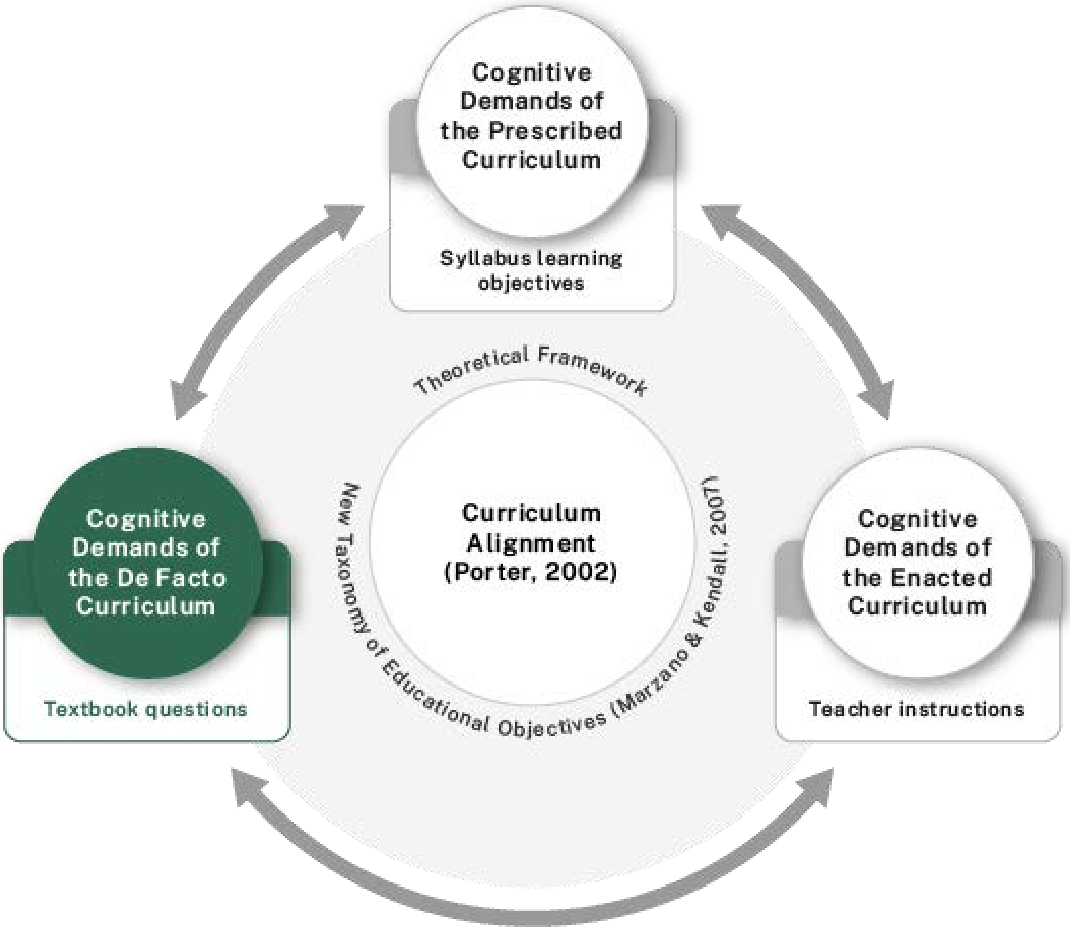
The syllabus analysis aimed to determine the cognitive demands of learning objectives in the reformed Queensland senior physics, chemistry, and biology syllabi. Furthermore, this analysis determined whether the development of students’ metacognitive and self-system is embedded in the curriculum. The three reformed syllabi were compared to their predecessors to reflect on the change legislated by the recent curriculum reform. Results show that the syllabi have moved from a flexible curriculum which lends itself to contextualisation but communicates vague learning expectations to a detailed but more inflexible curriculum. The reformed physics, chemistry, and biology syllabi are dominated by learning objectives prioritising retrieval and comprehension over higher-order cognitive skills like analysis or knowledge utilisation. There may now be a mismatch between some goals and trends portrayed in science education by Australian policy documents and the cognitive demands emphasised in the reformed syllabus subject matter content descriptors. This fuels the ongoing debate about the appropriate balance of teaching lower-order cognitive skills like retrieval or comprehension and higher-order cognitive skills like analysis or knowledge utilisation in senior secondary science. Teaching metacognition and self-system thinking are implicit rather than explicit objectives of the reformed syllabi. This is not unusual but may lead to the reduced implementation of such objectives, even though learners' engagement with metacognition and self-system thinking has a positive effect on student outcomes (Hattie, 2008). Following this analysis of the prescribed curriculum, the next chapter examines the cognitive demands of the de facto curriculum presented in textbooks designed to support the implementation of the curriculum reform.

Chapter 5. The De Facto Curriculum

The de facto curriculum is the second curriculum component examined in this study (see Figure 5.1). This component is conceptualised as the learning tasks and questions in textbooks published to support the implementation of the reformed Queensland senior science curriculum. Following a rationale for the inclusion of the de facto curriculum, this chapter first describes and then discusses the textbook analysis findings. The chapter ends by evaluating the analysis limitations and suggesting implications for textbook developers, teachers, and schools.

Figure 5.1

Focus of Chapter 5—The De Facto Curriculum



5.1. Rationale

Considering how consistently textbooks are used as lesson resources (McDonald, 2016), it is imperative to analyse their quality and their alignment with the prescribed curriculum. Past science textbook research predominantly focuses on content knowledge rather than the nature of learning activities, and the majority of studies are based on European or North-American textbooks (Vojíř & Rusek, 2019). There is scant research on the cognitive demands of science textbook learning activities in Australia or elsewhere, despite its perceived importance. McDonald (2016) surveyed 486 Australian schools on their reasons for choosing a textbook and found that the inclusion of high-quality questions and exercises is important for many teachers. Many survey respondents expressed concerns about the quality and complexity of questions in science textbooks.

This study's analysis of learning tasks and questions in Australian science textbooks could inform the future decision making of textbook authors, policymakers who set standards for textbooks, and teachers choosing textbooks. Subsequently, the findings have potential to inform changes in future textbook editions which could improve students' opportunities to learn and achieve. Moreover, a textbook analysis of cognitive demands can evaluate whether science textbooks are aligned with reform efforts in Australia, such as inquiry-oriented science teaching or the goal to teach a range of cognitive skills to prepare students for the 21st century.

To achieve these aims, this chapter analyses data pertinent to the study's second research question and its sub-questions:

2. What are the cognitive demands of the de facto curriculum presented in senior physics, chemistry, and biology textbooks?
    a. Which cognitive levels are emphasised by senior science textbooks that are prepared for the reformed syllabi?
    b. Do the cognitive demands of senior science textbooks differ between subject areas?

5.2. Results

The following results first present an overview of analysed textbook questions per subject and publisher. Thereafter, findings on the cognitive demands of textbook questions are described across all three subject areas. Lastly, the lack of differences in cognitive demands of physics, chemistry, and biology textbook questions is highlighted.

5.2.1. Analysed Textbook Questions

In total, 2222 questions were analysed in the three biology textbooks, 3067 in the physics textbooks and 2781 in the chemistry textbooks. With the exception of chemistry, the publishers did not vary greatly in the number of questions they chose to include in their textbooks for each subject. However, Pearson Education Australia textbooks for all subjects contain more questions with multiple subcomponents (e.g., a, b, c, etc., and/or i, ii, iii, etc.) than the other two publishers, which may bias the total question count. Table 5.1 provides a summary of the question count present in each analysed textbook.

Table 5.1

Textbook Questions Analysed Per Subject and Publisher

Publisher	Subject		
	Biology	Physics	Chemistry
Centage Learning Australia	760	1010	930
Oxford University Press	746	1050	723
Pearson Education Australia	716	1007	1128
Total	2222	3067	2781

Question types in all textbooks included multiple-choice, short response, and extended response questions. The purpose of questions varied between a review of the content presented on preceding pages, challenge or case study questions linking to real-world applications, and inquiry or discussion questions about practical activities. All questions started with either a cognitive verb from Marzano and Kendall's (2007) New Taxonomy of Educational Objectives such as *describe* or *compare*, or a question word such as *how* or *why*. Table 5.2 gives examples of textbook questions at each level for each subject.

Table 5.2

Examples of Textbook Questions at Each Cognitive Level

Cognitive level	Sample textbook question
Retrieval	Describe what random sampling means. (Biology) Define the term vector. (Physics) Identify the reagents and conditions required for an: (a) elimination reaction of a haloalkane (b) addition of water (c) addition polymerization. (Chemistry)
Comprehension	Explain why the classification system for organisms needed to be modified following the ability to sequence DNA. (Biology) Explain what the problem is for nuclear fission reactors when too few neutrons are released per fission event. (Physics) How do the ionisation energies of atoms and their electronegativities relate to the ability of an atom to gain or lose electrons and therefore their strength as an oxidant or reductant? Use francium and fluorine as examples to support your answer. (Chemistry)
Analysis	Distinguish between convergent and divergent evolution. (Biology) A boy kicks a football off the ground and it lands on the roof of his home 57.3 m away at a height of 3.8 m. The time of flight was 3.0 seconds. Determine the maximum height reached and the time of flight if he kicked the ball at the complementary angle. (Physics) Sort the following substances in order of increasing oxidation states of nitrogen: NO, K_3N, N_2O_4, N_2O, $Ca(NO_3)_2$, N_2O_3, N_2. (Chemistry)
Knowledge utilisation	In the future, corporations may be tempted to base their recruitment only on genetic profiles. Evaluate the validity of such a policy. (Biology) A propulsion method suggested for interstellar travel is a large plastic sail that is bombarded by photons from the sun. The argument is that if photons really do have momentum, they will push the sail along. Decide whether this would work and propose a suitable surface coating for the sail. (Physics) Investigate why pH + pOH = 14 for an aqueous solution at 25 °C. Consider how this equation may differ with a change in temperature. (Chemistry)

Metacognition	Comment on how sure you are of your classification of each ecosystem. (Biology) Identify a list of things you need to study. (Physics) Consider how managing your Chemistry workload affects your other subjects. (Chemistry)
Self-system thinking	Consider which topics you find interesting as these will be the best areas to research for your research investigation. (Biology) Identify the topics that appeal most to you, and those that you think you might find challenging. (Physics) Predict which aspects of each assessment [in Unit 3 and 4] will be most personally challenging and propose strategies to help meet these challenges. (Chemistry)

Note. The sample textbook questions are derived from the nine textbooks:

1. Adamson, S., Alini, O., Champion, N., and Kuhn, T. (2018). *Nelson Qscience Physics Units 3 & 4* (1st ed.). Cengage Learning Australia.
2. Walding, R. (2019). *New Century Physics for Queensland Units 3 & 4* (1st ed.). Oxford University Press.
3. Baker, M., Allinson, A., Devlin, J., Eddy, S., and Hore, B. (2019). *Pearson Physics Queensland 12 Units 3 & 4 Student Book* (1st ed.). Pearson Education Australia.
4. Stansbie, N., Steeples, B., and Windsor, S. (2019). *Nelson Qscience Chemistry Units 3 & 4* (1st ed.). Cengage Learning Australia.
5. Kuipers, K., Devlin, P., Brabec, M., Sharpe, P., and Bloomfield, C. (2019). *Chemistry for Queensland Units 3 & 4* (1st ed.). Oxford University Press.
6. Holmes, N., Bruns, E., Commons, C., Commons, P., and Hogendoorn, B. (2019). *Pearson Chemistry Queensland 12 Units 3 & 4 Student Book* (1st ed.). Pearson Education Australia.
7. Borger, P., Grant, K., Wright, J., and Munro, L. (2018). *Nelson Qscience Biology Units 3 & 4* (1st ed.). Cengage Learning Australia.
8. Huxley, L., Walter, M., and Flexman, R. (2019). *Biology for Queensland an Australian Perspective Units 3 & 4* (1st ed.). Oxford University Press.
9. Hall, M., Bliss, C., Fesuk, S. Jacobs, J., and Maher, F. (2019). *Pearson Biology Queensland 12 Units 3 & 4 Student Book* (1st ed.). Pearson Education Australia.

For further information about the location of these questions in each textbook, please contact the researcher.

5.2.2. Cognitive Demands of Textbook Questions

Table 5.3 shows the percentage and absolute frequency of questions at each cognitive level for each subject and publisher. Overall, retrieval questions are most common (32%), followed by analysis questions (28%) and comprehension questions (27%). Knowledge utilisation questions are less common (12%) and, critically, questions stimulating metacognition or self-system thinking are rare (1% and <1% respectively). In sum, 59% of all analysed questions require students to use lower-order cognitive skills and questions with the highest cognitive demand are the rarest (see Figure 5.2).

Table 5.3

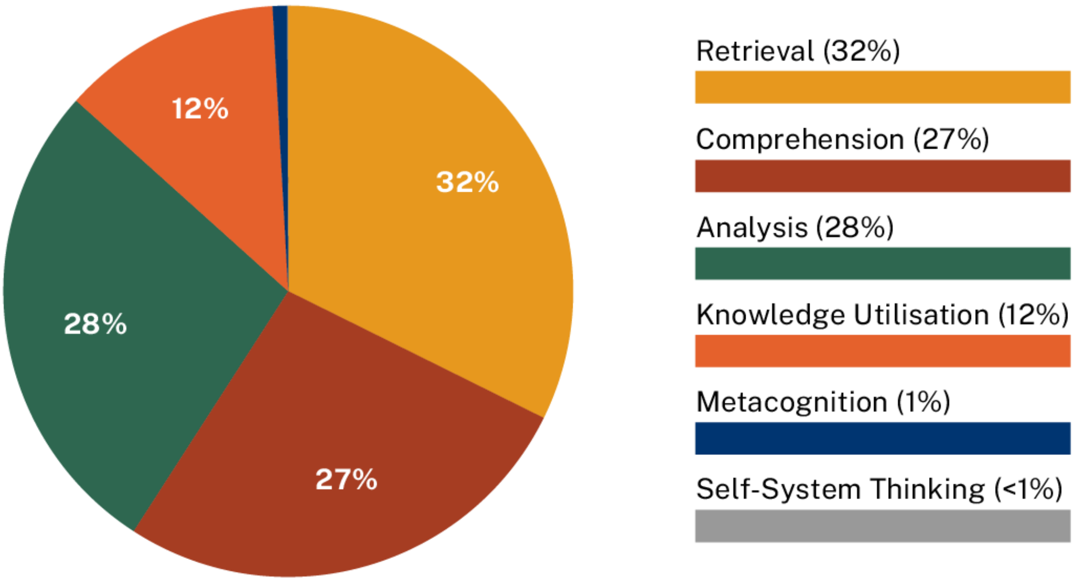
Cognitive Demands of Textbook Questions

Subject	Publisher	Cognitive level					
		Retrieval	Comprehension	Analysis	Knowledge utilisation	Metacognition	Self-system thinking
Biology		33% (735)	28% (623)	23% (521)	14% (311)	1% (30)	0% (2)
	Centage	37% (281)	31% (239)	18% (134)	12% (92)	2% (14)	0% (0)
	Oxford	33% (244)	27% (205)	23% (175)	16% (117)	0% (3)	0% (2)
	Pearson	29% (210)	25% (179)	30% (212)	14% (102)	2% (13)	0% (0)
Physics		35% (1075)	22% (687)	31% (936)	12% (353)	0% (15)	0% (1)
	Centage	35% (350)	30% (303)	29% (288)	7% (69)	0% (0)	0% (0)
	Oxford	27% (281)	18% (189)	35% (366)	20% (210)	0% (3)	0% (1)
	Pearson	44% (444)	19% (195)	28% (282)	7% (74)	1% (12)	0% (0)
Chemistry		29% (816)	30% (831)	28% (781)	12% (333)	1% (17)	0% (3)
	Centage	27% (250)	35% (325)	28% (260)	10% (92)	0% (3)	0% (0)
	Oxford	33% (236)	26% (190)	20% (145)	20% (147)	0% (2)	0% (3)
	Pearson	29% (330)	28% (316)	33% (376)	8% (94)	1% (12)	0% (0)
Total		32% (2626)	27% (2141)	28% (2238)	12% (997)	1% (62)	<1% (6)

Note. The full names of publishers are Centage Learning Australia, Oxford University Press and Pearson Education Australia. Percentages are rounded to whole numbers and absolute frequencies are stated in brackets.

Figure 5.2

Cognitive Demands of Textbook Questions Across All Subjects



Note. Percentages are rounded to whole numbers.

In the New Taxonomy of Educational Objectives, the category retrieval includes either recalling or recognising information accurately, without necessarily understanding the structure or components of the retrieved knowledge (Marzano & Kendall, 2007). For example, to recall information students may be asked to define a term; to recognise information students may be required to select the correct term from a given list of words. Retrieval also includes correctly executing a mental or psychomotor procedure, without necessarily knowing why or how it works (Marzano & Kendall, 2007). For example, students may be asked to follow steps in order to balance a simple chemical equation. Close to half of the retrieval questions in the analysed senior science textbooks require students to recall information that can be found on preceding textbook pages. One third of retrieval questions ask students to recognise information by primarily using multiple-choice questions. Executing procedures is the least common type of retrieval questions in the textbooks (see Figure 5.3). Consequently, retrieval questions focus more on information than on processes.

Comprehension of knowledge can be demonstrated by either integrating or symbolising knowledge. Questions requiring students to integrate knowledge ask for an identification of the critical or essential features and the structure of knowledge (Marzano & Kendall, 2007). For example, students may have to explain a concept, summarise or paraphrase a process, select relevant examples, or logically link different concepts. Symbolising knowledge requires students to identify critical or essential features and the structure of knowledge by constructing an accurate symbolic representation, such as a graphic organiser or a labelled diagram (Marzano & Kendall, 2007). Both integrating and symbolising knowledge often require students to make links between newly learned concepts and their previous knowledge. Over three quarters of comprehension questions in the analysed textbooks ask students to integrate knowledge (see Figure 5.3), prioritising linguistic answers over non-linguistic (symbolic imagery) responses.

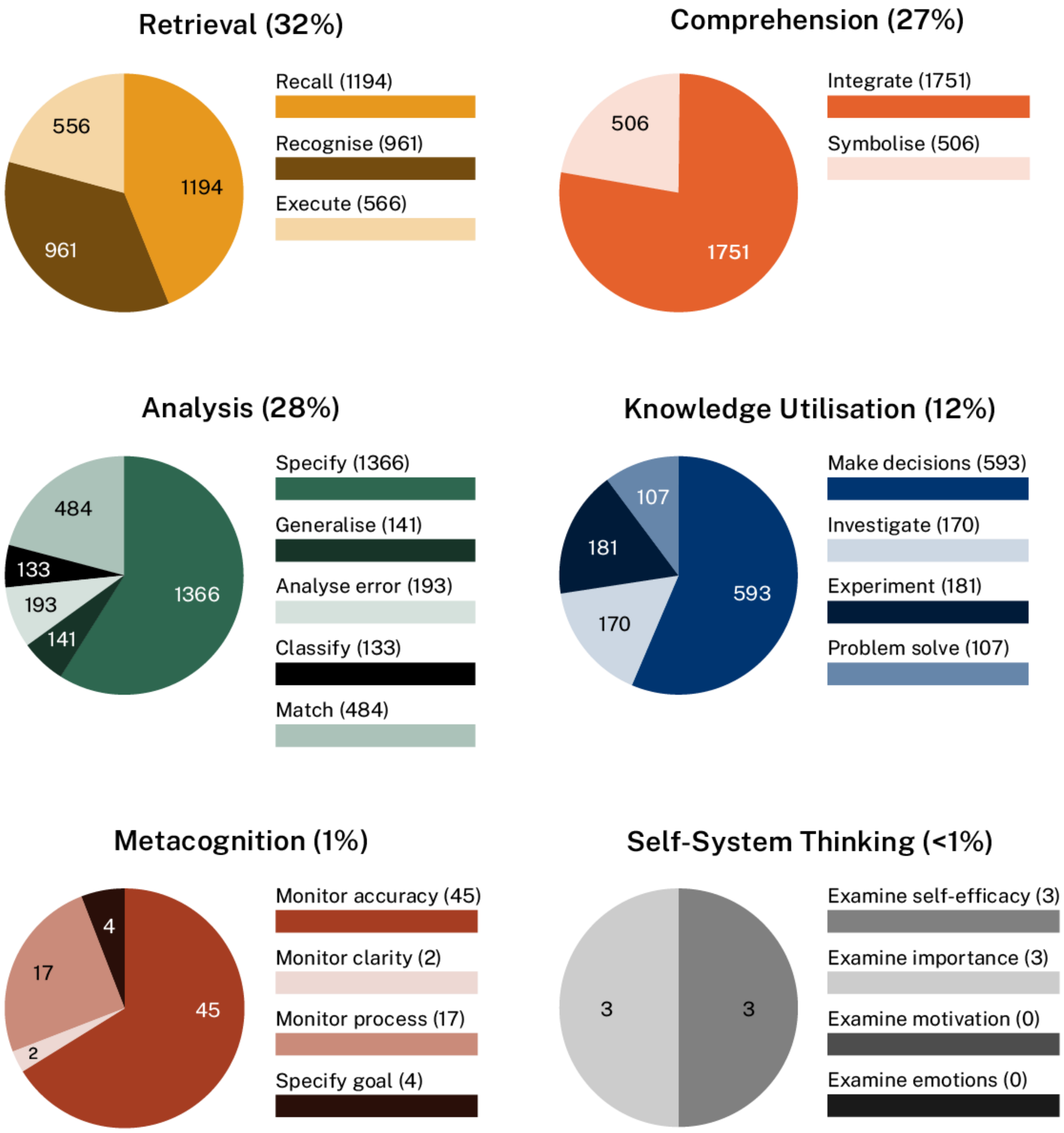
Analysis questions may ask students to specify, generalise, classify, and match knowledge, or to analyse an error. Almost two thirds of analysis questions in the analysed textbooks ask students to specify knowledge. This means students must identify a specific application or a consequence of knowledge presented to them, such as applying a scientific law to a given situation or by extrapolating data in a graph. This requires deductive thinking based on the learner's understanding of a concept or principle (Marzano & Kendall, 2007). Analysis questions asking students to reverse the process by generalising, making inferences from given information, classifying knowledge, or matching concepts based on similarities and differences are much less common in the analysed textbooks. Senior science textbook questions seem to emphasise deductive over inductive analytical skills. Additionally, analysis questions which require students to analyse errors in given information by checking its logic, accuracy, or validity are comparatively rare in the analysed textbooks (see Figure 5.3).

The New Taxonomy divides knowledge utilisation—the cognitive skill of using knowledge to accomplish a specific task—into four processes: investigating, experimenting, problem solving, and decision making (Marzano & Kendall, 2007). Knowledge utilisation questions in the analysed textbooks are dominated by decision making (>50%), which requires students to identify and choose between several alternatives (e.g., by suggesting a suitable environmental policy or evaluating an engineering solution). Questions directing students to investigate knowledge or to experiment by generating and testing hypotheses are much less common, even though they are central to scientific inquiry (Marzano & Kendall, 2007). Problem-solving questions that ask students to overcome obstacles are least common within the knowledge utilisation category (see Figure 5.3).

Most rare in all texts examined are questions addressing the metacognitive and self-system, which are thought to regulate students' use of cognitive skills, their decision to engage with learning, and their motivation (Marzano & Kendall, 2007). The majority of metacognitive tasks require students to monitor the accuracy of their responses to preceding questions or to monitor their learning process by reflecting on the effectiveness of their learning strategies (see Figure 5.3). Students are hardly ever asked to monitor the clarity of their thinking or to specify their own learning goals. Only six questions across all analysed textbooks ask students to examine their self-efficacy by reflecting on their perceived agency and ability to learn specific knowledge, or to examine how important students consider the presented knowledge to be (i.e., how far the knowledge can satisfy a need or personal goal of the student). No questions requiring students to examine their motivation or emotions were identified (see Figure 5.3), therefore analysed textbooks are omitting to engage students' affective domain.

Figure 5.3

Frequency of Textbook Questions at Each Cognitive Level

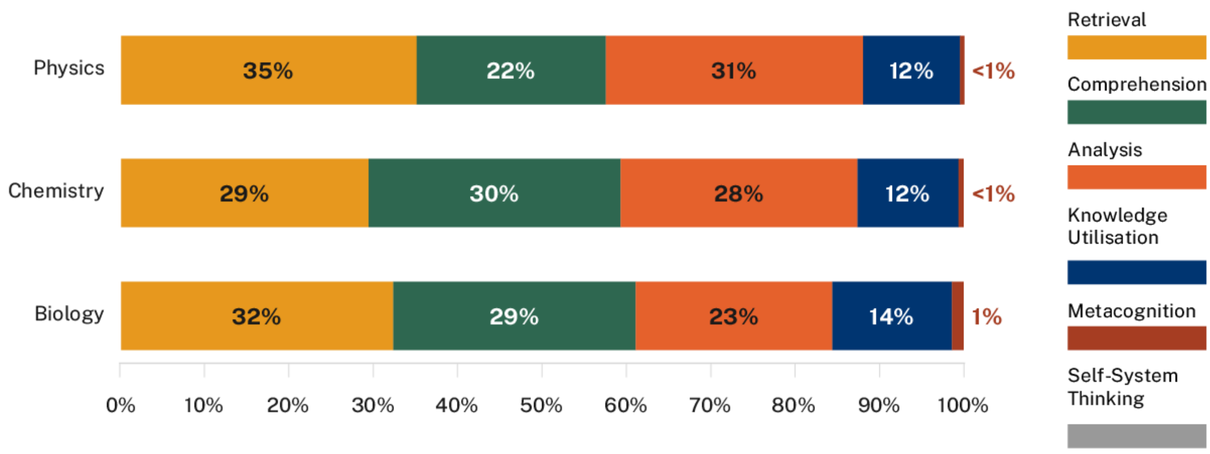


5.2.3. Differences Between Questions in Physics, Chemistry, and Biology Textbooks

The distribution of questions across different cognitive levels does not vary greatly between physics, chemistry, and biology (see Figure 5.4). The range of question percentages for each cognitive level is never greater than 8%. In each subject, the majority of questions are classified as retrieval or comprehension, resulting in 59% of questions addressing lower-order thinking skills in chemistry textbooks, 57% in physics textbooks, and 61% in biology textbooks. Physics textbooks have the most analysis questions (31%) when compared to chemistry (28%) and biology textbooks (23%). Many of these analysis questions require students to apply mathematical formulas to scenarios. Biology textbooks have slightly more knowledge utilisation questions (14%) when compared to physics and chemistry textbooks (12% each). As mentioned before, questions addressing the metacognitive and self-system are rare or not present at all in textbooks for these three subjects.

Figure 5.4

Cognitive Demands of Textbook Questions Per Subject



Note. Percentages are rounded to whole numbers.

5.3. Discussion

5.3.1. Dominance of Lower-Order Thinking Questions

In the three subject areas, well over half of all textbook questions ask students to use lower-order thinking skills by demonstrating retrieval or simple comprehension of knowledge. Textbook questions requiring higher-order thinking strongly focus on analysis, particularly in physics. Valverde et al. (2002) analysed 400 science and mathematics textbooks from 43 countries and found similar results; overall, students were rarely (<5%) expected to investigate concepts or to solve problems. Most frequently, students were asked to comprehend simple information or perform routine operations. This very large, cross-national study also found a high variance in textbooks' cognitive demands across countries. Notably, countries that perform well on international science tests (e.g., Singapore) have textbooks that focus on a variety of cognitive skills rather than emphasising recall and comprehension. The higher the cognitive demands of textbook questions, the greater the likelihood that higher-order thinking skills are taught and practised by students in lessons (Pratama & Retnawati, 2018). Moreover, studies of mathematics textbooks have shown that students' scores on summative assessments can be positively influenced by using textbooks with more questions at higher cognitive levels (Hadar, 2017; Yang & Sianturi, 2017).

Overman et al.'s (2013) analysis of senior secondary chemistry textbooks suggests that the dominance of certain cognitive demands in textbook questions may be linked to the pedagogical philosophy of the curriculum the textbooks have been prepared for. For example, textbooks written for context-based chemistry curricula include more questions requiring metacognition, such as "choose in which order you will do these activities" (Overman et al., 2013, p. 2977), when compared to textbooks prepared for more traditional chemistry curricula. The reformed Queensland senior science syllabi advocate inquiry-based pedagogies (e.g., QCAA, 2018b), hence one would expect more textbook questions requiring knowledge utilisation, which includes investigation and experimenting skills. The analysed textbooks may provide limited stimuli for inquiry learning emphasised by the curriculum reform across the sciences. Furthermore, a focus on retrieval and comprehension may send a covert message to students that scientific knowledge is not open for exploration or investigation, which is contrary to how science is practised beyond school (Andersson-Bakken et al., 2020). A lack of sufficient questions addressing metacognition is also of concern, considering Hattie's (2008) synthesis of meta-analyses on factors influencing student achievement strongly supports the benefits of teaching metacognitive strategies like self-questioning (effect size: 0.69) or goal setting (effect size: 0.56).

Another possible explanation for these textbook analysis results is that retrieval and comprehension questions require shorter responses than analysis and knowledge utilisation questions. Therefore, textbook authors may have decided to include a greater quantity of retrieval and comprehension questions for students to spend a more equal amount of time practising each cognitive skill. However, familiarity with a cognitive skill gained by repetition, not time spent on a cognitive skill, improves a learner's execution of that skill (Marzano & Kendall, 2007; Sanz de Acedo Lizarraga et al., 2010).

When lower- and higher-order textbook questions are examined separately, further trends emerge. Questions with lower-order cognitive demand favour the retrieval of facts and information over the retrieval of processes. Similarly, linguistic responses using words are favoured over symbolic responses using diagrams, graphics, symbols, or images. These trends may disadvantage students with weak language skills or strong spatial and visual preferences, even though spatial thinking is a critically important skill for many careers in science (Grandin, 2022). Results also show that analytical skills are dominating questions with higher-order cognitive demand and that within those analytical skills, students are required to use deductive reasoning much more frequently than inductive reasoning. Deductive logic leads to responses that can be judged as true or false, whereas inductive reasoning results in students constructing probable or likely responses which may reveal new knowledge about the natural world (Henderson, 2018). Therefore, the examined senior science textbooks may signal to students that certainty is valued over probability and that doing science consists predominantly of drawing conclusions from existing theories rather than creating new theories. Dimopoulos and Karamanidou (2013) argue that a static and absolute presentation of knowledge is a common problem in science textbooks. Such a view might limit students' ability to make informed decisions when meeting real-world challenges that involve dynamic or controversial knowledge in the making (Taylor et al., 2023). Furthermore, using questions to solely assess correct answers tends to lower the cognitive demands of classroom discourse as opposed to using authentic questions with answers that invite discussion (Keong et al., 2016).

Finally, the almost complete lack of textbook questions addressing the self-system, which includes students examining their motivation, emotions, self-confidence, and the perceived importance of content, carries the risk that some students feel science is unrelated to their personal lives, values, or strengths. McDonald (2016) suggests that this might lead to a declining interest in science and lower participation in post-compulsory science education. By omitting self-system thinking tasks and strongly limiting metacognitive tasks, textbooks are also missing the opportunity to develop students' self-regulation skills (Marzano & Kendall, 2007). Such self-regulation skills would enable learners to educate themselves as their scientific knowledge develops, which is important for preparing scientifically informed citizens for the future. Therefore, an argument can be made that future editions of senior science textbooks should attend to metacognition and self-system thinking.

5.3.2. Differences Between Subject Areas

A greater difference in the cognitive demands of physics, chemistry, and biology textbooks was expected, considering the subjects are often perceived to vary strongly in content matter, popularity, and difficulty. In Queensland, the three sciences are scaled differently for university entrance scores, with chemistry usually contributing a higher weighting than biology because it is deemed harder to achieve an A in chemistry than in biology (QTAC, 2021). In terms of popularity, biology generally has much higher student enrolments than physics (QTAC, 2021). Despite these differences, the textbooks' cognitive demands for the three subjects are very similar with retrieval, comprehension, and analysis sharing a relatively equal representation, and knowledge utilisation, metacognition, and self-system thinking sharing a much lower representation. Out of the three sciences, physics places the strongest emphasis on analytical skills and biology places the strongest emphasis on knowledge utilisation.

5.4. Limitations and Recommendations

This textbook analysis examines the cognitive demands of a potentially implemented de facto curriculum, not the extent and nature of teachers' textbook usage. Depending on their experience and teaching style, teachers will modify and use the analysed textbook questions to a varying extent in their lessons. In addition to textbooks, teachers have extensive electronic resources for curriculum materials in Australia (McDonald, 2016). These resources were not examined. Furthermore, this study did not analyse question difficulty and the complexity of content knowledge, two factors that may also have a strong impact on students' learning, assessment performance, and affective engagement. Finally, the study focused on Year 12 textbooks and excluded Year 11 textbooks.

Textbook choice can impact student achievement (van den Ham & Heinze, 2018) and needs to be acknowledged as a relevant factor influencing learning outcomes. Innovative textbook design will consider whether the cognitive demands of learning tasks meet the subject's learning goals and values as well as the needs of students. The currently reported cognitive demands of science textbooks may result in students' narrow and inaccurate perceptions of the real nature of science. A study investigating students' opinions on their biology textbooks indicate dissatisfaction with the lack of problem-solving activities or real-life applications (Cimer & Coskun, 2018). Future textbook design would benefit from student-centred approaches and an increased focus on metacognition as well as students' beliefs and emotions.

The theoretical framework and the methodology used in this study can be applied by teachers to critically analyse the cognitive demands of their current textbook(s) or to compare textbooks of different publishers. To achieve this, educators need to learn how to recognise and classify questions at different cognitive levels. This skill has the additional benefit of enabling teachers to consider the cognitive demands of questions they create themselves. Therefore, teachers would be able to supplement their teaching with questions that are aligned with learning objectives and offset any limitations of the textbook questions. For instance, physics teachers may alter certain analysis textbook questions in a way that increases their cognitive demands and requires students to solve problems or make decisions.

A further implication of the results discussed in this chapter is that the adoption of a new textbook should be accompanied by an analysis of the textbook's implicit goals and pedagogical ideologies. McDonald (2016) has found that the dominant reason influencing teachers' textbook choice in Australian high schools was the layout, colour, and use of illustrations. It is of concern that the quality of content or the alignment with curriculum goals was not deemed as more important, especially since the same survey of Australian schools also identified a key use of textbooks to be the support of non-specialist teachers, beginning teachers, and substitute teachers. Good science teaching therefore depends on textbooks with content and questions that are well aligned with the cognitive demands of curriculum learning goals.

The challenge for current and future science educators is to critically select high-quality teaching resources in a time of continuously increasing choice of suitable textbooks and electronic information sources. Additionally, teachers need to decide whether it is appropriate to adopt unchanged textbook content or to recreate it based on the requirements of the prescribed curriculum. The challenge for textbook developers is to write textbooks that are well aligned with the cognitive demands and underlying teaching philosophies of the courses these textbooks are designed for, rather than following the current practice of designing textbooks that are stronger aligned with previous textbook editions than with curriculum learning objectives (Polikoff, 2015).

5.5. Conclusion

Many new science curricula emphasise students' development of higher-order thinking skills as important educational goals, to develop the skills necessary for students to be successful in the 21st century (Valverde et al., 2002). Yet, this is not always reflected in textbooks designed to support new curricula. This textbook analysis shows that textbook questions designed to support the implementation of the recent senior curriculum reform in Queensland have a higher proportion of lower-order thinking rather than higher-order thinking questions in physics, chemistry, and biology. Questions challenging students to engage in metacognition or self-system thinking are rare across all examined textbooks and questions addressing students' affective domain are not present. Furthermore, within questions addressing lower-order cognitive skills, the retrieval of information dominates over retrieval of processes, and questions requiring linguistic responses far exceed symbolic ones. In questions addressing higher-order cognitive skills, the practice of deductive reasoning is called upon far more often than the practice of inductive reasoning, and the opportunity for decision making exceeds problem solving or investigating.

Currently, senior science textbooks seem to lack content that can effectively engage students who will be faced with difficult science-based decision about global challenges in their lifetime. Thus, teachers are advised to critically analyse the cognitive demands of textbook questions before including them in their enacted curriculum. Textbook writers should aim for high alignment between the cognitive demands of textbook questions and the learning goals of legislated syllabi and courses the textbooks are intended for.

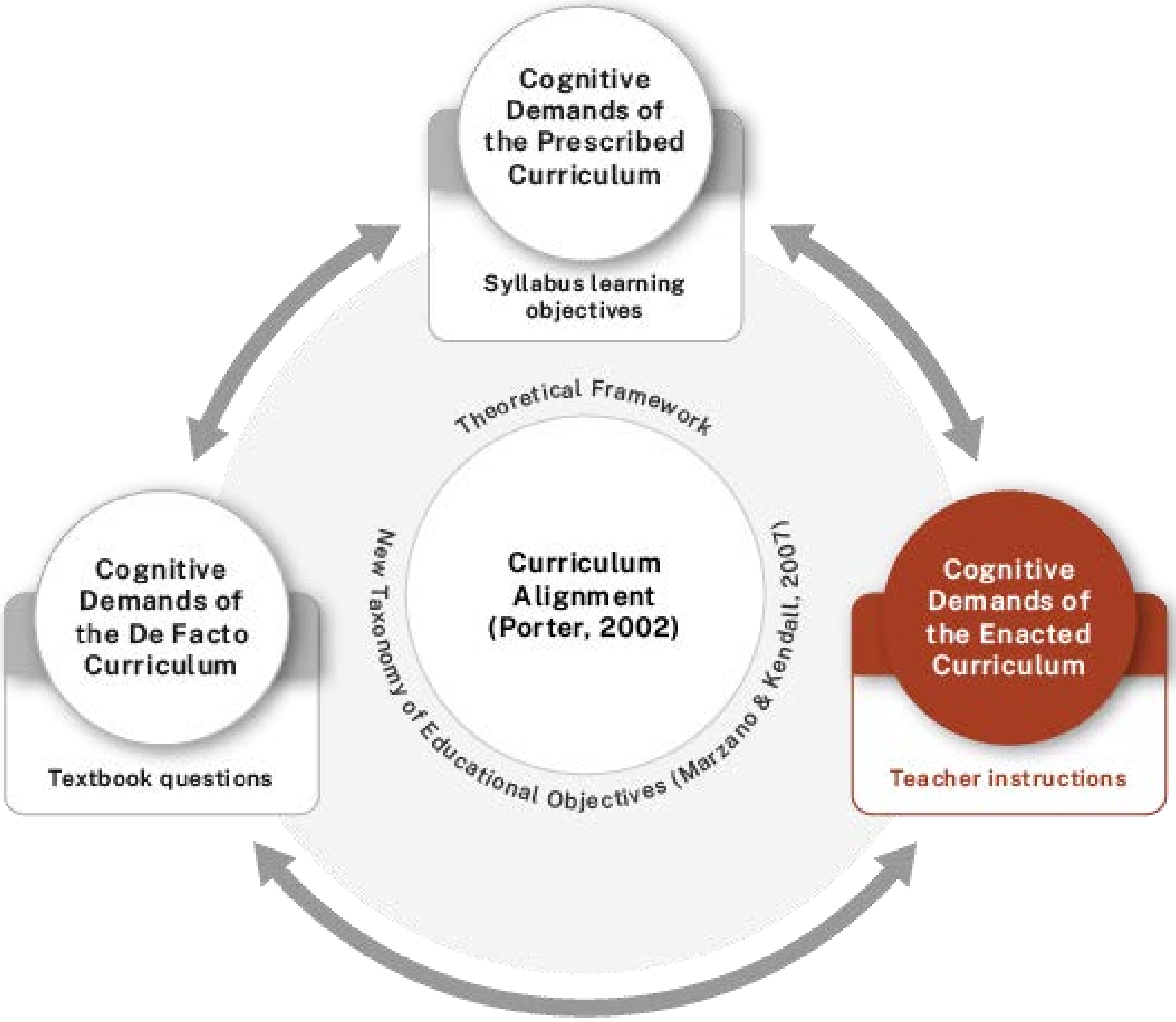
After establishing the cognitive demands of the prescribed and de facto Queensland senior science curricula, the next chapter analyses the cognitive demands of the curriculum enacted by teachers in the classroom. Studies of prescribed science curricula or science textbooks often conclude with the recommendation to extend and validate their research by collecting data on actual classroom learning (e.g., Overman et al., 2013). In line with these recommendations, data on the cognitive demands of classroom practice presented in the next chapter complete the analysis of the cognitive demands of syllabi and textbooks in Chapters 4 and 5, resulting in a more complete picture of Queensland's senior science curriculum.

Chapter 6. The Enacted Curriculum

A prescribed curriculum can never fully predict the curriculum occurring within the classroom. Classroom learning is constructed jointly by students and their teachers in the moment and it is influenced by a wide range of contextual factors (Remillard & Heck, 2014). This chapter reports on the cognitive demands of the enacted physics, chemistry, and biology curriculum in the first year of its state implementation in Year 11 and Year 12, as well as the instructional strategies teachers use to foster students' thinking (see Figure 6.1). It is the most significant analysis of this research project as the enacted curriculum has the strongest impact on students' learning and their engagement with science (Aubusson, 2011; Remillard & Heck, 2014). Following a summary of its rationale, this chapter reports on the proportion of lesson time senior science students were instructed to actively develop their cognitive skills. Then, the cognitive demands of teachers' instructional strategies are quantified and findings on teachers' predominant pedagogical choices are presented. The final discussion of results links relevant findings to Australia's goals for science education, such as the need to increase student engagement and participation in science.

Figure 6.1

Focus of Chapter 6—The Enacted Curriculum



6.1. Rationale

Past research on cognitive skills in enacted science curricula consistently indicates that the cognitive demands of teacher instructions or teacher questions are low (e.g., Eshach et al., 2014; Smart & Marshall, 2013). Several of these studies quantify this finding. For example, 80% of teacher questions in Israeli biology classes fostered lower-order thinking (Zohar et al., 1998), 84% of horticulture teacher instructions in the USA were classified as having low cognitive demands (Canon & Metzger, 1995), and US agriculture and science high school teachers spent 83–84% of their lesson time on instructions with low cognitive demand (Ulmer & Torres, 2007). These percentages are alarmingly high. Should a similar situation exist in Queensland's senior science classrooms, the recent curriculum reform could not be labelled as successful in its goal to equip students with a wide range of cognitive skills, nor to increase its focus on 21st Century Skills like problem solving and creativity. This study seized the unique opportunity to collect empirical data on the enactment of the reformed Queensland physics, chemistry, and biology syllabi at the very beginning of the reform's implementation.

Several aspects of classroom discourse, such as teacher questioning or student interactions, relate to students' use of cognitive skills (Smart & Marshall, 2013). Scholars argue that social constructivist teaching strategies, inquiry learning, and high-quality questioning effectively support the development of students' cognitive skills (Cian et al., 2018; Venville & Oliver, 2015). Opportunities for guided inquiry, although not explicitly prescribed by the reformed senior curriculum, feature frequently in the syllabi. However, there is no empirical data on the prevalence of inquiry or other pedagogical approaches in Queensland's science classrooms since the curriculum reform was implemented. As a result, this study also investigates instructional strategies commonly used by teachers.

The study's third research question and its sub-questions guided the data collection and analysis discussed in this chapter:

3. What are the cognitive demands of the enacted Queensland physics, chemistry, and biology curriculum?
    a. How many explicit opportunities do students have to actively practise cognitive skills during senior science lessons?
    b. What are the cognitive levels of teacher instructions during lessons?
    c. Which instructional strategies dominate the enacted senior science curriculum?

6.2. Results

The following results present the proportion of lesson time students were instructed to engage with cognitive skills before reporting the cognitive demands of the enacted curriculum across all three senior sciences and for each subject separately. Thereafter, predominant learning activities chosen by the teacher at each cognitive level are described.

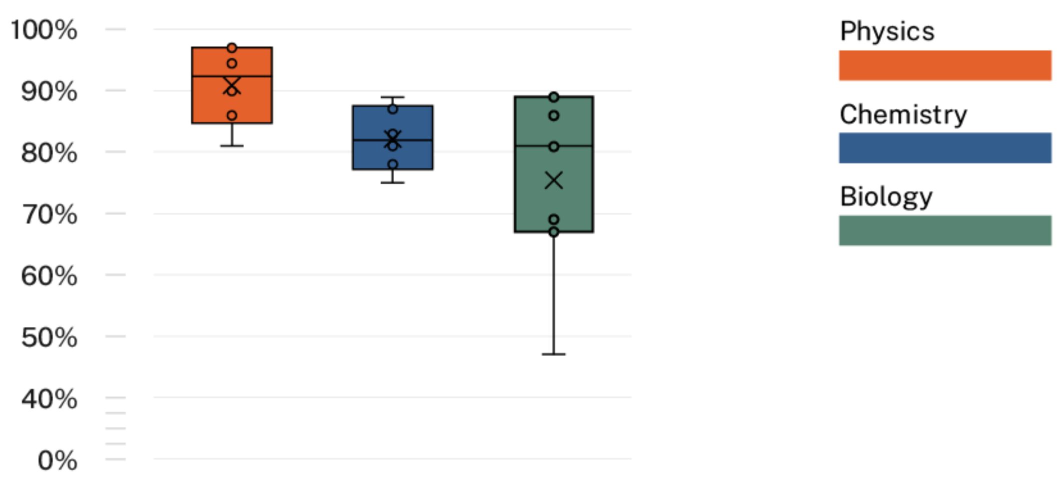
6.2.1. Opportunity to Practise Cognitive Skills

During the 82 lesson observations of 18 teachers working at seven different schools, 922 instances of teacher instructions that engage students in actively practising a cognitive skill were recorded. Specifically, 359 of these instructions occurred in physics lessons, 339 in chemistry lessons, and 224 in biology lessons. When teachers did not instruct students to practise any cognitive skill in a five-minute lesson interval, no observation was recorded. During such intervals, students were assumed to be passive learners and engaged in activities such as listening to teacher monologues (lectures), copying notes, or reading. Some students may have chosen to independently reflect on or integrate content knowledge without specific direction from their teacher. Thus, passive learning is not automatically a deficit, but it relies on students absorbing and assimilating knowledge presented by the teacher. The depth of students' learning during passive lesson intervals is unclear. Active learning, on the other hand, is characterised by students' participation in the instructional process through activities or dialogue; it requires students to think about, interact with and construct their knowledge based on the lesson's content matter (Chiappetta & Koballa, 2010), and it can lead to increased learning outcomes (Deslauriers et al., 2011).

This study's results suggest that active learning was emphasised across senior science lessons. Figure 6.2 shows that physics students were provided with opportunities to practise cognitive skills for more than 80% of the lesson time in all observed physics classrooms. On average, physics teachers engaged their students in some type of active thinking for 91% of their lesson time. Observed chemistry students were instructed to actively think on average 82% of their lesson time, with no chemistry teacher spending more than 25% of their lessons without tasking students to practise a cognitive skill. In comparison, biology teachers varied more in their use of lesson time. On average, biology students were active learners for 75% of their lessons, with some teachers not engaging their students with a thinking task or question for over 50% of the lesson. Data would suggest that physics students had the most opportunity to practise cognitive skills and therefore actively acquire knowledge and understanding through thought. However, the reported opportunities for cognitive skills development may be an overestimate. Observations of learning activities were recorded in five-minute intervals. If students were instructed to actively think at least once within these five minutes, the entire five-minute block was coded as active learning. This may require further research.

Figure 6.2

Opportunity to Practise Cognitive Skills as Proportion of Lesson Time



6.2.2. Cognitive Demands of Lessons

The percentage and absolute frequency of teacher instructions at each cognitive level of the New Taxonomy of Educational Objectives are shown in Table 6.1. Students were engaged most frequently in cognitive skills classified as retrieval (30%), followed by analysis-level cognitive skills

(21%) and metacognition (21%). Seventeen percent of observed teacher instructions were classified as comprehension and 10% as knowledge utilisation. Self-system thinking was rarely observed (1%). Therefore, the split between lower- and higher-order cognitive demands of teacher instructions in senior science lessons was close to half and half—47% and 53% respectively (see Figure 6.3). It is noteworthy that lower-order cognitive skills were dominated by retrieval rather than comprehension and that metacognition formed a significant component of the higher-order cognitive skills practised during lessons, despite the lack of explicit learning objectives addressing the metacognitive system in the syllabi.

The separate analyses of cognitive demands for Year 11 and Year 12 lessons did not suggest any notable change in cognitive demands as students progressed through the subject. This may be because, in terms of cognition, assessment objectives and tasks in Year 11 and Year 12 are identical. Teachers evaluate students' performance in Year 11 based on the same criteria as in Year 12 to provide students with opportunities to familiarise themselves with Year 12 expectations and to practise working at the right level of complexity. An analysis of the change in cognitive demands within each unit of content may have shown increased cognitive demand with time. Unfortunately, this study could not collect sufficient data on each enacted unit for such an analysis due to COVID-19-related school closures and online learning.

Table 6.1

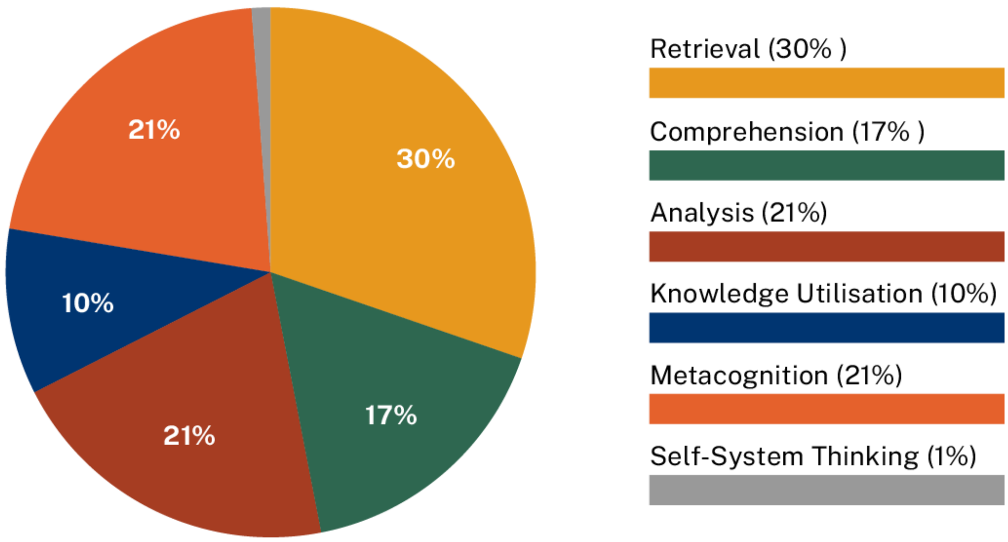
Cognitive Demands of Observed Lessons

Subject	Cognitive level					
	Retrieval	Comprehension	Analysis	Knowledge utilisation	Metacognition	Self-system thinking
Physics	26% (92)	10% (37)	25% (89)	11% (39)	27% (96)	2% (6)
Chemistry	35% (120)	18% (61)	23% (79)	6% (20)	17% (57)	<1% (2)
Biology	30% (75)	24% (60)	11% (27)	15% (37)	19% (48)	1% (3)
Total	30% (287)	17% (158)	21% (195)	10% (96)	21% (201)	1% (11)

Note. Percentages are rounded to whole numbers and absolute frequencies are stated in brackets.

Figure 6.3

Cognitive Demands of Observed Lessons Across All Subjects



Note. Percentages are rounded to whole numbers.

As explained in the previous chapter, each category of thinking in the New Taxonomy is comprised of several mental processes. For example, retrieval includes recalling information, recognising information, and correctly executing a mental or psychomotor procedure (Marzano & Kendall, 2007). Figure 6.4 shows the absolute frequencies of each observed mental process within each category of thinking, while Table 6.2 states sample teacher instructions observed at each cognitive level.

Figure 6.4

Frequency of Teacher Instruction at Each Cognitive Level

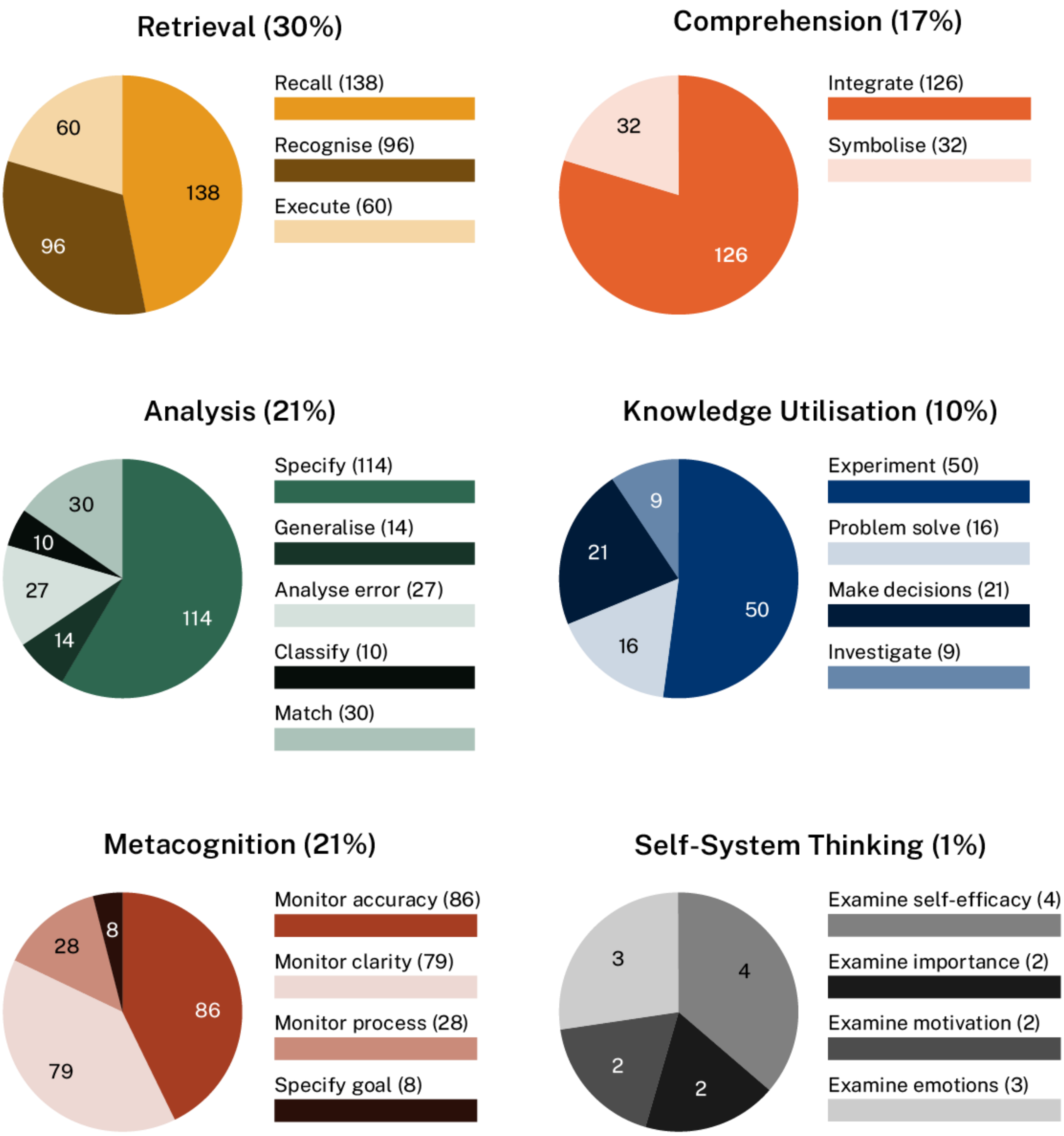


Table 6.2

Examples of Teacher Instructions at Each Cognitive Level

Cognitive level	Mental process	Sample of teacher instructions
Retrieval	Execute (60)	After a demonstration: Calculate the magnification on your microscope and add it to your diagram.
	Recall (138)	Worksheet task: Name each organic compound and circle its functional group.
	Recognise (96)	This is a diagram of a covalent bond. True or false?
Comprehension	Symbolise (32)	On your whiteboards, draw a diagram of the nitrogen cycle using all keywords on this slide.
	Integrate (126)	Lesson starter question on the board: Explain how the volume of the bubbles exhausted by a scuba diver change as they rise to the surface, assuming that they remain intact.
Analysis	Specify (114)	An equation for the production of ethanol from glucose is projected on the board. Students are asked to determine the number of moles of ethanol produced per mole of glucose.
	Generalise (14)	What do all the examples on the board have in common?
	Analyse error (27)	Raise your hand if you can see the mistake in the working.
	Classify (10)	Sort your cards into two stacks: mitosis and meiosis. (Cards have statements or diagrams on cell division.)
	Match (30)	Worksheet task: Complete a Venn diagram for passive vs. active immunity.
Knowledge utilisation	Investigate (9)	Internet research task: Make a list of evidence that supports the Big Bang Theory and find out if it is scientifically unchallenged.
	Experiment (50)	A simulation of Young's Double Slit Experiment is projected: Write down how you think the interference pattern will change if I increase the wavelength to 600 nm … Let's check.
	Problem solve (16)	After students have identified sources of error in their experiment: Let's come up with strategies to reduce or eliminate these errors (brainstorm on board).
	Make decisions (21)	Go to the right if you think GMO foods have negative health implications and to the left if you think they don't. Be ready to defend your choice.
Metacognition	Monitor accuracy (86)	Assign marks to your responses as we go through the answers.
	Monitor clarity (79)	Final question on a digital learning platform task: Write down one question you still have about patterns in the Periodic Table.
	Monitor process (28)	Teacher-led discussion about the advantages and disadvantages of choosing each available practical for the student experiment assessment.
	Specify goal (8)	After the return of a practice examination: Reflect on your mistakes and complete the *Areas to Work On* section at the bottom of the page.
Self-system thinking	Examine motivation (2)	Ask yourselves honestly, how much are you applying yourself?
	Examine emotions (3)	How do we feel about the data test?
	Examine self-efficacy (4)	Give me a show of thumbs if your result is better or worse than you anticipated.
	Examine importance (2)	Why did you choose to study physics? (Directed at the entire class.)

Note. Total observed frequencies are in brackets.

When students engaged in retrieval during observed lessons, they were asked to recall or recognise information more frequently than to execute a procedure. Similarly to textbook questions analysed in this study, lesson tasks prioritised information over processes. For example, students had to remember facts or choose correct definitions more frequently than they had to follow predetermined steps to complete an algorithm or use a dichotomous key.

Comprehension lesson tasks prioritised the integration of knowledge through summaries or explanations over symbolic representation of knowledge through diagrams or graphic organisers. Thus, students were provided with more opportunities to practise linguistic skills than non-linguistic skills. These results also mirror the results of the textbook question analysis (see Section 5.2.2.).

More than half of all analytical skills practised during observed lessons required students to specify knowledge by determining an application or a consequence of given information. Students had to use deductive reasoning to draw specific conclusions from presented data or apply their knowledge of general scientific principles to answer questions about context-dependent case studies. Inductive reasoning in the form of generalisations, classification, or recognition of differences and similarities was observed less frequently, as was error analysis. Again, the lesson observation results match the textbook analysis results, hinting at the influence of textbook questions on the enacted curriculum.

Knowledge utilisation is the first cognitive level for which the enacted curriculum results differ from the textbook analysis results. Half of all lesson tasks classified as knowledge utilisation required students to apply their knowledge in the form of a scientific experiment, including the modification of the design and the evaluation of the experiment. All observed scientific experiments were either mandatory or suggested practicals explicitly outlined in the subject's syllabus. Often, practical work was used to illustrate already taught scientific principles rather than for new knowledge construction. Decision making, the most common process within knowledge utilisation textbook questions, was observed less frequently, as was problem solving and investigating.

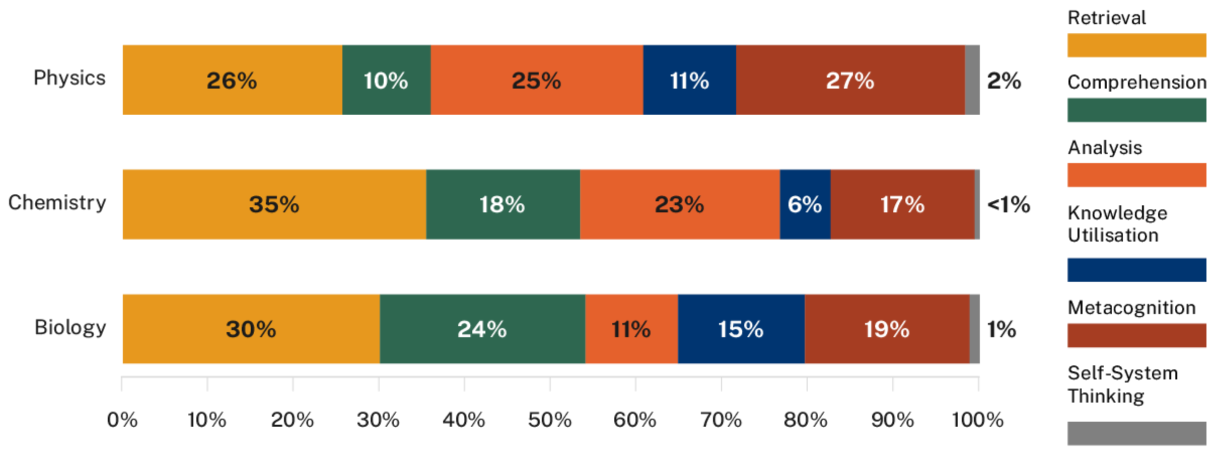
Metacognitive lesson tasks mostly asked students to monitor the accuracy and clarity of their responses, for example, by self- or peer-marking responses, by reflecting on common misconceptions, or by evaluating the extent to which they have achieved the lesson objectives. Tasks requiring students to set goals for their learning or monitor their learning process were rare.

Across all 82 lessons, only eleven instances of students engaging in self-system thinking were observed. These instances included students being instructed to examine their motivation to engage in learning for the subject, to reflect on their emotions when learning subject content matter, to verbalise their perceived self-efficacy, or to examine how important learned knowledge is to their personal needs and goals.

Results indicating the cognitive demands of teacher instructions for each separate subject show limited deviation from the results of the combined analysis (see Figure 6.5). Physics teacher instructions placed a noticeably high emphasis on higher-order cognitive skills (65%), mostly due to a strong emphasis on metacognition (27%) and analysis (25%). Knowledge utilisation tasks were less common (11%). Teacher instructions with lower-order cognitive demand in physics lessons were dominated by retrieval (26%) and there was much less emphasis on comprehension (10%). Chemistry teachers emphasised the practice of retrieval (35%), followed by analysis (23%). Comprehension and metacognitive tasks were set less frequently (18% and 17% respectively), while knowledge utilisation tasks were observed only 6% of the time. Overall, the cognitive demands of chemistry lessons were classified as lower-order 53% of the time. Observed biology lessons also placed the most emphasis on the two lower-order cognitive skills: retrieval (30%) and comprehension (24%). Thus students were engaged in lower-order thinking 54% of the time. Higher-order cognitive tasks in biology were predominantly classified as metacognition (19%) or knowledge utilisation (15%), with fewer instances of analysis tasks (11%). In all three subjects, students rarely practised self-system thinking (<1–2%).

Figure 6.5

Cognitive Demands of Observed Lessons in Each Subject

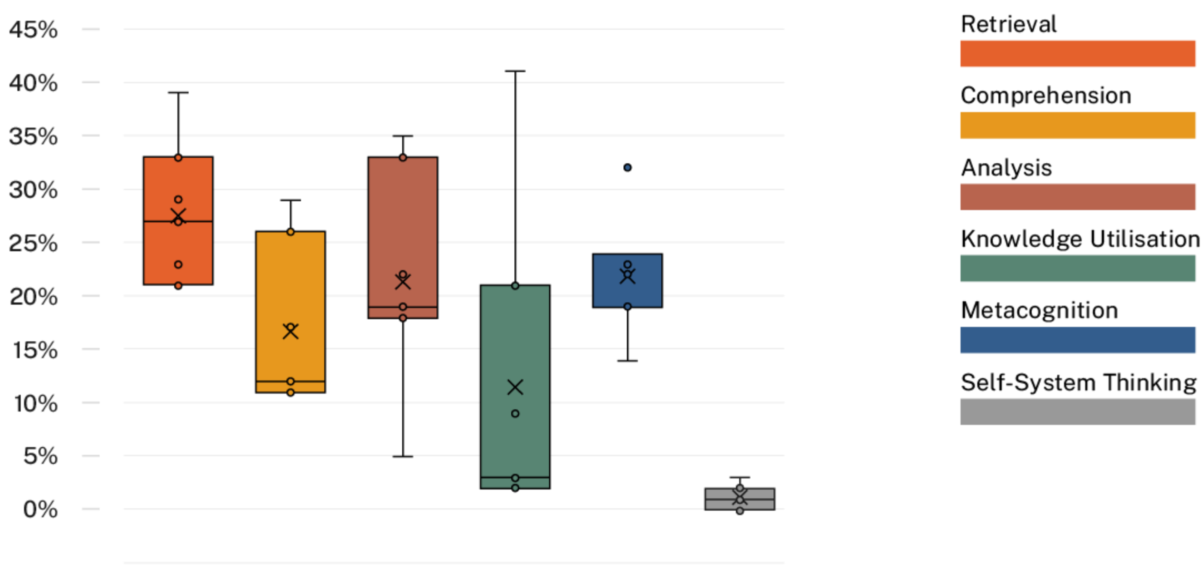


Note. Percentages are rounded to whole numbers.

While this study did not aim to investigate the difference in cognitive demands of lessons at different schools, a brief analysis was conducted to triangulate data. The objective of this analysis was the comparison of data from different research sites to judge the influence of local context on conclusions (see Section 3.4.3.). Results show a surprisingly high variance in the cognitive demands of the enacted curriculum at the seven sampled schools (see Figure 6.6). Particularly, the proportion of observed teacher instructions classified as retrieval, comprehension, analysis, and knowledge utilisation varied strongly between schools—often by more than 15%. The greatest variance between schools was observed in the proportion of knowledge utilisation tasks within the enacted curriculum. These findings are not discussed in this study as they exceed the scope of its research questions, but they are worth noting for future research. They support the notion that despite a state-wide and standardised prescribed curriculum, schools' local contexts—such as student socio-economic backgrounds, student abilities, school leadership, teachers' professional development opportunities, and teaching resources—have a strong impact on the enacted curriculum. Thus, sampling across seven schools with contrasting characteristics (e.g., ICSEA scores, enrolment numbers, and education providers) resulted in a case study that represents the diversity of Far North Queensland's enacted senior science curriculum.

Figure 6.6

Variance of Teacher Instructions at Each Cognitive Level Between Schools



6.2.3. Predominant Instructional Strategies

Teacher instructions with the same cognitive demand were repeatedly observed in conjunction with similar learning activities. The most frequently observed learning activities at each cognitive level across all three subjects are described in this section. Figure 6.7 shows what proportion of learning activities at each cognitive level required students to work individually and collaboratively.

Students were most frequently instructed to practise retrieval in response to their teacher's spoken questioning and written practice questions. For example, while displaying a slide explaining the burning of hydrocarbons, one teacher asked, “What gas is needed to create a combustion reaction?” and waited for students to raise their hands. Alternatively, teachers wrote or projected retrieval questions on the board or instructed students to answer retrieval questions from the textbook or on a worksheet in writing. Most retrieval questions had to be answered individually. Students practised retrieval only 2% of the time during collaborative work, but 28% of the time during individual work.

Similar to retrieval, students’ comprehension practice most frequently took the form of answering spoken or written questions set by the teacher or the textbook. In addition, students were often instructed to practise comprehension by summarising or paraphrasing knowledge they had either heard or read in writing. For example, one teacher showed a brief video explaining DNA transcription and translation and then gave students a few minutes to summarise each process in their notebooks. Again, students’ individual practice of comprehension was observed more often than collaborative practice (16% and 1% respectively).

Despite increased complexity, analysis was also practised predominantly by answering questions. As opposed to retrieval and comprehension questions, analysis questions were less frequently asked orally by the teacher. Instead, the questions were often displayed visually by projecting or writing them on the board, or by asking students to read questions on a worksheet or from the textbook. Critiquing a model response, an exemplar presented by the teacher, or a peer’s response was another frequently observed learning activity that challenged students to use analytical skills. For example, one teacher projected a worked example of a projectile motion calculation and asked students to identify an error in the working. The collaborative practice of analysis was observed less often (2%) than individual practice (19%).

Students' practice of knowledge utilisation was more diverse than the practice of any other cognitive skills category. Frequently observed learning activities in this category included designing or modifying the methodology of scientific experiments, collecting and processing data through real or digitally simulated experiments, online research tasks, small group or one-on-one dialogue with the teacher, and responding to spoken and written questions asked by the teacher or sourced from the textbook or a worksheet. For example, one teacher projected an interactive simulation of Young's (1804) Double Slit Experiment on the whiteboard and asked students to predict and test how changing certain variables in the simulation (e.g., the distance between the slits) affects other measured variables. Notably, most learning activities fostering knowledge utilisation were completed collaboratively (7%) rather than individually (3%). On several occasions, responding to textbook questions turned from an individual to a collaborative learning activity with permission or explicit direction from the teacher when students encountered a knowledge utilisation question.

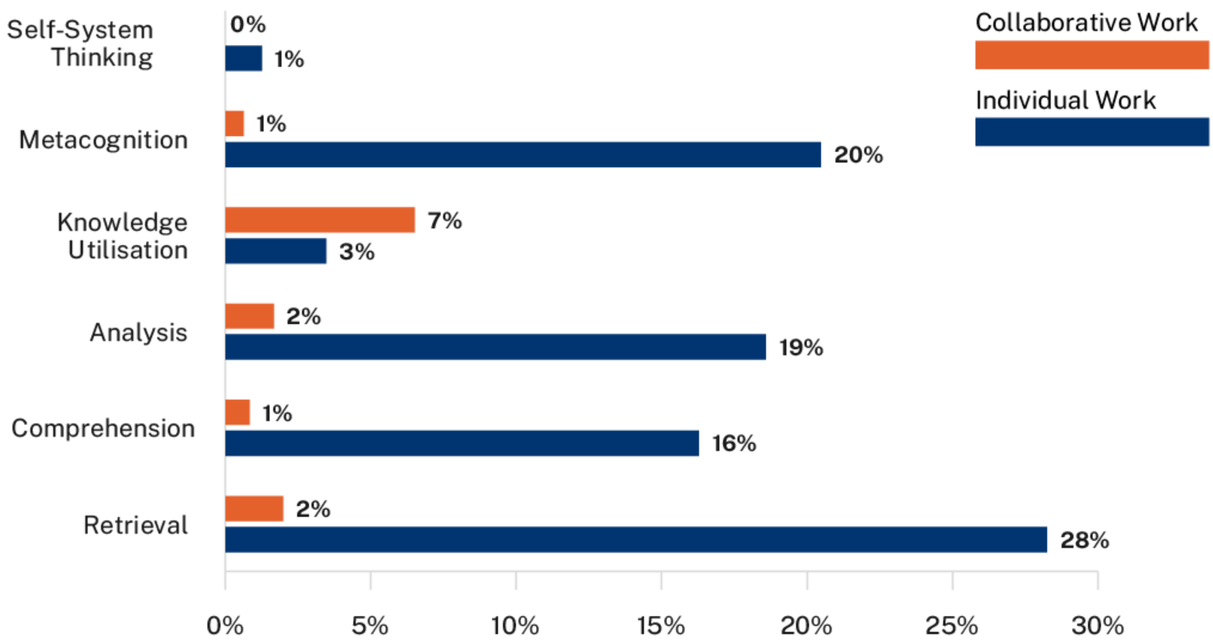
Metacognition was also stimulated by a diverse range of learning activities. Most commonly, students were asked to self-mark their work by comparing it to exemplars, by marking against criteria or by responding to reflective teacher questions. As opposed to teacher questions in other categories, responses to metacognitive questions were occasionally answered using physical movement, such as pointing, moving to a certain area of the room, showing a thumbs up or down, nodding or shaking the head, or contributing to the teacher whiteboard. Students were also encouraged to formulate their own questions, specify individualised goals for their study, and share their learning strategy or process for solving a specific problem. The observed teachers rarely used concept maps or graphic organisers to stimulate metacognition, even though such visual tools have been used frequently for metacognitive classroom instructions in science education (Zohar & Barzilai, 2013). Tasks stimulating metacognition were usually set as individual work (20%) rather than collaborative work (1%). They were also often individualised (i.e., given to specific students during one-on-one teacher check-ins). For example, one teacher had a series of one-on-one conversations with several students, asking them to describe their weekly revision strategies for the subject.

Learning activities that stimulate self-system thinking were rarely observed (1%) and never collaborative. They involved teachers' spoken questioning with no expectation of students sharing their responses with the class, and teachers' spoken questioning of individual students during one-on-one check-ins. For example, after returning the results of students' latest summative assessment, one teacher asked students to indicate with their thumb how they felt about their result (i.e., how satisfied they were), then the teacher asked students to privately reflect on why they chose to study physics and why they are interested in the content matter.

There were no notable differences in the range of instructional strategies observed between physics, chemistry, and biology. Such findings may indicate that teachers' subject areas did not influence their choice of learning activities at each cognitive level in this study. Further research is needed to investigate if instructional strategies would differ between teachers from different departments or teachers who are teaching subjects with different summative assessment.

Figure 6.7

Proportion of Individual and Collaborative Learning at Each Cognitive Level

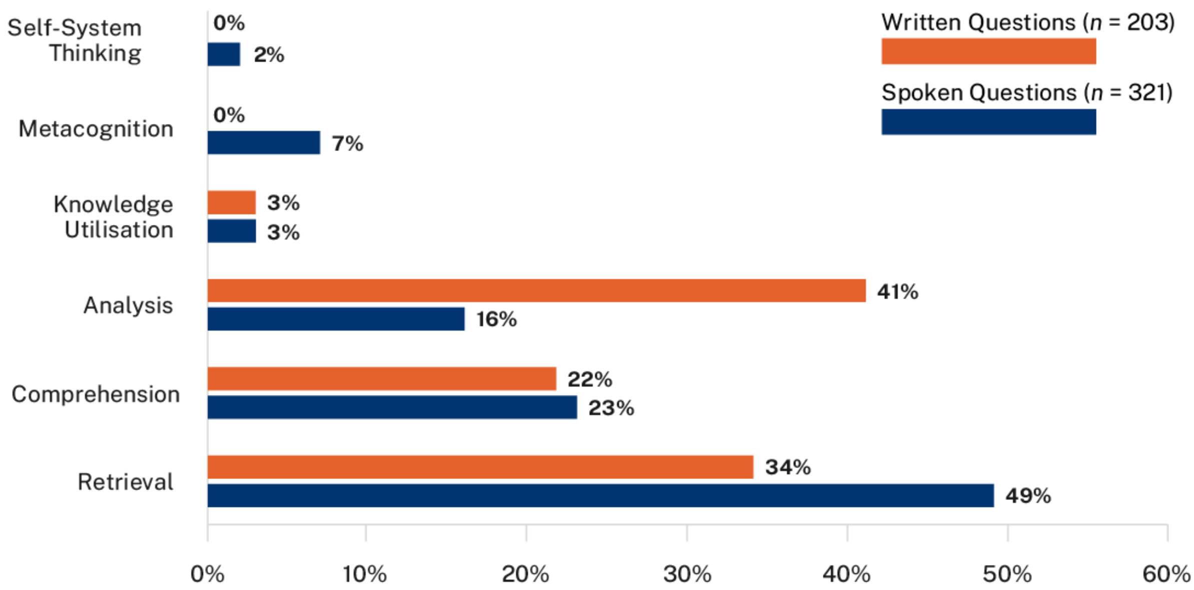


Note. Percentages are rounded to whole numbers.

Since teacher questioning was the most prevalent teaching strategy at each cognitive level, teachers' spoken and written questions were analysed further. Figure 6.8 shows the proportion of spoken and written teacher questions targeting each cognitive level. Results indicate that spoken questions were predominantly lower-order thinking and classified as retrieval (49%) or comprehension (23%). Spoken higher-order thinking questions were mostly classified as analysis (16%) or metacognition (7%), with rare incidences of spoken questions fostering knowledge utilisation (3%) or self-system thinking (2%). Pre-prepared written questions on worksheets, teacher presentations or selected textbook questions were mostly classified as analysis (41%), followed by retrieval (34%) and comprehension (22%). Only 3% of written questions were classified as knowledge utilisation and no written questions fostering metacognition or self-system thinking were observed.

Figure 6.8

Cognitive Demands of Teacher Questions



Note. Percentages calculated out of total observed spoken questions (n = 321) and total observed written practice questions (n = 203). They are rounded to whole numbers.

6.3. Discussion

6.3.1. Active Learning With Balanced Cognitive Demands

Queensland's reformed senior syllabi emphasise the importance of purposefully and actively involving students in a variety of thinking processes (QCAA, 2021). At the same time, the introduction of high-stakes external examinations in senior science subjects and the large scope of content matter carries the danger of an increased emphasis on passive knowledge transmission and reductive teaching (Aubusson, 2011; Krüger et al., 2013). However, results of 82 lesson observations across three senior sciences show that senior science students were actively engaged in tasks that develop their cognitive skills for more than 75% of their lesson time, with the exception of some biology lessons. Tomas et al.'s (2022) in-depth case study of one Queensland senior science teacher implementing the reformed curriculum indicates a consistent and explicit focus on cognitive skills in lessons, with particular focus on students' understanding of cognitive verbs in assessment tasks and syllabus objectives. This study's results also indicate that students are provided with adequate lesson time to actively develop cognitive skills.

Furthermore, results suggest the presence of well-balanced cognitive demands in the enacted senior science curriculum. The cognitive demands of teacher instructions were classified as 47% lower order (retrieval or comprehension) and 53% higher order (analysis, knowledge utilisation, metacognition, or self-system thinking). Australian and international literature regarding the cognitive demands of the enacted curriculum suggests a majority of class time in science and mathematics is spent on lower-order thinking (e.g., El Hassan & Baassiri, 2019; Ulmer, 2005; Ziebell & Clarke, 2018). Hence this study's nearly equivalent proportions of lower- to higher-order thinking skills in the enacted curriculum is an unexpected positive result.

A second positive result is that metacognitive tasks formed a relatively high proportion of teachers' higher-order instructions. Metacognition is not formally assessed or explicitly addressed in the syllabus learning objectives of the reformed senior science syllabi, yet the omission in the prescribed curriculum does not reduce its importance. Self-regulation through metacognition, such as goal setting or reflecting on the learning process, has fostered cognitive development (Higgins et al., 2005; McEwen et al., 2001; Venville & Oliver, 2015) and reliably increased student learning in thousands of studies worldwide (Victoria State Government Department of Education and Training, 2017). The senior science teachers observed in this study recognised the significance of metacognition for student learning outcomes and created space for its development.

Overall, the observed teachers facilitated learning activities with a balance of lower- and higher-order cognitive demand, and they stimulated metacognition regularly. It is possible that teachers who participated in this study during the first year of the new syllabus implementation are more confident, motivated, and possibly more skilled than a random sample of teachers would have been. School leaders are also more likely to assign capable staff to the task of implementing the new curriculum and preparing students for the first instalment of external examinations. Teachers with high efficacy and high subject content knowledge may be more comfortable with the open-ended and often unpredictable nature of higher-order cognitive tasks (Smart & Marshall, 2013). As the analysis of teacher demographics indicates (see Table 3.2), all teachers but one were teaching within their subject area of expertise. Further, the modal teaching experience was 10 to 20 years and most teachers had a science bachelor's or master's degree. Teachers' experience and education may also have contributed significantly to the relatively strong focus on higher-order thinking skills in observed lessons.

6.3.2. Low Emphasis on Inquiry, Interdisciplinary Problem Solving, and Student Engagement

Despite the balanced cognitive demands in the enacted curriculum, it is problematic that only 10% of observed teacher instructions were classified as knowledge utilisation. This category includes problem solving, decision making, investigating, and experimenting—skills that are arguably fundamental for inquiry-learning (Chiappetta & Koballa, 2010). Inquiry-based learning and real-world problem solving are part of the Australian Government's National School Education Strategy (Education Council, 2015) and a wide range of studies has shown the benefits of inquiry-based teaching strategies for students' learning outcomes (Minner et al., 2010). Clearly, the observed low proportion of knowledge utilisation tasks in the enacted senior science curriculum is not optimal. Figure 6.4 shows that most observed knowledge utilisation tasks required students to apply their knowledge during scientific experiments, all of which were practicals explicitly suggested in the syllabus. Teachers seem to have restricted inquiry-learning tasks to activities that are mandated by the prescribed curriculum and are relevant to assessment pieces.

Possible reasons for these findings are multifaceted. Knowledge utilisation tasks often require more lesson time than teaching approaches that aim to transmit knowledge. Thus, knowledge utilisation tasks may be omitted by teachers who are pressured by the scope of externally assessed subject matter in the reformed syllabi (Krüger et al., 2013; Zohar et al., 2001). Alternatively, the high variance in cognitive demands of lessons in different schools (see Figure 6.6) indicates that contextual factors may limit teachers' choice to implement knowledge utilisation tasks. For example, school leaders, parents, and students may have reduced the frequency of knowledge utilisation tasks in enacted curricula by demanding traditional or transmission-based pedagogies (Zohar et al., 2001). Furthermore, Sherriff (2019) showed how the physical and social classroom environment, student demographics and students' prior knowledge affect opportunities to engage with higher-order thinking in science lessons. Particularly, a class with a large proportion of academically struggling students may result in teachers avoiding or reducing the number of tasks with higher cognitive demands (Zohar et al., 2001).

To problematise the use of observed higher-order thinking tasks further, it seems that the nature of those tasks may foster students' compartmentalisation of knowledge by subject. For example, observed knowledge utilisation tasks were exclusively teacher-led and highly structured with a predetermined research question and an envisioned outcome. While research positions teacher-led inquiry as having a larger effect on learning than student-led inquiry (Furtak et al., 2012), observations in this study suggest that such highly structured and inflexible practicals often result in students attempting to match recently learned subject content knowledge with obtained results. Students did not use their understanding of scientific principles to create new insights or integrate knowledge from various fields to solve real-world problems. In other words, observed lessons may limit the Australian Government's goal for STEM education to implement an effective transdisciplinary curriculum that builds learners' interest (Education Council, 2015). Moreover, the most frequently observed higher-order thinking activities were analysis tasks requiring students to use deductive reasoning to specify applications or consequences (see Figure 6.4). As opposed to inductive analysis, deductive analysis tends to encourage applications of established scientific principles within a field rather than uniting various fields of study under an overarching new principle. Therefore, findings from the lesson observations suggest that students are mostly instructed to develop compartmentalised subject-specific knowledge, which is not easily utilised in new contexts with unfamiliar circumstances. However, current issues, such as anthropogenic climate change or sustainability, need scientists who integrate knowledge from a range of fields to find practical solutions. This may prove more engaging for students, as subject matter can seem irrelevant and boring if it is rarely applied to current issues (Danaia et al., 2013).

The perceived relevance of subject matter may be further reduced by the lack of learning activities addressing self-system thinking. Only 1% of observed teacher instructions in 82 lessons required students to examine their motivation, emotions, self-efficacy, or the importance of the knowledge they are learning. This result seems to be at odds with the Australian Government's goals to nurture students' curiosity towards STEM and increase participation in senior secondary STEM subjects (Education Council, 2015). Ideally, the enacted science curriculum addresses students' experiences, perspectives, and concerns (Goodrum & Rennie, 2007; Tytler, 2009) and includes emotional thinking (McBain et al., 2020). However, the teachers observed in this study did not instruct students to reflect on such matters, despite research showing that many Australian high school students do not find science interesting or relevant to their lives (Danaia et al., 2013; Lyons, 2006) and that a perceived lack of usefulness is contributing to lower enrolments in science (Kennedy et al., 2014). This finding aligns with the trend of minimising instructional time on personal values and emotional awareness in standard-based educational systems (Kereluik et al., 2013). The problem is that impactful science cannot be isolated from contemporary societal issues, subjective value perceptions, and human emotion, as is evident by the anti-vaccination movement that emerged during the COVID-19 pandemic.

The nature of lower-order teacher instructions may further contribute to reduced student engagement. Observed teacher instructions with lower-order cognitive demands were dominated by retrieval rather than comprehension. Retrieval implies that there is no expectation for students to have an in-depth grasp of learned knowledge or to identify the key characteristics of memorised information (Marzano & Kendall, 2007). For example, retrieval is akin to a student’s ability to recall relevant and irrelevant facts from a story, while comprehension requires an understanding of the storyline. A high frequency of retrieval learning activities may indicate that curriculum breadth is prioritised over depth. Highly prescriptive learning objectives, such as those found in the reformed syllabi, improve the uniformity of education across the state, but may sacrifice conceptual depth that makes content more meaningful for students (Goodrum & Rennie, 2007). This proposition is supported by a study measuring the performance of US university science students, which found that students who covered at least one topic in depth at high school earned higher grades at university than students who did not, while students who experienced a greater breadth of content matter in high school did not outperform students who did not experience the same breadth of content (Schwartz et al., 2009). Curriculum depth has also been associated with positive achievement in TIMMS physics tests (Murdock, 2008). A greater balance of retrieval and comprehension learning activities is therefore desirable in the enacted Queensland senior science curriculum.

When examining the cognitive demands of the enacted curriculum for each subject separately, the identified trends are sustained. In all three subjects, knowledge utilisation learning activities formed a small proportion of higher-order thinking tasks, activities fostering self-system thinking were rare, and retrieval was observed more often than comprehension. There are two exceptions: biology lessons seem to have a greater balance between knowledge utilisation and analysis tasks, and in physics, almost two thirds of all observed teacher instructions were classified as higher order. On average, physics students also had the most opportunity to practise cognitive skills during lessons. Based on enrolments across Queensland, biology is the most popular senior science (QTAC, 2021) and Australian students report intrinsic reasons (e.g., interest) for choosing to study biology (Fullarton et al., 2003). More frequent opportunities to apply learned content knowledge to relevant and possibly concrete tasks, and a less decontextualised analysis of data may be contributing factors. Physics, on the other hand, is often perceived as a challenging science—even by high-achieving students (Lyons, 2006). This may be a result of intrinsic higher cognitive demands of the physics curriculum (Ekici, 2016) or increased willingness of physics teachers to focus on complex higher-order thinking. Alternatively, some scholars argue that types of knowledge are linked to certain cognitive demands (Larsen et al., 2022). For instance, the physics syllabus contains a high proportion of procedural knowledge, which lends itself more to teaching at an analysis level than factual knowledge.

6.3.3. Lack of Diversity in Instructional Strategies

Findings on predominant instructional strategies show a lack of diversity. Except for knowledge utilisation tasks, students were instructed to practise cognitive skills almost exclusively through individual work and usually by answering teacher or textbook questions verbally or in writing. Arguably, such a classroom experience may not meet Australia's Strategic Plan for STEM school education which envisions "pedagogical approaches that build student interest" (Education Council, 2015, p. 5). Lyons's (2006) interviews of high-achieving Australian Year 10 students confirm that many students perceive science as boring and teacher centered by nature. Answering questions independently simulates how students must demonstrate their knowledge in the examination. However, the prevalence of this instructional strategy at the expense of other pedagogical approaches is problematic. Vygotsky's (1978) Social Constructivist Theory argues that social interaction plays a fundamental role in the development of students' cognitive skills and facilitates intentional learning. Empirical studies have since repeatedly demonstrated that collaborative work, cooperative learning, dialogue with peers, and similar socially mediated learning activities enhance students' cognitive development (Coll et al., 2005; Gillies & Nichols, 2015; McGuiness, 1999). Burke and Williams (2008) specifically compared the effectiveness of a thinking skills intervention implemented as individual versus collaborative learning. These researchers found that the intervention's collaborative learning condition led to a greater increase in student performance. The QCAA's (2020b) online professional development resource for teachers' effective assessment preparation also lists collaborative learning as an instructional strategy that maximises students' learning, as does Marzano et al.'s (2000) research synthesis on effective classroom strategies. In short, a more diverse and collaborative practice of retrieval, comprehension, analysis, metacognition, and self-system thinking skills may benefit the engagement and achievement of Queensland's senior science students.

Learning activities requiring knowledge utilisation showed a much greater diversity of instructional strategies. Knowledge utilisation was also the only cognitive skills category that was practised more often through collaborative work than individual work. This is expected as some scholars argue that certain higher-order knowledge utilisation tasks cannot be fully achieved individually (Ikuenobe, 2002; Vygotsky, 1978). However, knowledge utilisation tasks constitute only 10% of all observed teacher instructions, meaning that diverse collaborative learning activities were the exception rather than the rule in the enacted senior science curriculum.

It is noteworthy that certain teaching strategies that are praised as highly effective in developing cognitive skills in the literature were rarely part of the enacted curriculum. For example, research has shown that class discussions can be highly effective in promoting higher-order thinking (Baideme et al., 2014; Marsh, 2010). In this study, class discussions were almost never observed. Instead, classroom discourse was limited to student-teacher dialogue. Furthermore, classroom research has demonstrated that modelling (e.g., thinking aloud by the teacher) is particularly effective in teaching thinking (Beyer, 2008; Fairbrother, 2000). QCAA's (2021) professional development module on cognitive verbs also recommends explicit modelling to support students' mastery of cognitive skills. However, modelling of cognitive skills was also rarely observed (4% of recorded observations); observed instances almost exclusively modelled analysis tasks in form of worked examples. Thirdly, Marzano et al. (2000) argue that effective instructions reinforce knowledge through the frequent use of non-linguistic representations. Teachers in this study focused heavily on linguistic information and student responses. Certain other instructional strategies recommended by the QCAA (2020b) in professional development modules (e.g., peer instruction, journaling, or use of graphic organisers) were never observed, possibly due to time constraints or teachers' lack of experience with these pedagogies. Similar to Victorian schools, the isolation of secondary science teachers from pedagogical discussion with colleagues or teacher educators may be a major issue in Queensland schools (Tytler, 2009).

6.3.4. The Importance of Teacher Questions for Cognitive Skills Development

Questioning was the only instructional strategy frequently observed to foster thinking at every cognitive level of the New Taxonomy. Different types of questions asked by the teacher can stimulate different kinds of thinking in students (Marsh, 2010). For example, closed questions used as comprehension checks generally promote lower-order cognitive skills, while open-ended questions or referential questions can promote higher-order cognitive skills (Oliveira, 2010). Non-evaluative follow-up questions that reformulate students' answers to previous questions and prompt students to elaborate further or justify their reasoning can also increase the cognitive demands of classroom discourse (Keong et al., 2016).

Unsurprisingly, high-quality teacher questioning has been identified as a very reliable teaching strategy for raising learning outcomes by a wealth of international research (Victoria State Government Department of Education and Training, 2017). When science teachers across Prep to Year 12 were asked why their questioning was important, the development of thinking skills was listed as one of four reasons (Eshach et al., 2014). Unfortunately, senior high school teachers did not include the development of their students' thinking skills in their list of reasons and instead preferred to use questions as a means to evaluate knowledge and increase student engagement. These study results highlight the importance of teachers being more consciously aware of how their questions influence students' cognitive skills development.

The analysis of questioning observed in the enacted curriculum shows a distinction between the cognitive level of teachers' spoken and written questions. 72% of teachers' spoken questions were classified as lower-order, while written questions displayed during teachers' presentations, on worksheets, or selected from the textbooks were mostly classified as analysis, followed by retrieval and comprehension. This reiterates international classroom research showing that the frequency of spoken higher-order thinking questions in science lessons is low (Eshach et al., 2014; Smart & Marshall, 2013; Zohar et al., 1998). Planning questions in advance can increase the likelihood of posing questions with higher cognitive demands (Marsh, 2010). This may explain a greater proportion of higher-order questions in written than in spoken classroom discourse. Zohar et al. (1998) also found that written classroom tasks in high school biology had higher cognitive demands than spoken tasks.

The analysis results demonstrating the type of retrieval, comprehension, and analysis questions show similar patterns as the analysis of textbook questions in the previous chapter. For example, retrieval prioritised information over processes, comprehension focused on linguistic tasks over symbolic representations, and analysis tasks mostly required students to specify applications rather than to generalise or theorise. This may indicate that textbooks were a major source of questions for teachers.

6.4. Limitations and Recommendations

Lesson observations were conducted in the first year the reformed senior syllabi were implemented for Year 11 and Year 12. Consequently, the observed senior teachers were under immense pressure to prepare their students for the first instalment of new internal and external assessments. Teachers' workloads were also considerably higher than in previous years as they were sequencing and planning the new units, learning new content matter, and preparing new classroom resources. These factors could have impacted the learning activities in the enacted curriculum. Results may differ in a repeat study conducted several years after the initial reform. Moreover, this study recorded and classified classroom learning tasks set by the teacher. This may not always equal the cognitive level of tasks implemented by students (Remillard & Heck, 2014). Student interviews could be used to investigate the cognitive skills used by various students during classroom learning activities. This research can therefore draw conclusions from the learning opportunities provided during the enacted curriculum, but not the learning outcomes.

A further limitation is that content matter taught in different units of each senior science course may be inherently different in its level of difficulty and required cognitive demand. While lessons in each unit are part of this study's sample, it was not possible to observe the same quantity of lessons in each unit or obtain a sample size big enough for a meaningful comparison of units within a subject, due to disruptions to face-to-face teaching during the COVID-19 pandemic. For the same reason, this study also does not provide data on a potential change of cognitive demands within each unit and with the development of each content topic. Instead, each subject is examined in its entirety.

Australia's National STEM Education Strategy (Education Council, 2015) aims to increase STEM teaching quality and teacher capacity. Results presented in this chapter can direct teachers' attention to the cognitive demands of their enacted curriculum. Consequent learning of cognitive classroom techniques may diversify instructional practices, resulting in a more engaging and relevant curriculum, which may lead to higher student enrolments in senior high school science. Mindful monitoring of questioning strategies and pedagogical choices may also increase student-centred discourse and the cognitive demands of the enacted science curriculum. Panizzon and Pegg (2008) show that teachers who understand theoretical models, such as a taxonomy of cognitive demands, feel better prepared to implement learning strategies with cognitive demands tailored to their students. There will always be diversity in teachers' pedagogical choices across the state as the responsibility for pedagogical approaches is located at a school level rather than a government level. Future studies could investigate Australian science teachers' motivations for choosing certain instructional strategies and the dominant sources of influence on pedagogical choices.

6.5. Conclusion

This chapter reports on the cognitive demands of the enacted senior science curriculum in Queensland after a major curriculum reform. Results show that Year 11 and Year 12 physics, chemistry, and biology students were actively engaged in learning tasks with a range of cognitive demands. The distribution of learning activities fostering students' higher-order and lower-order cognitive skills was close to equivalent and teachers provided ample opportunities for metacognition. However, knowledge utilisation tasks and inquiry learning, both carrying the potential to increase the relevance of subject matter and student engagement, only comprised 10% of all learning activities. Moreover, higher-order thinking tasks promoted subject-specific analysis or problem solving as opposed to integrated interdisciplinary thinking. Outside of school settings, the latter is more likely to result in innovative solutions to global problems. Self-system thinking was almost never observed in the enacted curriculum, which may further reduce students' perception of the content's relevance and their emotional involvement in learning, reducing their participation in high school senior science subjects. Learning activities with lower-order cognitive demands were biased towards retrieval rather than comprehension, suggesting that the enacted curriculum may value breadth over depth, which makes subject content less meaningful to students. The analysis of the cognitive demands of each subject's enacted curriculum individually resulted in similar patterns, except for physics lessons including a greater proportion of higher-order thinking tasks, and biology lessons more frequently including knowledge utilisation tasks. This links to the subjects' reputations of being a 'popular' science (biology) and a 'hard' science (physics).

Results also show that instructional strategies fostering students' cognitive development lack diversity. The dominance of independent work and answering spoken and written questions may limit students' learning and motivation. It may also explain why students perceive science as teacher-centred and content-focused. As many knowledge utilisation tasks require collaboration by nature, an increase in knowledge utilisation in the enacted curriculum may also improve the balance of individual and collaborative learning. Some well-researched instructional strategies for cognitive development, such as class discussion, modelling, journaling, or peer instruction (Baideme et al., 2014; Beyer, 2008; QCAA, 2020b), were never or rarely observed in this study. Analysis of teacher questioning indicates that teachers' spoken questions predominantly have lower-order cognitive demands and written questions, which were prepared or selected before the lesson, have a greater mix of cognitive demands.

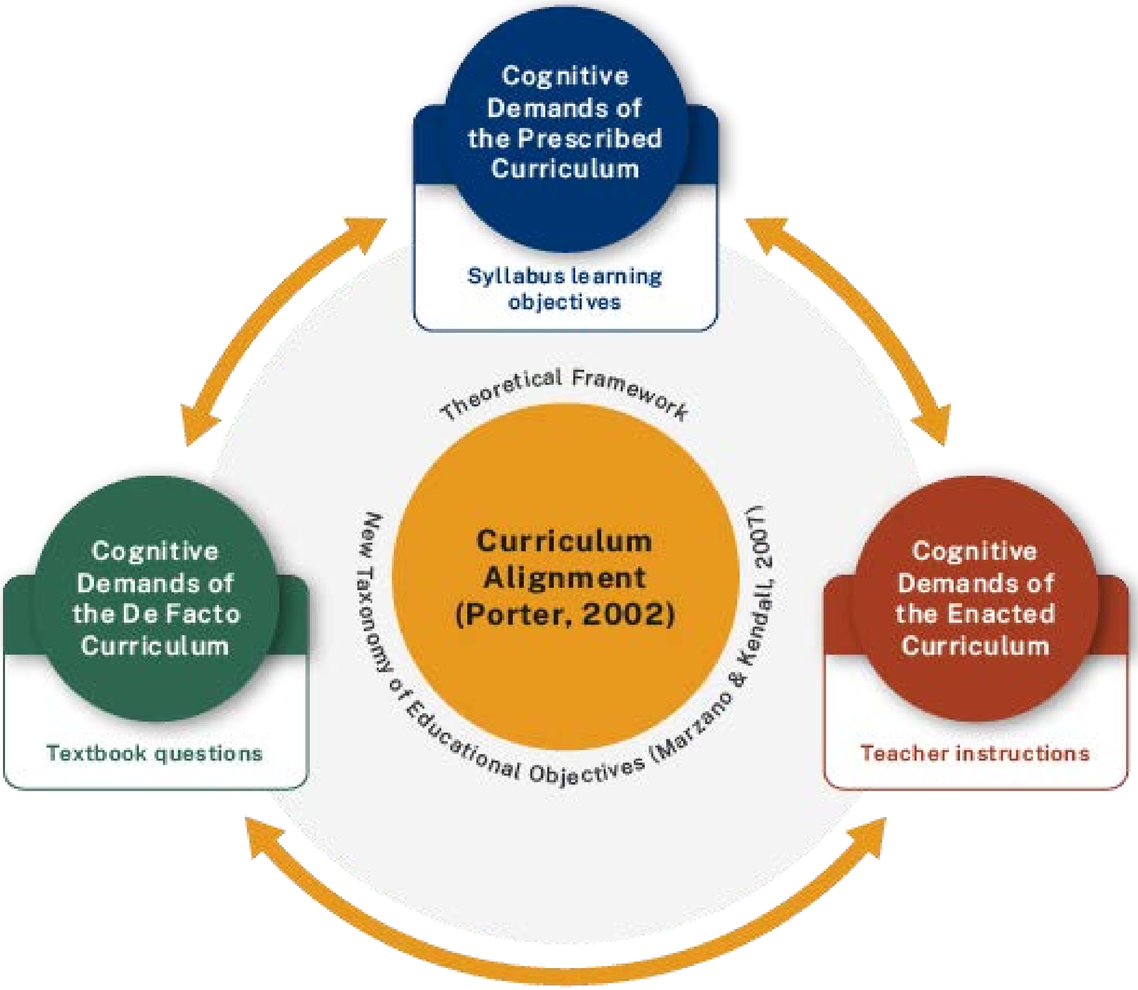
Australia currently has skills shortages in occupations requiring science degrees, particularly in the engineering and medical fields, and future demand for qualified personnel in science industries is expected to rise (National Skills Commission, 2021). The demand for senior science teachers in Australia is also increasing (Hobbs et al., 2022). It is therefore imperative to inspire future generations of Australian students to engage with and enrol in science subjects. The current cognitive demands and learning activities of the enacted senior science curriculum in Queensland may be missing the chance to maximise student interest and engagement and it is not clear whether policy intentions for science education are enacted in the classroom. The next and final results chapter reports on the strength of alignment between the cognitive demands of senior science lessons, syllabus learning objectives, and textbooks.

Chapter 7. Curriculum Alignment

The previous three chapters categorised the cognitive skills present in senior science syllabi, textbooks, and lessons. These categories were framed by the levels of cognitive processing theorised in Marzano and Kendall’s (2007) New Taxonomy of Educational Objectives. Using the same theoretical framework for the analysis of the prescribed, de facto, and enacted curriculum allows for cross comparison of their cognitive demands. This chapter examines the alignment between cognitive demands of (a) syllabus objectives and textbook tasks, (b) syllabus objectives and teacher instructions, and finally (c) teacher instructions and textbook tasks (see Figure 7.1). The findings provide a snapshot of the first round of application of Queensland’s recent senior curriculum reform. They may also identify gaps in current classroom teaching that can lower curriculum alignment. Addressing these gaps can increase the alignment of the prescribed and enacted curriculum, which has been linked to higher student achievement (Kurz et al., 2010).

Figure 7.1

Focus of Chapter 7—Alignment of Curriculum Components



7.1. Rationale

Curriculum alignment research in science is dominated by studies comparing content knowledge and cognitive skills in policy documents with summative assessment, and particularly with examinations (Çil, 2015; Contino, 2013; Edwards, 2010; El Hassan & Baassiri, 2019; Kara & Cepni, 2011; Liang & Yuan, 2008; Liu & Fulmer, 2008). Often, there is an inherent assumption that policy documents and assessments eventuate in matching learning resources and lesson activities, and to an aligned enacted curriculum. Despite the strong influence of textbooks on teachers' lesson planning (Reys et al., 2004), curriculum alignment research has given the de facto curriculum presented in textbooks little attention.

This study shifts the focus of alignment research to the educative process between students' prescribed learning objectives and their assessment; namely, teachers' classroom instructions that direct students to engage in specific learning activities. The present study also extends curriculum research by examining how the de facto curriculum in textbooks agrees with both policy documents and classroom teaching. This chapter aims to answer the fourth research question and its sub-questions:

4. How aligned are the cognitive demands of the prescribed, de facto, and enacted Queensland physics, chemistry, and biology curriculum?
    a. Do the cognitive demands of textbook questions align with the cognitive demands of syllabus learning objectives?
    b. Do the cognitive demands of teacher instructions during lessons align with the cognitive demands of syllabus learning objectives?
    c. Do the cognitive demands of teacher instructions during lessons align with the cognitive demands of textbook questions?

7.2. Results

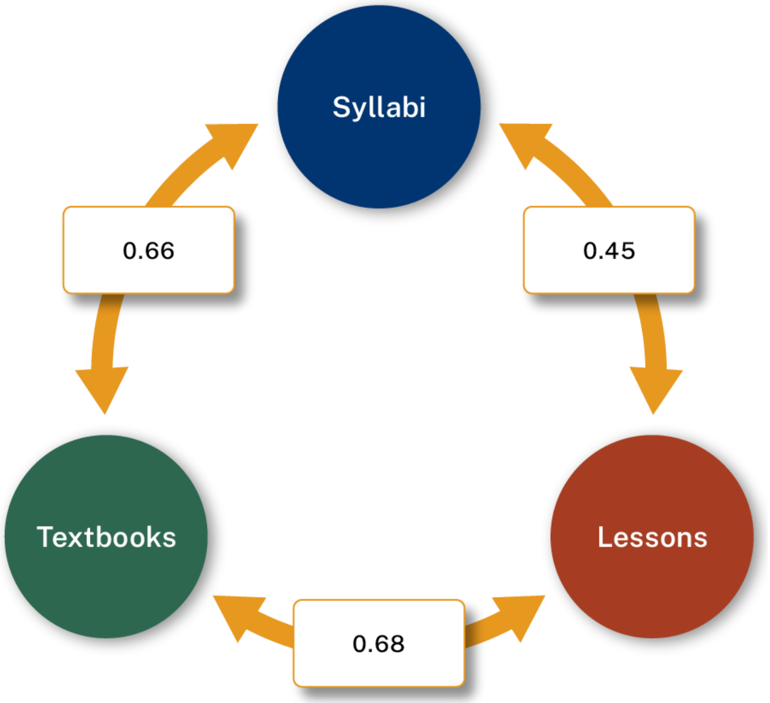
The results presented in this chapter first focus on the strength of alignment between different curriculum components across all three sciences. Thereafter, the subject-specific alignment of cognitive demands is analysed and specific areas of misalignment are identified.

7.2.1. Alignment of Cognitive Demands Across All Subjects

The calculated alignment indices show a moderate alignment of the de facto curriculum with the prescribed curriculum as well as with the enacted curriculum, and a low alignment of the enacted curriculum with the prescribed curriculum (see Figure 7.2). The cognitive demands of textbooks and classroom instructions have the strongest alignment in this study, with an alignment index of 0.68. The cognitive demands of syllabus learning objectives and textbooks have a similar alignment index of 0.66. The alignment index of syllabus learning objectives and lesson instructions is comparatively low at 0.45.

Figure 7.2

Alignment Indices

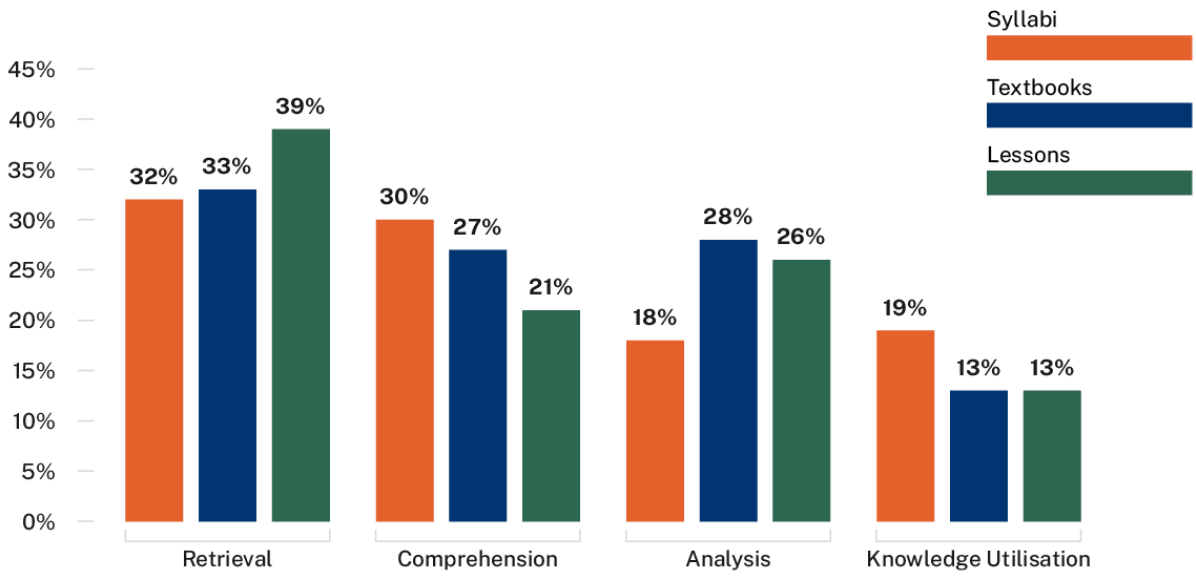


Note. Porter's (2002) alignment indices range from 0 (no alignment) to 1.00 (perfect alignment).

Figure 7.3 visualises the alignment of cognitive skills at each cognitive level across all three senior sciences. While syllabus learning objectives and textbooks have a similar proportion of objectives or questions at a retrieval level (32% and 33% respectively), lesson instructions seem to overemphasise retrieval (39%). Textbooks feature a lower proportion of comprehension questions (27%) than prescribed by syllabus learning objectives (30%), while lesson instructions place even less emphasis on comprehension (21%). Analysis is overrepresented in both textbooks (28%) and lessons (26%) when compared to the prescribed syllabus learning objectives (18%). The opposite is the case for knowledge utilisation, which is underrepresented in textbooks (13%) and lessons (13%) when compared to syllabus learning objectives (19%). The following section presents subject-specific alignment results on cognitive skills in the prescribed, de facto, and enacted curriculum.

Figure 7.3

Alignment of Cognitive Demands Across All Subjects



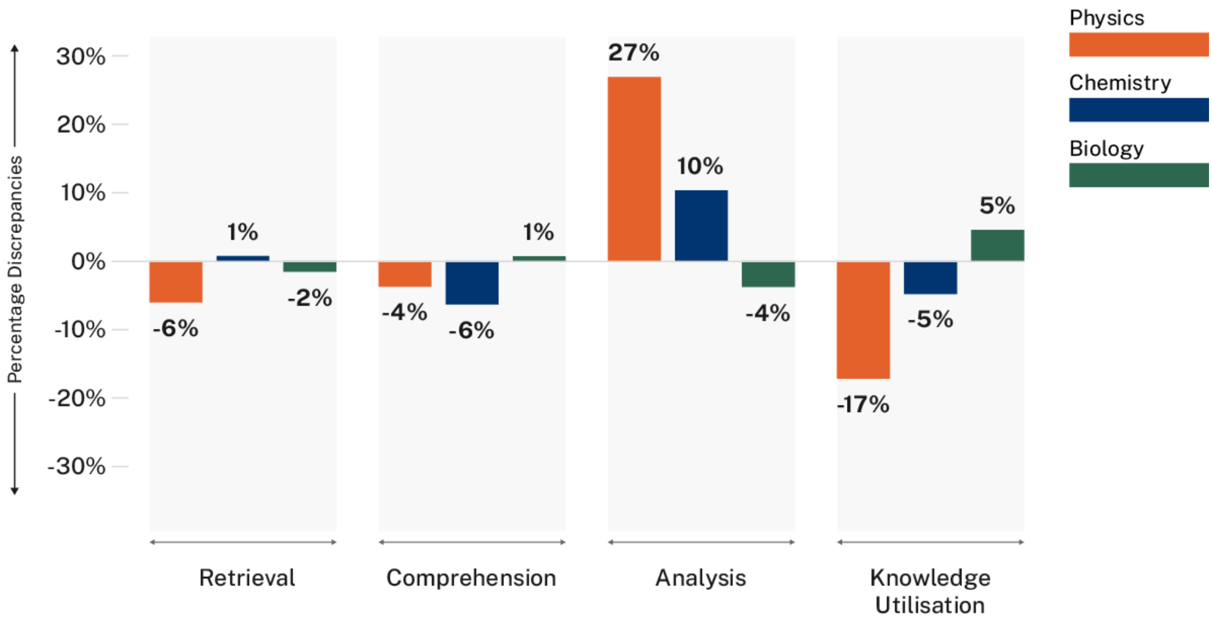
Note. Percentages are rounded to whole numbers.

7.2.2. Subject-Specific Alignment of Cognitive Demands

Porter's (2002) alignment index for the cognitive demands of syllabus learning objectives and textbooks is 0.66, which is moderate. Figure 7.4 shows the discrepancies for each cognitive level in each subject. In biology, textbook questions are well aligned with the cognitive demands of syllabus learning objectives. The percentage discrepancies do not exceed 5% for any cognitive level. In chemistry, the number of retrieval questions match the number of syllabus learning objectives requiring students to demonstrate retrieval skills. However, there are 6% fewer comprehension questions, 10% more analysis questions, and 5% fewer knowledge utilisation questions than the chemistry syllabus objectives prescribe. Physics textbooks have the lowest alignment with their respective syllabus learning objectives. Retrieval and comprehension questions are both underrepresented in physics textbooks (6% and 4% respectively) when compared to syllabus learning objectives. Analysis questions are greatly overrepresented by 27% and knowledge utilisation questions are underrepresented by 17%. In short, while the physics syllabus learning objectives emphasise task-driven problem solving, textbook questions focus more heavily on theoretical analysis. For example, the syllabus asks students to solve problems using Newton's Laws of Motion, which should involve an investigation of real-world situations and decision making based on the application of Newton's Laws (e.g., improving the design of sports equipment). Instead, textbook questions on the topic predominantly require students to determine a theoretical value given a highly controlled scenario (e.g., the mass of an unknown object given the applied force, acceleration, and friction). Notably, Oxford University Press had a higher (>10% more) proportion of knowledge utilisation questions in chemistry and physics than the other two publishers. The variance between publishers at the other cognitive levels was negligible.

Figure 7.4

Alignment Between the Cognitive Demands of Textbooks and Syllabus Learning Objectives

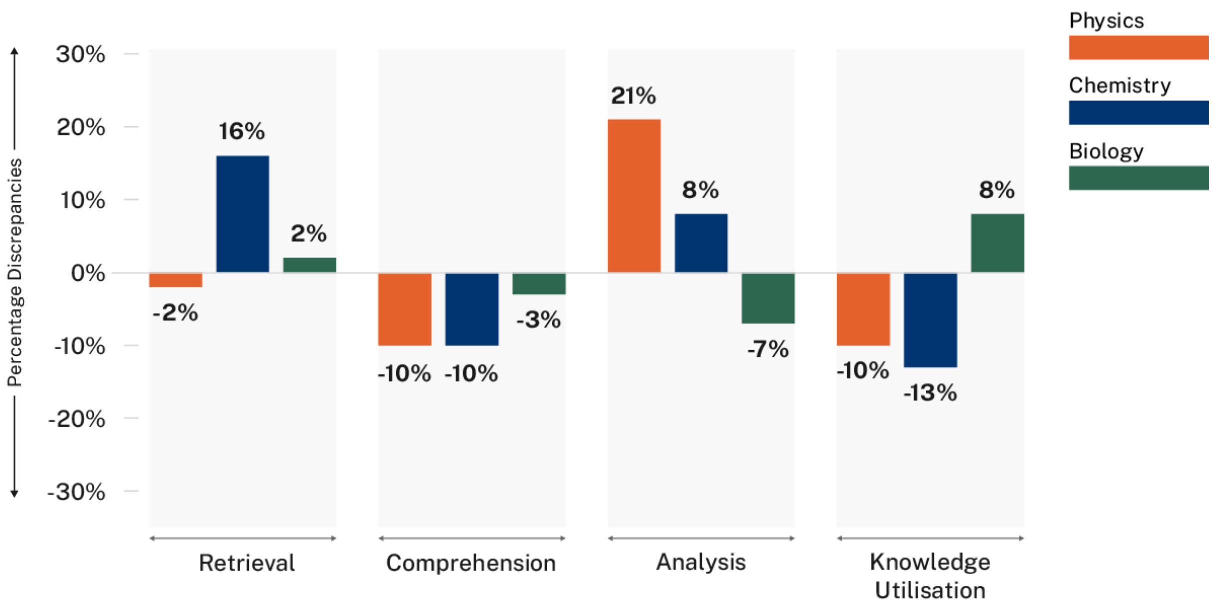


Note. Percentage Discrepancies = Textbook Question % – Syllabus Learning Objective %. Percentages are rounded to whole numbers.

Porter's (2002) alignment index for the cognitive demands of syllabus learning objectives and lesson instructions is 0.45. This indicates a low alignment between the cognitive demands of the prescribed and enacted curriculum in senior science. Figure 7.5 shows the subject-specific discrepancies for each cognitive level. In physics, lessons underemphasised comprehension and knowledge utilisation tasks by 10% when compared to syllabus learning objectives. Instead, students were instructed to engage with analysis tasks 21% more frequently than outlined in the prescribed curriculum. Physics teachers made disproportional time during lessons for analysis-level thinking, at the expense of other cognitive levels. In chemistry, the cognitive demands of the enacted curriculum overemphasised retrieval by 16% and analysis by 8% when compared to chemistry syllabus learning objectives. The chemistry enacted curriculum also underemphasised comprehension and knowledge utilisation by 10% and 13% respectively. In other words, superficial acquisition of knowledge was disproportionally overrepresented in chemistry lessons over in-depth meaning making, and decontextualised or theoretical application of knowledge in analytical skills was overrepresented at the expense of knowledge application to specific real-world tasks. In biology lessons, lower-order cognitive skills were well aligned with biology syllabus learning objectives (<5% discrepancy) and the alignment of higher-order cognitive skills showed the opposite trend to the results for physics and chemistry. Namely, analysis tasks were underemphasised in lessons by 7% and knowledge utilisation tasks were overemphasised by 8% when compared to biology syllabus learning objectives.

Figure 7.5

Alignment Between the Cognitive Demands of Syllabus Learning Objectives and Lessons

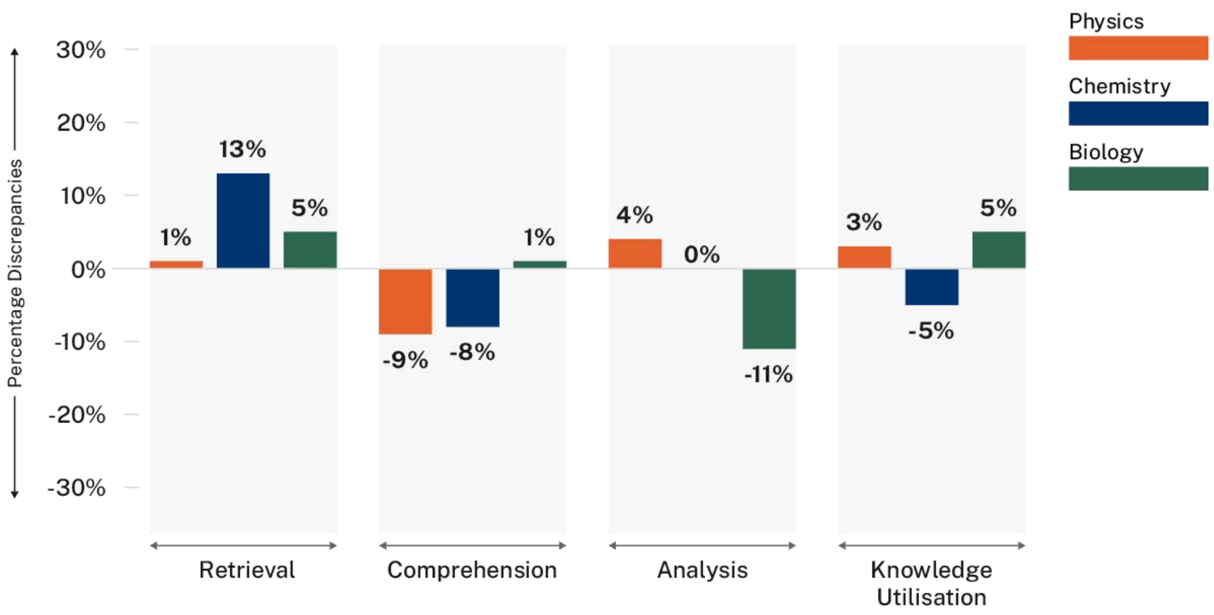


Note. Percentage Discrepancies = Lesson Instructions % – Syllabus Learning Objectives %. Percentages are rounded to whole numbers.

The cognitive demands of textbooks and lesson instructions across all subjects have a moderate alignment index of 0.68. Figure 7.6 shows the degree of misalignment (i.e., percentage discrepancies) between cognitive skills in the enacted curriculum and textbook questions for each subject. In physics, the cognitive demands of teachers' classroom instructions were very similar to the cognitive demands of physics textbooks (<5% discrepancy), except for comprehension constituting a lower proportion of lesson tasks than textbook questions by 9%. Similarly, the higher-order cognitive demands of chemistry lesson instructions were well aligned with textbook questions (≤5% discrepancy), but lower-order cognitive demands were less aligned. Lesson instructions have a greater proportion of retrieval by 13% and a lower proportion of comprehension by 8% than chemistry textbook questions. Biology lesson instructions were again well aligned with the cognitive demands of biology textbook questions (≤5% discrepancy), with the exception of a lower proportion of analysis tasks in biology lessons by 11% than in biology textbooks.

Figure 7.6

Alignment Between the Cognitive Demands of Lessons and Textbooks



Note. Percentage Discrepancies = Lesson Instructions % – Textbook Questions %. Percentages are rounded to whole numbers.

7.3. Discussion

7.3.1. Alignment of Textbooks With Syllabus Learning Objectives (Alignment Index: 0.66)

The results of the alignment analysis suggest a moderate alignment between the cognitive demands of senior science textbooks and their respective syllabus learning objectives. Syllabus learning objectives outline the knowledge and skills a student should demonstrate upon completion of the subject. In the current Queensland senior system, Year 12 syllabus learning objectives are assessed formally through three school internal assessments and one externally set assessment. Textbooks can only be used as a resource to adequately prepare students for such formal assessment if they are well aligned with the knowledge and skills of syllabus learning objectives. Superficially, the analysed textbooks represent the reformed syllabi well in content and order of presented knowledge. However, the textbooks do not necessarily offer questions and tasks at the same cognitive depth as suggested by the syllabus and are not always aligned with the syllabi's philosophy. This resembles findings from similar studies examining the coherence of textbooks with prescribed curricula (e.g., Saher & Kashif, 2020; You et al., 2019; Yu et al., 2022).

A significant source of misalignment between the prescribed curriculum and textbooks is the overemphasis of analysis and the simultaneous underemphasis of knowledge utilisation tasks in chemistry and physics textbooks. Therefore, teachers who rely on textbooks to implement the reformed syllabi will use misaligned instructions that may limit their ability to teach content to a sufficient cognitive depth. The misalignment is particularly pronounced in physics where syllabus learning objectives require students to demonstrate their knowledge by solving authentic problems, by making decisions based on physics concepts, or by investigating physical phenomena. Textbook questions seem to have frequently substituted the opportunity to practise such skills with questions that require students to process and analyse data by finding categories, analysing errors or limitations, generalising, predicting, or identifying specific consequences of the data. Many analysis questions in physics textbooks require students to apply their knowledge of a formula and perform a calculation to specify a value. While analytical skills can challenge students to create new insights (Marzano & Kendall, 2007), the link to real-world situations may not be as clear as in knowledge utilisation tasks. Knowledge is also likely to be perceived as fixed by students because analysis tasks often have one predetermined correct answer, whereas knowledge utilisation tasks tend to be open with multiple possible solutions. Therefore, there may be a gap between how textbooks present physics knowledge and how physics knowledge is generated or used by scientists beyond school. The finding that textbook publishers have varied emphasis on knowledge utilisation tasks demonstrates the importance of teachers choosing textbooks with a critical lens.

To exacerbate the problem, analysed textbook questions have often been labelled with incorrect cognitions. Similar to previous research examining the cognitive demands of textbooks (Qhibi et al., 2020), this study revealed that the execution of routine procedures, such as the application of memorised formulas, was often labelled as problem solving when in fact it is of lower cognitive demand. Misaligned or incorrectly labelled resources may hinder teachers' successful implementation of the syllabus learning objectives and the intent of the curriculum reform.

Biology textbooks stood out in the study by providing a higher proportion of knowledge utilisation questions than required by syllabus learning objectives. The bulk of these knowledge utilisation questions fosters students' evaluation and decision-making skills, which may be a remnant influence of the replaced biology curriculum that formally assessed the evaluation of biological issues across all units (Queensland Studies Authority, 2014).

7.3.2. Alignment of Lessons With Syllabus Learning Objectives (Alignment Index: 0.45)

This study found a low alignment between the syllabus learning objectives and the cognitive demands of teacher instructions during observed senior science lessons. Based on the alignment index interpretation of Australia’s curriculum mapping project (Jane et al., 2011), this result could be labelled as very low. Such low alignment suggests that the cognitive skills aspects of Queensland’s senior science curriculum reform may have not been fully implemented yet in 2020. Past studies investigating the alignment between the enacted curriculum and prescribed curriculum in various subjects have found similarly low alignment when using Porter’s (2002) alignment index. For example, past studies found a maximum alignment index of 0.41 (Polikoff & Porter, 2014), 0.33 (Porter et al., 2011), 0.22 (Porter et al., 2011), or a median alignment index of 0.12 (Kurz et al., 2010).

There may be various reasons for such low alignment. Boesen et al. (2014) argue that while new curriculum content goals can be quickly implemented, newly introduced learning goals relating to cognitive skills are not taught consistently. The cognitive demands of lessons are too dependent on teachers’ knowledge, experience, and teaching philosophies to be altered reliably by reformed policy alone (Krüger et al., 2013; Mishra & Mehta, 2017). This includes teachers’ opinions on the purpose of teaching science and their convictions about what constitutes good science teaching (Wallace & Priestley, 2017). In other words, the teachers observed in this study were filtering the cognitive demands of the reformed syllabi’s learning objectives according to what they believed to be desirable, or their understanding of the objectives, which transformed the cognitive demands of the curriculum until it no longer represented the cognitive demands of the prescribed curriculum. For example, privileging lower-order cognitive skills, such as retrieving a wide range of facts, may feel natural for some teachers working in knowledge-rich domains like the sciences (Christensen, 1991).

More experienced teachers are less likely to implement curriculum reforms as intended (Wilhelm, 2014), which could be due to long-ingrained beliefs about the purpose of science education and how to best teach the subject matter (Tytler, 2009). The teacher sample in this study had a disproportional amount of highly experienced teachers, which may have contributed to the low alignment between classroom instructions and the reformed prescribed curriculum. Scholars argue that an effective change in how curricula are enacted may need to address teachers' emotions and values (Dinan Thompson, 2001). Finally, many secondary science teachers in Queensland teach outside of their area of expertise due to a shortage of qualified specialist teachers (Independent Schools Queensland, 2018; Queensland Audit Office, 2013). To increase curriculum alignment, teachers' understanding of subject matter and pedagogical content knowledge will also need attention.

Besides teacher-internal variables, many external or contextual factors can influence the departure from a curriculum's prescribed cognitive demands, such as students' learning needs, access to teaching resources, or expectations of the school community (Remillard & Heck, 2014; Ziebell et al., 2017). Even when teachers intend to implement higher-order thinking tasks, they may unintentionally decrease the cognitive demand of the task during the lesson if the classroom environment or students' capabilities are not conducive to the demands of the task (Wilhelm, 2014). Considering the diversity of students and learning environments in Queensland, a high alignment of cognitive demands between the enacted curriculum and a relatively inflexible prescribed curriculum may be an unrealistic goal.

Low curriculum alignment in this study is predominantly due to excessive emphasis on retrieval and analysis and insufficient emphasis on comprehension and knowledge utilisation in the enacted curriculum. The overemphasis on retrieval is very pronounced in chemistry, and the underemphasis on comprehension is most evident in chemistry and physics. There are several possible explanations for the dominance of information and process memorisation over the in-depth meaning making required for comprehension. Time constraints coupled with a wide breadth of content covered on high-stakes external examinations may result in teachers sacrificing comprehension-focused learning activities for more time-efficient retrieval activities (Dai et al., 2011; Öztürk Akar, 2014). The reformed chemistry syllabus has noticeably more cognitive verbs in subject matter content descriptors, and thus more learning objectives, than the physics syllabus. The physics syllabus, in turn, has more learning objectives than the biology syllabus (see Chapter 4). Therefore, one can argue that chemistry teachers are under greater time pressure to cover prescribed content matter in class, resulting in the overemphasis of retrieval.

The overemphasis of analysis and underemphasis of knowledge utilisation in lessons is evident in physics and chemistry. While the observed teachers provided their students with sufficient opportunities to practise higher-order thinking skills, they focused on the least complex and most decontextualised level of higher-order thinking skills in the New Taxonomy. Analysis-level skills are easier to assess in examinations with multiple-choice and short-response questions than knowledge utilisation questions. Moreover, international studies of physics examinations have repeatedly shown that analysis-level questions feature more frequently than questions at any other cognitive level (Liang & Yuan, 2008; Motlhabane, 2017). Thus, it can be hypothesised that the assessment mode in Queensland influences the cognitive demands of lessons. Once sufficient external examination papers for each subject have been released, an analysis of their cognitive demands may shed light on the influence of examination questions on lesson instructions. An alternative explanation may be that observed teachers were catering to the perceived needs of their students and may have implemented tasks tailored to the level of competence they believed their students had.

Interestingly, the alignment of higher-order cognitive skills in biology shows the opposite trend to the alignment of higher-order cognitive skills in physics and chemistry. The observed biology teachers incorporated more opportunity for knowledge utilisation and less opportunity for analysis than prescribed by syllabus learning objectives. This could be a result of biology subject matter, which often relies on contextualised case studies of real-world phenomena and lends itself to concrete knowledge utilisation. Alternatively, the prioritisation of knowledge utilisation over analysis could be a result of biology teachers' intentions and skills. Zohar and Schwartzer's (2005) assessment of 150 teachers' pedagogical subject knowledge on how to teach complex higher-order cognitive skills gave biology teachers a significantly higher score than physics or chemistry teachers. These authors argue that the higher scores indicate a traditionally stronger emphasis on inquiry in biology than in chemistry or physics. Lewthwaite et al. (2014) analysed chemistry teachers' pedagogical choices and concluded that they are influenced by their epistemological beliefs about the nature of chemistry. Thus, biology teachers in this study's sample may carry a different philosophy about desired practices in science education than chemistry or physics teachers. Further research is needed to uncover these beliefs and values.

The low alignment of cognitive demands between the enacted curriculum and prescribed curriculum highlighted in this study can potentially negatively impact student outcomes. If students are not provided with sufficient opportunity to learn knowledge at the cognitive depth that it is assessed, they may be disadvantaged. Naturally, this assumes that Queensland's assessed curriculum, particularly the heavily weighted external examination, is well aligned with the prescribed curriculum. Until there is data on the cognitive demands of the assessed curriculum, this assumption is based on QCAA's senior assessment quality assurance processes, which include a focus on the alignment of assessment with syllabus objectives under the label validity (QCAA, 2018a). A lack of opportunity to learn certain skills in the classroom can have a disproportionally larger effect on achievement for students from minority groups (Anderson, 2002), further increasing the unequal participation of minority groups in Australian science careers. An argument can be made that strengthening curriculum alignment could be socially just.

7.3.3. Alignment of Lessons With Textbooks (Alignment Index: 0.68)

The highest alignment index found in this study was between the cognitive demands of teachers' lesson instructions and textbook questions. This is particularly true for the alignment of higher-order cognitive skills; both teacher instructions and textbook questions focused more on analysis tasks and less on knowledge utilisation tasks than syllabus learning objectives. This finding provides additional evidence that, even in a time of seemingly unlimited online resources, textbooks do affect what is taught. Further, the finding indicates that textbooks have been a key planning resource for teachers in the first two years of the senior curriculum reform implementation. Past studies on Australian and overseas science curricula have identified similar patterns of textbooks influencing the cognitive depth of teacher questions more than curriculum standards (Nakiboğlu & Yildirir, 2011; Ziebell et al., 2017). This provides textbook authors with control over defining the nature of school science disciplines.

A higher alignment index between lessons and textbooks than between lessons and syllabus learning objectives suggests that the sample of Queensland science teachers observed in this study may be influenced more by textbooks than by syllabus documents. Even when teachers begin planning lessons with syllabus learning objectives in mind, choosing textbook tasks and questions that match the syllabus content matter may change the cognitive depth intended by the prescribed curriculum for that content matter (Son & Kim, 2015). For example, if the chemistry syllabus instructs students to evaluate biofuels, but the textbook asks students to categorise a given list of biofuel strengths and weaknesses, the cognitive demand of the objective has been altered from knowledge utilisation to analysis. Time-poor teachers and teachers lacking expertise in their subject may be more likely to adopt the textbook question ad verbatim than to change its cognitive demand, or they may not recognise the altered cognitive demand of the textbook task. Authors therefore carry the responsibility to align textbook questions with syllabus objectives as closely as possible. In addition, teachers could benefit from an awareness that any standard curriculum resources may not offer an appropriate range of cognitive demands. Thus, teachers' choice of lesson activities should not be limited to such materials. Many teachers may also benefit from additional learning on how to identify the cognitive demand of a task, so they can make more discerning choices when selecting learning resources.

Alternatively, more frequent inquiry-based learning may carry the potential to challenge the textbook's role as the de facto curriculum. Inquiry tasks actively involve students in exploring concepts, with the teacher responding to students' ideas (Chen & Tytler, 2017). Therefore, inquiry learning tasks tend to deviate from a predictable path, making it less likely for teachers to follow or adopt textbook content uncritically. The stronger alignment between textbooks and lessons observed in this study may be linked to the fact that inquiry learning was also observed infrequently (see Chapter 6). An impetus for more inquiry, and therefore more authentic knowledge utilisation tasks, may result in higher alignment between the prescribed and enacted curriculum instead of a high alignment between the enacted curriculum and de facto curriculum presented by textbooks.

Although textbooks and lessons are the strongest aligned curriculum components in this study, their alignment index of 0.68 is only considered moderate. Teacher instructions in chemistry and physics lessons featured a higher proportion of retrieval tasks and a lower proportion of comprehension tasks than textbooks, which lowered the alignment index. Hence, textbooks prioritise retrieval questions over comprehension questions when compared to the syllabus, and teacher instructions prioritise retrieval over comprehension even more than textbooks. Yet again, an emphasis on content breadth over depth seems to be evident.

Teachers in this study seem more likely to adopt retrieval textbook tasks than comprehension textbook tasks, possibly because retrieval questions can be answered faster by students and marked more efficiently by teachers than comprehension questions, which usually require a longer response. Alternatively, teachers may have altered the cognitive demand of comprehension textbook questions by providing additional scaffolding with the question in class, until students are only required to retrieve the knowledge. Such lowering of cognitive demand when the de facto curriculum is translated into the enacted curriculum has already been well documented in mathematics (Wilhelm, 2014). In the sciences, a textbook question may require students to explain which features characterise pictured plants as pioneer species, but the teacher may have instructed students to copy down characteristics of pioneer species before asking the question, therefore lowering its cognitive demand from comprehension to retrieval.

7.4. Limitations and Recommendations

As with any measure of alignment, Porter's (2002) alignment index has several limitations. It is influenced by the number of cells in the cognitive demand matrices. For example, increasing the number of cells by increasing the number of content topics or subjects automatically lowers the alignment index as there are more opportunities for discrepancies between proportions (Polikoff & Fulmer, 2013). If this study had investigated a fourth subject, the matrix would have increased by four cells, which may have lowered the alignment index disproportionally to the change in curriculum alignment. The index's matrix size dependency needs to be acknowledged when comparing these research results to other studies using Porter's (2002) alignment index. A further limitation of Porter's (2002) alignment index is its lack of ability to determine reasons behind low alignment (Martone & Sireci, 2009). Future studies can address this limitation by conducting qualitative teacher interviews. Finally, it is important to remember that a low- or high-alignment index does not convey a value judgement about the appropriateness of cognitive demands in a curriculum or the quality of education (Blumberg, 2009). It is simply a measure of agreement between different curriculum components.

This study investigated the alignment of cognitive skills only. It does not claim to measure all aspects of curriculum alignment (e.g., no data were collected on the breadth of curriculum content). Instead, this study focuses on the cognitive demands of curricula, a curriculum dimension which has been repeatedly reported to have weak alignment (Resnick et al., 2004a; Webb, 1999).

Conclusions drawn from results in this chapter are limited by the number of teachers observed and the boundaries of the cognitive skills categories stipulated by the New Taxonomy of Educational Objectives (Marzano & Kendall, 2007). Moreover, all alignment studies rely on human judgement of classification criteria. Therefore, the quality of alignment studies and trustworthiness of results depends on the expertise and training of researchers (Martone & Sireci, 2009). The researcher in this study worked as a senior biology teacher throughout the transition and after the implementation of the reformed QCE system, and is highly familiar with syllabus standards, assessment, and instructions in Queensland senior science classrooms. In addition, the researcher rigorously applied a transparent standardised inquiry protocol for all lesson observations (see Section 3.3.4.) and triangulated data from different sites (see Section 3.4.3.).

Finally, the findings on alignment between the enacted and de facto curriculum are limited to general alignment between the instructions of all observed teachers and all analysed textbooks. The analysis did not calculate the alignment between each specific teacher and the textbook used by this teacher. However, each analysed textbook in this study was used by at least two participating teachers.

This study provides an early snapshot of the 2019 senior curriculum reform in Queensland. Follow-up studies that examine the change of curriculum alignment with time may prove insightful. An increase in curriculum alignment could ascertain that reform efforts have been successful (Porter, 2004). Further in-depth exploration of science curriculum authorship in Queensland would also help uncover sources of curriculum misalignment by explicating the main influences on teachers' planning of the enacted curriculum (Ziebell et al., 2017).

7.5. Conclusion

Curriculum enactment involves the interpretation and translation of standards and objectives. This process is influenced by teachers' beliefs and philosophies, teachers' expertise, and learning resources or other contextual factors of the school community (Remillard & Heck, 2014). Therefore, curriculum enactment inherently transforms the prescribed curriculum, which can result in imperfect alignment between intention and practice. In this study's small sample of Queensland senior science teachers, the alignment between the enacted curriculum and prescribed curriculum was low, suggesting that curriculum developers' intentions may not yet be implemented fully and that students may be missing out on learning opportunities, which can particularly disadvantage students from minority groups (Anderson, 2002). A major source of misalignment was teachers' omission of opportunities for students to practise comprehension and knowledge utilisation of content matter, in favour of skills that are traditionally more likely to be assessed on examinations such as retrieval or analysis.

Notably, the alignment between the enacted curriculum and textbook questions was higher than the alignment between the enacted curriculum and prescribed curriculum, suggesting an influence of textbooks on the cognitive demand of teachers' instructions, and as a result, on students' conceptualisation of scientific knowledge. This is problematic as the cognitive demands of textbooks specifically published for the implementation of the curriculum reform may not preserve the reformed syllabi's philosophy because their cognitive demands were only moderately aligned with the prescribed curriculum. The next and final chapter of the thesis synthesises the findings presented in this chapter and the previous three chapters, to discuss insights gained from the cognitive demands of senior science curricula in Queensland and to make recommendations for practice.

Chapter 8. Conclusion

This research project analysed the cognitive demands of the recently reformed Queensland senior science curriculum. Three curriculum components were examined: the prescribed curriculum presented in syllabus documents, the de facto curriculum in textbooks developed to support the implementation of the reformed syllabi, and teachers' classroom instructions in the enacted curriculum. The study's quantified alignment between the cognitive demands of these three curriculum components was determined by observations of teachers' classroom instructions, and analyses of the syllabi's and the textbooks' cognitive demands. This chapter summarises the key findings for each research question and discusses the significance of those findings. It also proposes that this research contributes original knowledge to benefit stakeholders in science education. The chapter ends by reviewing the limitations of the study and proposing opportunities for future research.

8.1. Research Findings

The systematic literature review presented in Chapter 2 underscores the necessity for empirical data regarding the alignment of cognitive demands in secondary science education during the curriculum implementation process. Curriculum reforms can lower alignment between the prescribed and enacted curriculum (Kuiper et al., 2013), increasing the need for and value of curriculum alignment research (Edwards, 2010). This case study seized the opportunity to collect data in the first two years after a senior curriculum reform in Queensland. It analysed the reformed physics, chemistry, and biology curriculum with a focus on its cognitive demands. This focus was chosen because the development of students' cognitive abilities is emphasised by the senior curriculum reform (QCAA, 2018e) and because cognitive skills tend to be the least-aligned curriculum component (Blumberg, 2009).

The case study provides the first analysis of the reformed senior science curriculum in Queensland and probes its congruence with Australia's goals for science education. The study also adds to scant research on the cognitive demands of science textbooks in Australia. Furthermore, this is the first study to report on the cognitive demands imposed by Queensland science teacher instructions and their instructional approaches since the curriculum reform. The study was guided by four research questions (see Section 2.3.). The key findings for each research question are summarised in the following paragraphs.

Research Question 1: What are the cognitive demands of the reformed Queensland physics, chemistry, and biology syllabus? In terms of the type and depth of content knowledge taught, the reformed physics, chemistry, and biology syllabi are more prescriptive and less flexible than the replaced Queensland senior science syllabi. The cognitive demands of the syllabi's learning objectives show an increased emphasis on retrieval and comprehension of a broad knowledge base, as opposed to the more open but also vague choice of fewer content topics provided to teachers before the reform. Thus, prescribed knowledge and cognitive skills are now standardised across the state, resulting in more detailed and specific learning objectives. This standardisation process counters the global trend observed in Western science curricula over the previous decade, where there has been a shift towards more generic content specifications provide opportunities to contextualise learning (Priestley & Sinnema, 2014).

The cognitive demands of the reformed senior science syllabi are skewed towards lower-order thinking skills. Over half of the cognitive verbs in the three syllabi's learning objectives were classified as retrieval or comprehension of knowledge, which comprise the first two cognitive levels of the New Taxonomy of Educational Objectives (Marzano & Kendall, 2007). This emphasis aims to increase students' foundational subject knowledge, addressing the criticism of replaced Queensland syllabi concerning insufficient rigour and students' inconsistent preparation for many university courses in the natural sciences (Matters & Masters, 2014). It is important to monitor whether the reformed syllabi can build the knowledge base required for successful tertiary study while simultaneously engaging students with authentic and relevant scientific problems through higher-order thinking. An overemphasis on retrieval and comprehension may reduce students' intrinsic motivation to study a senior science (Krüger et al., 2013). It may also reduce students' ability to become critical consumers of science in an age of increasing access to misinformation.

A final key finding is that no learning objectives in the reformed senior science syllabi explicitly instruct teachers to engage students in metacognition or self-system thinking, most likely because metacognition and self-system thinking are difficult to assess. The syllabus documents make implicit references to students' self-regulation, motivation, and affective domain (e.g., their values and beliefs about learning subject content matter). However, these student-centred dimensions of learning do not feature in the learning objectives or assessments outlined in the syllabi. Despite mounting evidence that metacognition and self-system thinking have strong effects on students' learning (Beyer, 2008; Goodrum & Rennie, 2007; Hattie, 2008), the reformed syllabi leave it up to individual teachers to decide when, how and to what extent these types of thinking should be included in their teaching. Hence, the reformed syllabi appear to be content centred, which contradicts their adoption of the New Taxonomy of Educational Objectives, a student-centred theoretical framework (Marzano & Kendall, 2007).

Research Question 2: What are the cognitive demands of the de facto curriculum presented in senior physics, chemistry, and biology textbooks? The nine textbooks analysed in this study were specifically published to support the implementation of the reformed physics, chemistry, and biology syllabi. Results show that the textbooks contain a higher proportion of questions with low cognitive demands than with high cognitive demands. Questions requiring lower-order thinking are dominated by retrieval, whereas questions requiring higher-order thinking are dominated by analysis. Specifically, science textbooks seem to prioritise deductive over inductive thinking. Creative problem solving, which requires students to overcome an unfamiliar obstacle, is the least commonly identified higher-order thinking skill. This implies that students using the analysed textbooks are provided with few opportunities to question existing science knowledge or theorise knowledge. Instead, they are frequently prompted to learn knowledge in decontextualised theoretical contexts. These findings align with international research on the cognitive demands of science and mathematics textbooks (Valverde et al., 2002).

Furthermore, textbook questions stimulating metacognition or self-system thinking are rare across all three subjects. Notably, no analysed questions address students' affective domain. Teachers have to locate other resources or formulate their own questions to engage students in reflections about their learning progress, motivation, or the significance of learning the subject matter.

Differences in cognitive demands of textbook questions between the three subject areas are small. However, it was noticeable that physics textbook questions had the strongest emphasis on deductive analysis and biology textbook questions placed more emphasis on knowledge utilisation than the other two sciences. Biology textbooks thus provide slightly more opportunities for students to link content knowledge to authentic and relevant contexts.

Research Question 3: What are the cognitive demands of the enacted Queensland physics, chemistry, and biology curriculum? Lesson observations suggest that the enacted physics, chemistry, and biology curricula provide students with ample opportunities to develop cognitive skills and actively acquire knowledge. Results show a balance of lower- and higher-order cognitive demands, with 53% of teacher instructions fostering higher-order thinking. This is a positive and rare research finding contributing to literature on the cognitive demands of science lessons. Teacher observations showed frequent (21%) stimuli for students to engage in metacognition, despite no explicit syllabus learning objectives on metacognition.

It appears that observed senior science teachers value the benefits of metacognition and create space in their enacted curriculum for its explicit development.

Further analysis of teacher instructions suggested several parallels to the analysis of textbook questions, hinting at a possible influence of textbooks on the enacted curriculum. For example, recall of information is prioritised over the recall of procedures, linguistic skills are valued more than symbolic representations of knowledge and students are asked to engage more frequently in deductive analysis than in inductive analysis.

Observed teacher instructions with lower-cognitive demands showed a clear preference for retrieval over comprehension activities and teacher instructions with high-cognitive demands prioritised analysis over knowledge utilisation. An inflated focus on retrieval of knowledge at the expense of in-depth comprehension may result in a perceived lack of relevance of subject matter as few links are created between concepts and students' prior knowledge. Similarly, a strong focus on analysis at the cost of knowledge utilisation results in few opportunities for students to link subject matter to their lives outside of school by solving authentic problems, investigating theories, designing experiments, or making contextualised decisions based on the knowledge they have learned in the subject.

Knowledge utilisation tasks and teacher instructions fostering self-system thinking were least frequently observed in this study. Across all subjects, only 10% of teacher instructions were classified as knowledge utilisation. Within this cognitive level, experimenting was observed most frequently; however, observed practical experiments were limited to guided inquiries explicitly mandated by the syllabus. Tasks requiring students to engage in self-system thinking constitute only 1% of all observed teacher instructions. A lack of authentic inquiry, combined with a lack of opportunities to examine one's emotions or beliefs about the subject matter can lead to disengagement and reduced motivation of students. This may further lower student participation in Year 11 and Year 12 science subjects. Moreover, students may develop a false impression of the nature of science and how new scientific knowledge is created. For example, students may fail to understand that current scientific knowledge is regularly disproven, changed, or refined by new discoveries and research.

The instructional strategies observed in this study may also reduce some students' engagement with science at secondary school. This can be proposed by the learning activities' lack of diversity and prioritisation of individual work consisting of answering spoken or written questions. Collaborative work and activities mirroring scientists' work outside of the classroom (e.g., peer discussions or formulating scientific arguments) were rarely observed. Knowledge utilisation tasks formed an exception by being more diverse and collaborative than learning tasks set by the teacher at any other cognitive level. Therefore, an increase in knowledge utilisation tasks may lead to more variety in instructional approaches and cater to the diverse learning needs of more students.

A final key finding is the dominant role teacher questioning plays in fostering cognitive skills. Questioning was the only instructional strategy observed frequently at all cognitive levels. Interestingly, pre-planned written questions had noticeably higher cognitive demands than teachers' spoken, and possibly spontaneously formulated, questions. This finding should encourage educators to purposefully plan key questions with desired cognitive demands for each lesson. Textbooks seemed to constitute a major source of teachers' classroom questions.

Research Question 4: How aligned are the cognitive demands of the prescribed, de facto, and enacted Queensland physics, chemistry, and biology curriculum? This study found low alignment between the cognitive demands of the prescribed and enacted senior science curriculum in the second year of its implementation. This means that students present in the observed classrooms were not necessarily learning content to the same depth as is prescribed by the reformed syllabi. For example, the enacted chemistry curriculum overemphasised superficial knowledge acquisition through retrieval and underemphasised in-depth comprehension of knowledge when compared to the subject's prescribed curriculum. Students may also not be engaging with the same range of cognitive skills the reform aims for. For example, learning tasks in physics classrooms were dominated by theoretical analysis and lacked some task-driven problem solving prescribed by the syllabus. The low alignment identified in this study adds to the global body of literature cautioning against misaligned cognitive demands following curriculum reforms (e.g., Boesen et al., 2014; Krüger et al., 2013). If alignment remains low, students may be disadvantaged in their summative assessment and educational outcomes may not match policy writers' intentions.

The de facto curriculum and enacted curriculum had the highest alignment index calculated in this study. The cognitive demands of teacher instructions were more strongly aligned with textbook questions than with syllabus learning objectives, indicating that textbooks are a core planning resource and may influence teachers' implementation of this curriculum reform more than new policy documents. In light of this finding, textbook authors' and publishers' influence on science education should not be discounted.

Curriculum alignment in biology showed different trends than curriculum alignment in physics or chemistry. Biology was the only science subject with more knowledge utilisation tasks observed in the enacted curriculum than prescribed by syllabus learning objectives. Biology textbooks also had a higher proportion of knowledge utilisation tasks and a lower proportion of analysis tasks than syllabus learning objectives. Physics and chemistry lessons and textbooks showed the opposite trend, with fewer knowledge utilisation tasks than prescribed by the respective syllabus. Biology students therefore seem to have more opportunities to utilise their knowledge to solve problems, experiment, investigate, or evaluate the content matter.

8.2. Significance of Findings

This section synthesises the significance of the above key findings for stakeholders in science education. It aims to highlight the contribution of knowledge about alignment of cognitive demands, draw attention to problematic aspects of results, and pose questions that may guide future science curriculum development and implementation.

8.2.1. The Trade-Off Between Lower- and Higher-Order Thinking Skills

When the standardised Australian Prep to Year 10 Curriculum was first implemented in 2014, the focus of science education seemed to shift away from the attainment of content knowledge. Instead, conveying an understanding of how scientists work, think, and solve problems has become a priority (Firn, 2016). In an era of highly accessible digital information, the prescribed science curriculum up to Year 10 seems to value retrieval and comprehension of facts less than the application of higher-order thinking skills. In Queensland, this emphasis on processes and critical thinking in science carried through to the senior years of secondary schooling, but was soon criticised for providing inconsistent learning expectations and an insufficient breadth of students' subject knowledge (QCAA, 2016). Critics argued that the use of educational taxonomies fails to acknowledge the important role of lower-order thinking skills as a foundation for higher-order thinking (Booker, 2007) and that a broad knowledge base in any discipline is required for effective and creative knowledge utilisation (Christensen, 1991; Kereluik et al., 2013; Mishra & Mehta, 2017). When Queensland's previous senior system was reviewed, experts asked that "an appropriate focus is placed on content knowledge along with the higher-order skills" (Matters & Masters, 2014, p. XV), without specifying how this should be achieved.

The reformed senior science syllabi analysed in this study support the acquisition of a broad knowledge base; most currently prescribed learning objectives in physics, chemistry, and biology require students to retrieve or comprehend knowledge. At the same time, the reformed syllabi still emphasise the importance of students developing the wide range of cognitive skills needed in the 21st century, including higher-order thinking skills (QCAA, 2017a). However, content goals frequently tend to be prioritised over thinking goals during the implementation of curricula (Zohar, 2013). This leads to the question: Does the reformed senior science curriculum constitute an appropriate trade-off between lower- and higher-order cognitive demands that develops students' knowledge base as well as their ability to think critically and creatively? The challenge lies in balancing the political demand on science education to produce the next generation of scientists with the societal demand to produce scientifically literate citizens (Clark, 2022). The publication of the New Taxonomy does not, in fact, specify an optimal balance of lower- versus higher-order thinking skills in a curriculum by stipulating that "It [the New Taxonomy] is not intended to prescribe the objectives that a school or district should adopt, only to articulate the range of possible objectives that a classroom teacher or an entire school or district might address" (Marzano & Kendall, 2007, p. 121). It is up to curriculum designers and teachers to consider and choose the cognitive learning outcomes that best prepare today's students for life after school.

Such decision making requires a reflection on how cognitive levels are portrayed in different educational taxonomies. If there was a hierarchical nature to cognitive skills, as argued by Bloom and his colleagues (1956), knowledge utilisation (e.g., in the form of problem solving) could be actualised more by students demonstrating a greater recall of facts. Similarly, metacognitive reflection would be more effective with a deeper comprehension of subject matter. In other words, complex cognitive tasks depend on pre-requisite learning of less complex cognitive skills, justifying the increased emphasis on lower-order learning objectives. Marzano and Kendall's (2007) New Taxonomy, on the other hand, assumes that cognitive levels are not hierarchical and can be developed independently. This would explain why learners may have varying levels of proficiency for each cognitive level (Soozandehfar &

Adeli, 2016) and why quizzes with low cognitive demands may not enhance higher-order learning (Agarwal, 2019). If cognitive skills are not hierarchical, prioritising lower-order learning objectives in the reformed curricula may not be justified.

One pitfall of subscribing to the hierarchical model of cognitive skills is that it may widen the gap of learning opportunities provided to high- and low-achieving students. Zohar et al. (2001) showed that low-achieving students chronically experience teacher instructions with lower cognitive demands than their academically stronger peers. Teachers may feel that low-achieving students are not yet ready for tasks requiring higher-order thinking. However, a follow-up study demonstrates that both low- and high-achieving students make significant gains from interventions fostering higher-order thinking (Zohar & Dori, 2003). Research has also shown that the cognitive demand of a task does not automatically correlate with the task's difficulty (Momsen et al., 2013). Thus, learning objectives with higher-order cognitive demand must remain an essential component of the reformed syllabi for all students, rather than being seen as an extension for more able learners.

Finally, a side effect of an increased emphasis on retrieval and comprehension of a broad knowledge base is that learning objectives in the reformed syllabi have become more prescriptive. Tight specifications for the type and depth of content knowledge to be taught at a specific cognitive level have replaced more flexible and student- or context-orientated syllabus specifications. A standardised one-size-fits-all approach to curricula may result in teachers resisting some reform changes (Barton et al., 2014; Tytler, 2007b). Moreover, there have been greatly reduced opportunities for the differentiation of content matter based on students' backgrounds or local contexts, and participation of students in community or industry-linked projects. The implementation of such standardised learning objectives may be problematic in settings with a high diversity of students and learning environments. Regional, remote, and rural students may be particularly disadvantaged and disengaged by a "subject-based" rather than "place-based" curriculum (Halsey, 2018, p. 33). The nature of subject-based learning seems to favour lower-order thinking, while place-based learning, which is characterised by interdisciplinary and learner-centred inquiry, can increase opportunities for higher-order thinking (Vander Ark et al., 2020). In this manner, the structure of the reformed syllabi favours learning objectives with lower cognitive demands.

8.2.2. Textbooks as De Facto Curriculum Trump Syllabus Learning Objectives

International studies of science curricula mirror this study's results on the alignment between lessons and textbooks. For example, Ziebell et al.'s (2017) curriculum alignment project examined science curricula in Australia, China, Finland, and Israel. These researchers reported a strong influence of textbooks on science teachers' lesson planning and the cognitive demands of questions asked in class. The study also found that science teachers' planned instructions were not always as well aligned with the prescribed curriculum as with textbook content. It may therefore not be unusual that the influence of science textbooks as de facto curriculum on teachers' planning trumps the influence of learning objectives in curriculum documents.

Reasons for teachers relying strongly on textbooks centre around practicality, institutional conventions, and funding. Research suggests that textbooks reduce teachers' perceived workload (Moulton, 1994; Stewart, 2014). Senior teachers implementing the reformed Queensland syllabi in 2020 had to develop new teaching and learning sequences and learn how to scaffold new types of assessment. Therefore, these teachers would have likely embraced textbooks as a time-efficient planning resource. Textbooks are traditionally seen as credible sources of information that provide a familiar structure or routine to lessons (Stewart, 2014), which may have been particularly welcomed when teachers were delivering new and unfamiliar content. In some schools with low budgets for learning resources, textbooks may have been the only available resources for classroom instructions that are tailored specifically to the reformed curriculum, easy to use and clearly organised. Last but not least, teachers in this study may have been less inclined to implement curriculum flexibly by deviating from textbook content in the first year of reform implementation in Year 12. This is particularly relevant when considering the impending first round of external examinations that may have forced them to focus on the "exam's needs" more than on "students' needs" (Scott & Husain, 2021, p. 243).

The problem is that textbooks do not necessarily offer learning tasks with the same cognitive demands as envisioned by syllabus developers. This study has found that lower-order thinking tasks dominate textbook questions in all three sciences. Therefore, teachers relying on textbooks may be less likely to teach content to the prescribed cognitive depth and students may receive fewer opportunities to develop higher-order thinking skills. This inequality would be magnified in remote areas where teachers' reliance on textbooks may be higher, as fewer specialist science teachers are available to fill positions and more teachers are employed to teach outside of their area of expertise (Halsey, 2018; Weldon, 2015).

Considering these issues, the learning philosophies and values of textbook authors and publishers may require greater attention. Textbook authors who are not part of the syllabus writing team might assume pedagogical intents that are not necessarily in line with the intents of syllabus writers. For instance, textbooks examined in this study do not emphasise inquiry learning in the same way the reformed syllabi do. Therefore, not all textbook authors may carry the same beliefs about Australian science education as curriculum writers, including the belief that students learn science by practising a wide range of cognitive skills (QCAA, 2021). Textbook authors' choices of cognitive demands also have the potential to send covert messages to students about the nature of scientific knowledge (e.g., knowledge not being open for exploration), and define students' experience of a subject (Valverde et al., 2002), in the worst case by introducing students to a narrow range of learning tasks with low cognitive demands. Additionally, textbook authors may underestimate the degree to which their interpretation of syllabus documents and their subsequent design of learning tasks may influence the enacted curriculum by dictating what type of thinking is practised during lessons. Thus, science textbook writers may need information and guidance to purposefully write tasks with higher cognitive demands that positively influence teaching practice.

Finally, the literature review identified a lack of ample teaching resources as one significant factor lowering the alignment of cognitive demands (Albadi et al., 2019; Boesen et al., 2014; Öztürk Akar, 2014; Penuel et al., 2009). Considering the high cost of textbooks, equity disparities between schools with varying access to different textbooks and resources may widen (Yu et al., 2022). Such impact of varying opportunities to learn is larger for students from minority groups (Anderson, 2002), thus contributing to social injustice. As such, a school's textbook selection needs to be acknowledged as a factor impacting student achievement and learning outcomes (van den Ham & Heinze, 2018) and should ideally not be linked to the school's business relationships with specific publishers. This study has found that textbook publishers vary in their emphasis on knowledge utilisation tasks, so teachers require access to multiple textbooks to source questions of varying cognitive demands on any content topic.

8.2.3. Low Alignment of Cognitive Demands After Reform Efforts

Compared to past research on the cognitive demands of science lessons (e.g., Canon & Metzger, 1995; Ulmer & Torres, 2007; Zohar et al., 1998), this study found that senior science teachers provide their students with frequent opportunities to actively develop cognitive skills at all levels. An almost even balance of teacher instructions fostering higher- and lower-order thinking was observed, and students were encouraged quite frequently to use metacognition. Nevertheless, the reported alignment between the cognitive demands of the prescribed and enacted curriculum is low, indicating that the change of enacted curricula after reforms takes time and may not yet be fully completed two years after the reform implementation. It would be unrealistic to expect perfect alignment as no prescribed curriculum remains completely unchanged while it is enacted in diverse contexts (Sherin & Drake, 2009). However, very low curriculum alignment may limit student achievement (Kurz et al., 2010) and result in a negative judgement of teaching quality, regardless of the actual quality of teachers' instructions (Anderson, 2005). For both reasons, schools are held accountable for the provision of student learning opportunities that are in line with curriculum documents prescribed by a state curriculum authority.

It seems that, to increase curriculum alignment after reforms, teachers' professional philosophies, values, and habits need to be acknowledged as factors that can slow or inhibit change (Alfrey et al., 2017; Dinan Thompson, 2001; Krüger et al., 2013). Wilhelm (2014) showed more specifically that teachers' beliefs about what constitutes high-quality instructions relate to the type of tasks they select for their students and the cognitive demands of teachers' instructions when implementing those tasks. Of course, contextual factors in the school community (e.g., school culture, parent expectations, or available resources) also play a role in diversifying the enactment of prescribed curricula (Krüger et al., 2013) and may explain different school's high variance in the cognitive demands of the enacted curriculum.

Furthermore, the alignment of the prescribed and enacted curriculum is interrelated with a third aspect of schooling, namely the assessment (Bernstein, 1977; Ziebell & Clarke, 2018). Research has demonstrated a *washback effect* (Tsagari & Cheng, 2017) of assessment, in particular high-stakes examinations, on the enacted curriculum. This effect is caused by narrowing curriculum content to assessed content, fragmenting knowledge into test-related segments, and increasing the use of content-centred transmission pedagogy (Au, 2007; Jonsson & Leden, 2019; King & Zucker, 2005). Therefore, the emphasis on retrieval and analysis found in this study may be partially due to the alignment of the enacted curriculum with the assessment of learning outcomes through a heavily weighted external examination which may be restricted in its assessment of cognitive skills by inherent demands for efficiency, reliable scoring, and standardisation (Jonsson & Leden, 2019). For example, multiple-choice and short-response questions, which tend to be overrepresented in examinations, lend themselves best to the assessment of retrieval and analytical skills (Marzano & Kendall, 2007).

Queensland's Review of Senior Assessment and Tertiary Entrance (Matters & Masters, 2014), which informed changes introduced by the senior curriculum reform, promised that "new assessment technologies will provide capability to assess a much wider range of outcomes, including higher-order cognitive processes such as problem solving and creativity" (p. X) and that "it [the assessment] must promote high-quality teaching and learning of the entire subject syllabus" (p. 38). Data are needed to evaluate whether newly introduced assessment types meet this description. If the new assessment modes and their relative contributions towards students' final grades do not align with the prescribed curriculum's aims for cognitive skills development, contradicting messages may be sent through curriculum objectives and the assessment (Gallagher et al., 2012). Research shows that in high-stakes testing regimes, authentic higher-order thinking tasks may be replaced by repeated practice or 'drilling' of specific higher-order thinking exam questions (Zohar & Alboher Agmon, 2018). Therefore, the assessment regime of the reformed senior system may constrain the full realisation of learning objectives structured according to the New Taxonomy of Educational Objectives, which aims to foster a learner-centred curriculum and provide the opportunity to teach and assess a wide range of cognitive skills.

In this study, one significant source of misalignment between the prescribed curriculum and enacted curriculum is insufficient knowledge utilisation tasks in chemistry and physics lessons. It may be that the increased number of specific learning objectives in the reformed syllabi has decreased opportunities for time-intensive knowledge utilisation in lessons. Subjects with more learning objectives (i.e., chemistry) provide fewer instances of knowledge utilisation tasks in the enacted curriculum than subjects with noticeably fewer learning objectives (i.e., biology). Furthermore, the more prescriptive senior syllabi may have contributed to teachers opting for a didactic teaching style that focuses on the transmission of content knowledge (Krüger et al., 2013). The problem is that reducing uncertainty around knowledge, and thus the need for students to figure out some knowledge for themselves, may automatically decrease the cognitive demands of the enacted curriculum (Wilhelm, 2014). The observed teachers seemed to have limited inquiry learning to address a short list of mandated practical investigations that are relevant to assessment, and students were consequently exposed to fewer knowledge utilisation tasks than intended by the syllabus.

Emphasising inquiry learning as suggested in the Teaching and Learning section of each senior science syllabus (e.g., QCAA, 2018b) may increase alignment between the enacted and prescribed curriculum and raise the cognitive demands of lessons. Additionally, it may limit or constrain the influence of textbooks on teachers' instructions because authentic knowledge utilisation tasks leave less room for uncritically adopting decontextualised analysis tasks, which are more prevalent in textbooks than prescribed by the syllabi. Increasing the frequency of knowledge utilisation tasks will require intentional effort by science departments as well as clear endorsement of professional development opportunities for inquiry learning from educational authorities like the QCAA.

8.2.4. Lack of Congruence Between the Enacted Curriculum and National Goals for Science Education

Effective science education in Australian schools is described as relevant to students' lives and interests, resulting in meaningful understanding of science knowledge (Australian Science Teachers Association, 2002; Rennie et al., 2001). However, lessons and textbooks that favour analysis over knowledge utilisation tasks and retrieval over comprehension tasks can result in a lack of the subject's authentic content knowledge application. Analysis tasks typically consist of subject-specific scenarios in highly controlled circumstances that do not mirror real-world situations, while knowledge utilisation tasks more frequently require interdisciplinary solving of realistic problems (Marzano, 2009). Retrieval tasks do not require students to make personally meaningful connections between learned knowledge like comprehension tasks do. In addition, self-system thinking is almost omitted in all examined components of the senior science curriculum, suggesting a content-centred curriculum rather than a student-centred curriculum, which has been shown to characterise successful secondary science programs (Scogin et al., 2018).

Combined, these findings potentially contribute to low student engagement and motivation due to a perceived irrelevance of senior science subject matter to students' personal lives. In the long term, neglecting the affective involvement of students by treating self-system thinking as an optional component of the hidden curriculum can reduce the number of secondary students who enrol in a senior science for intrinsic reasons (Krüger et al., 2013), thus exacerbating the declining interest in science education (Ong et al., 2022). This is incongruent with national science education goals to increase young people's engagement with and aspirations for STEM careers (Education Council, 2015). It seems the implementation of the reformed syllabi is currently lacking an impetus for creating sustained interest and long-term engagement with science, which would require an increased focus on students' personal experiences and concerns (Goodrum & Rennie, 2007). This may also involve the application of subject matter with ethical, social, and economic matters relevant to students' immediate environment, so students can appreciate the contribution of scientific knowledge to advancements in their communities.

Interviews with Australian students revealed that disengagement with science subjects also stems from teachers' dominant pedagogical approaches (Lyons, 2006). The lessons observed in this study were dominated by a narrow range of instructional approaches that prioritise individual over collaborative learning, and mostly teacher centred learning activities. Research suggests that the observed narrow range of learning activities may be typical for senior science lessons (Danaia et al., 2013; McEwen et al., 2001). Thus, the nature of science teacher instructions, and particularly infrequent student-centred and collaborative learning, may further reduce the relevance of science to students, resulting in lower engagement (Danaia et al., 2013). To combat this situation, practitioners in STEM fields call for school science education to better represent contemporary science practice (Tytler & Symington, 2006).

The implementation of an effective interdisciplinary curriculum as a further goal of the Australian Government for national STEM education (Education Council, 2015) may not be congruent with the lessons observed in this study. Inquiry tasks were highly structured to prevent diversion from prescribed subject matter and analysis tasks were dominated by deductive reasoning. Therefore, lessons did not typically foster knowledge integration from related school subjects, although it is necessary to solve authentic problems in life beyond school. Prescriptive syllabus objectives coupled with summative assessment regimes often constitute a big obstacle to interdisciplinary STEM education (Falloon et al., 2022). The mandated split of scientific knowledge into pure disciplines itself may provide a constraint to multidisciplinary knowledge integration and authentic knowledge utilisation tasks. Due to this lack of an interdisciplinary curriculum, combined with the infrequent collaborative practice within each subject, observed senior science lessons did not resemble workplaces in STEM careers.

Finally, fostering critical and creative thinking is a cross-curriculum goal of Australian Prep to Year 10 education (ACARA, 2018) and the reformed Queensland senior system (QCAA, 2015). However, the dominance of retrieval in lower-order thinking tasks and the dominance of theoretical analysis in higher-order thinking tasks, both in lessons and textbooks, may contribute to students' perceptions that science knowledge is fixed with an indisputable correct answer. It may not be conducive to developing active citizens who scrutinise authority and critically evaluate information presented in media (Tanchuk, 2020). There is a tension in Queensland between statements in policy documents that call for a focus on scientific literacy or 21st Century Skills and actual classroom practice which is restrained by the standardised and content-heavy learning objectives in the prescribed curriculum. This tension has also been reported in other jurisdictions in Australia (Tytler, 2007a) and overseas (Zohar, 2013). It seems to be an unresolved gap between rationales for science education in policy documents and the realities of classroom teaching (Fensham, 2009).

8.3. Research Contributions

The research findings carry implications for the study of curriculum alignment, the implementation of curriculum reforms, teacher education, and science education pedagogy. The following section elaborates on the research contributions to each field.

8.3.1. Implications for the Study of Curriculum Alignment

This study describes the interplay between the cognitive demands of the prescribed, de facto, and enacted curriculum. As curriculum moves from learning objectives in official documents to instructional resources (e.g., textbooks) and to classroom learning experiences, it is transformed and reformulated (Remillard & Heck, 2014). This study illustrates how learning tasks can change their cognitive demands throughout this process. While most curriculum alignment research focuses on the comparison of tasks in the assessed curriculum with other curriculum components, this research is unique in measuring the alignment between three aspects of a curriculum that build on each other during implementation: the learning goals, the resources aiming to achieve those goals, and the teaching which relies on those resources. It shows that the de facto curriculum's influence, which is often overlooked in alignment studies, should not be underestimated.

Furthermore, this study demonstrates that educational taxonomies can be highly useful classification frameworks for alignment research. The selection of the appropriate educational taxonomy for each new study will be context dependent and founded on awareness that no educational taxonomy is free of limitations (Dettmer, 2005). The New Taxonomy of Educational Objective was appropriate for this research as it underpins the reformed senior science syllabi (QCAA, 2017b). However, the cognitive level *analysis* is very broad in the New Taxonomy, which makes it difficult to differentiate between applying or specifying knowledge and the reverse process of generalising knowledge. Other educational taxonomies, such as Bloom's Taxonomy, distinguish between the application of knowledge, which includes specifying, and the analysis of knowledge, which includes generalising (Bloom et al., 1956). In these frameworks, application is often classified as lower-order thinking whereas analysis is classified as higher-order thinking. A differentiation between application and analysis in this study may have resulted in classifying more cognitive skills as lower-order thinking in all three analysed curriculum components. This example shows how the chosen classification framework can influence the results of alignment studies. Nevertheless, the methods employed in this study represent an effective and relevant adaptation of published curriculum research models, linking Marzano and Kendall's (2007) New Taxonomy of Educational Objectives with Porter's (2002) curriculum alignment model.

Finally, this research questions the assumption that full alignment of curriculum components is the most desirable outcome of alignment studies. Since knowledge in the enacted curriculum is constructed together with students in unique contexts, it may not be feasible or even beneficial to aim for perfect alignment (Remillard & Heck, 2014). A state-wide *one size fits all* curriculum may materialise as a *one size fits few* curriculum because it cannot align with diverse learning needs (Bondie et al., 2019). An extensive review of regional, rural, and remote education in Australia emphasises the benefits of curricula that are interpreted with attention to local circumstances (Halsey, 2018). Standardisation comes with many benefits, but also at the cost of losing local context and the ability to differentiate effectively for a diverse student body that might be motivated by local contexts. As in other Australian jurisdictions, there is a tension between the desire for curriculum uniformity and the need for teachers to have the autonomy to incorporate relevant local initiatives in their curriculum (Tytler, 2007a). In the reformed Queensland senior system, the summative school-based assessment instruments were designed to reflect students' interests and local contexts (Matters & Masters, 2014). Future research on implemented assessment pieces must determine whether this has been achieved.

8.3.2. Implications for the Implementation of Curriculum Reforms

The Queensland senior curriculum reform has been accompanied by a range of online resources supporting teachers' interpretation of syllabus requirements, correct use of cognitive verbs in the New Taxonomy, and implementation of new assessment types (QCAA, 2022). The standardised nature of the reformed senior science syllabi increases external control of the curriculum and may limit teachers' ability to adapt the curriculum in response to students' needs (Scott & Husain, 2021). Thus, teachers implementing the curriculum reform may be less involved in curriculum design than in the implementation of resources that match, or seem to match, prescribed syllabus objectives. In this case study, textbooks constitute such a curriculum implementation resource as their impact on the cognitive demands of the enacted curriculum seemed to be high. Therefore, textbook authors carry great responsibility for determining the cognitive demands required for students to construct their science knowledge. The role of science textbooks may need to be reconceptualised from a summary of static knowledge to a resource that stimulates higher-order thinking about knowledge prescribed by the reformed syllabi. Additionally, textbooks could provide greater opportunities for metacognitive and self-system thinking to develop motivated and independent learners who will become scientifically informed citizens.

The research findings suggest a necessity for informing textbook publishers and authors of the intentions and philosophies behind each curriculum reform. The low alignment of higher-order cognitive demands between the syllabus objectives and textbook questions may reflect ineffective coordination between curriculum developers and textbook authors, who may have diverging beliefs or assumptions about how science should be taught at a secondary level. To enhance the alignment between the prescribed curriculum and textbooks, it would be good practice to have at least one author on the writing team who has also been involved in the development of the reformed curriculum, which is the case in some but not all textbooks analysed in this study. The methodology used in this study to assess the alignment of textbook questions with syllabus learning objectives may also be of interest to textbook publishers who aim to publish more aligned textbook editions.

For curriculum reforms to be implemented fully, it seems crucial to communicate that a change in learning objectives entails a change in cognitive demands as well as a change in content knowledge. Too often, the intent to align a new curriculum focuses exclusively on a change in content knowledge. Cognitive skills can be perceived as independent to content knowledge rather than a tool for learning the prescribed knowledge to a certain cognitive depth. Intentionally aligning this prescribed cognitive depth with the cognitive demands of classroom learning would result in a more successful implementation of a reformed curriculum. To achieve this, teachers need to receive explicit training in how to enact both knowledge and cognitive skills of each learning objective, and how to recognise or create learning tasks at any cognitive level. The next section elaborates on such teacher education.

8.3.3. Implications for Teacher Education

Teaching content matter at the prescribed cognitive level requires teachers' intentional effort and planning. It also requires teachers' deep understanding of differences between cognitive levels. Ideally, teachers need opportunities to practise formulating lesson instructions and activities at each cognitive level. To date, professional development providers in Queensland have primarily emphasised teaching the definitions and use of cognitive verbs to students, so they know how to correctly respond to examination questions. However, teaching the meaning of cognitive verbs does not automatically change the cognitive demand of teachers' learning activities. Provided teacher webinars and resources (e.g., the Cognitive Verb Toolkits; QCAA, 2018e) contain limited focus on exemplary teaching at each cognitive level, even though professional development that focuses predominantly on resource provision and curriculum content (i.e., the definition of verbs) has been discredited (Tytler, 2007a).

Zohar and Dori (2003) suggest structuring teachers' professional development focused on cognitive skills around three themes: theoretical considerations, empirical evidence, and practical tools. To develop Queensland teachers' understanding of the theoretical underpinnings of cognitive skills in the reformed syllabi, the QCAA has developed online modules and webinars addressing the structure and uses of the New Taxonomy of Educational Objectives. Such learning about theoretical frameworks allows teachers to recognise what level of understanding their students are demonstrating. This learning also cultivates teachers' awareness that different learning tasks allow students to demonstrate their learning at different cognitive levels (Panizzon & Pegg, 2008). Furthermore, the learning supports different teachers' consistent interpretations of cognitive verbs in the syllabi by creating a shared understanding of the words' meanings.

The same QCAA online modules list empirical evidence that supports the use of educational taxonomies for interpreting syllabus objectives and lesson planning. Arguably, challenging teachers to generate empirical evidence themselves by using the educational taxonomy for curriculum mapping exercises may be more effective professional development (Martone & Sireci, 2009; Shalem et al., 2013). Mapping the cognitive demand of curricula and analysing curriculum alignment carries inherent benefits as it helps educators become more familiar with standard and assessment details (Martone & Sireci, 2009). It also improves educators' ability to interpret learning objectives and assessment questions (Ziebell & Clarke, 2018). For reflection on cognitive demands of classroom practice, schools could use observation protocols like the one used in this study for peer observations.

Practical tools for professional development could entail subject-specific examples of instructional strategies at each cognitive level and learning activities that integrate lower with higher-order thinking. Such examples could be provided as sample lesson plans or short videos on best practice for teaching cognitive skills, metacognition, and self-system thinking. In this way, professional development could strengthen teachers' pedagogical content knowledge; that is, how to effectively teach particular content at a particular cognitive depth (Loughran et al., 2012). A successful Victorian professional development model for science teachers strengthened pedagogical content knowledge by prioritising team planning of units, collaborative development of learning resources, and sharing of ideas about pedagogy (Tytler, 2009). Improved pedagogical content knowledge is, in turn, a factor contributing to the successful implementation of reforms by increasing teachers' ability to align the enacted curriculum (Avargil et al., 2012).

To make integrated STEM education a national priority, the government may need to invest in courses, initiatives, and practical resources that help science teachers change their pedagogical practices and align the cognitive demands of their instructions with the cognitive demands of STEM workplaces. For example, teachers could be provided with opportunities and time to participate in the application of science during local community and industry events. Since funding for teachers' professional development is controlled at a school level, courses and resources would need to be incentivised and advertised. To achieve a lasting impact, such initiatives would also need long-term funding and enough flexibility to respond to the current needs of teachers or schools (Tytler, 2007a).

An additional focus on cognitive skills during pre-service teacher education may assist in influencing new beliefs and practices that are aligned with the reformed science curriculum. Teachers' beliefs about the structure and interdependence of cognitive levels influence how they teach (Zohar et al., 2001). For example, teachers who carry a conviction that the retrieval of a broad knowledge base is a prerequisite of higher-order thinking may prioritise lower-order thinking skills in their lessons. Teachers' views on what constitutes good teaching in their subject area can also influence their receptiveness to unfamiliar pedagogical approaches (Collopy, 2003; Tytler, 2007b). Thus, teacher education is responsible for shaping pre-service teachers' attitudes towards appropriate teaching strategies that foster a range of cognitive skills in science lessons. Such education is particularly relevant because it is likely that pre-service teachers have experienced traditional teacher-centred pedagogies with predominantly low cognitive demands in science lessons during their own schooling.

8.3.4. Implications for Science Education Pedagogy

Lastly, the research findings stimulate discussion regarding senior science pedagogy, which may be the key element for improving students' learning outcomes (Tytler, 2009).

These discussions should aim to increase diversity in learning activities and increase the alignment of cognitive skills in the enacted curriculum and prescribed curriculum. Teachers would benefit from more specific information on how to incorporate different cognitive skills in students’ learning experiences, ideally via demonstrations delivered by professional development tutors in teachers’ classrooms (Adey, 2006). Modelling effective science pedagogy, such as cooperative learning in teacher education courses can also increase teachers’ willingness and ability to implement the pedagogies (Keramati & Gillies, 2022).

An increased emphasis on cooperative learning or inquiry learning in science classrooms may subsequently have a positive impact on the cognitive demands of the enacted curriculum (Cian et al., 2018; Gillies, 2008; Gillies & Boyle, 2006). The result may be an increased focus on authentic knowledge utilisation, metacognition, and self-system thinking. A shift towards such student-centred learning increases students’ opportunities to develop self-regulation skills, which would enable their independent and life-long learning (Marzano & Kendall, 2007). In this manner, more future citizens would be empowered to follow current scientific developments, and public perceptions or attitudes towards contemporary science may improve. This is valuable for today’s knowledge society, as it may not be possible to be a productive citizen without engaging with current science-based issues (Symington & Tytler, 2004).

The findings drawn from this study’s analysis of lesson observations also highlight the importance of teachers’ questioning skills for curriculum alignment. These findings call attention to the need for consciously and purposefully asking questions during lessons that develop students’ cognitive skills at all levels. Planning key questions in advance for each topic would support such an outcome (Marsh, 2010). Teachers tend to question in the same manner they have been questioned throughout their own education (Hus & Abersek, 2011). To break a potential cycle of favouring lower-order thinking questions, teachers could benefit from observing examples of higher-order questioning in their subject area that may challenge their perspectives on how to teach certain content knowledge (Smart & Marshall, 2013).

School departments, in turn, could benefit from identifying and examining the sources of authority their teachers consult for their lesson planning. Learning activities in school unit plans, textbooks, or shared departmental resources like PowerPoint presentations need to be well aligned with the cognitive demands of syllabus learning objectives. Following school closures during the COVID-19 pandemic, online teaching resources have become increasingly convenient. However, these resources may not be well aligned with the prescribed curriculum. The methods for evaluating curriculum alignment adopted in this study may thus become more relevant for teachers. For example, this study's analysis framework can be applied by teachers who choose to critically analyse or compare available digital resources or textbooks. The framework could help educators categorise textbook tasks based on their cognitive demands, and support the selection of appropriate learning activities to address each syllabus objective while simultaneously creating an awareness that any one textbook may not offer the required range of cognitive demands. If possible, the department's textbook choice should not be the responsibility of a single person and it should entail a reflection on whether learning tasks in the textbook align with the school's philosophy on science education and the local context. Appropriate funding for lesson planning resources is also vital to avoid overreliance on a single source of authority (Scott & Husain, 2021).

8.4. Study Limitations and Recommendations for Further Research

Some contextual and methodological factors limit the validity of this study's conclusions and implications. This section describes the limitations of this study's sample, restrictions placed on data collection due to the COVID-19 pandemic, limitations of the chosen analysis framework, and curriculum components that exceeded the scope of this study. Where appropriate, these limitations are followed by recommendations for future research.

Time and budget constraints restricted the outcomes of this higher degree research project. For example, the number of lessons observed for the case study was limited to 82 and the number of sites visited was limited to seven schools within 100 km of Cairns, Far North Queensland. Therefore, the results are not generalisable to teachers across other parts of the state. Regardless, these results offer a valuable and authentic snapshot of alignment issues that may arise while implementing a curriculum reform. Follow-up studies could consider collecting longitudinal data on the reform implementation to determine if the cognitive demands of the enacted curriculum change as teachers become more familiar with syllabus expectations over several years.

Restricted access to schools due to COVID-19, combined with the hesitance of school principals to allow additional visits by the researcher, resulted in a change of study aims. The de facto curriculum of textbooks was analysed and conducting qualitative follow-up interviews with the observed teachers to discuss factors influencing teachers' planning of the enacted curriculum was not possible. Consequently, this study cannot confirm the main influences on teachers' enacted curriculum in Queensland following the reform. Future research on teacher beliefs about quality science teaching, as well as contextual factors and planning resources that affect the cognitive demands of lessons, is needed to devise practical strategies that increase curriculum alignment. Such research may also clarify whether senior science teachers working in different subject areas have different teaching philosophies that influence lesson instructions with different cognitive demands. Ziebell and Clarke's (2018) curriculum alignment study in Australian mathematics and science classrooms suggests that the cognitive demands of teachers' instructions can be subject specific.

This study analysed the alignment of cognitive skills, which is only one aspect of curricula. The used analysis framework cannot determine the alignment of content knowledge or the difficulty of content matter, which is distinct from cognitive demand (Polikoff et al., 2020). Furthermore, the classification of cognitive demands was limited by the cognitive levels theorised by the New Taxonomy of Educational Objectives (Marzano & Kendall, 2007). This theoretical framework was chosen to reflect the decision of curriculum developers to use the New Taxonomy as an underpinning framework for syllabus objectives and assessment items (QCAA, 2017b). Further data collection is needed to explore the taxonomy's usefulness for increasing the alignment of the enacted curriculum. For instance, action research projects could determine whether teachers' knowledge about the cognitive levels of the taxonomy correlates with an increased alignment of the prescribed curriculum and enacted curriculum.

The analysis of teacher instructions offers valid conclusions about the cognitive demands of offered learning, but not necessarily the depth of students' thinking. Therefore, the study does not draw conclusions about students' learning outcomes or the attained curriculum (International Bureau of Education, 2022). The relationship between the enacted curriculum's provided opportunities to learn and students' actual learning outcomes is complex (FitzPatrick et al., 2015) and exceeded the scope of this research. Future studies could use think-aloud protocols to determine how factors such as prior knowledge and experience influence the cognitive skills students use to complete a learning task. For example, think-aloud protocols can be used while students respond to questions of varying cognitive demands, as demonstrated by Gierl (1997) in mathematics classrooms.

It is still unclear how to best balance standardised and rigorous senior science curricula. Such curricula must build a broad knowledge base to prepare students for STEM tertiary courses, yet must simultaneously allow for the authentic and contextualised inquiry that professional scientists engage in. Educators' regular empirical evidence and critical reflection will be necessary to achieve this balance in the reformed syllabi. Further research on the effects of the reformed enacted curriculum may clarify the reform's effect on students' participation in the sciences both during and beyond school.

Analysing the cognitive demands of the assessed curriculum also exceeded the scope of this research project. The alignment of the assessed curriculum has been more thoroughly studied than the alignment of other curriculum aspects, thus the gap in knowledge was not acute. Moreover, very limited data on the cognitive demands of summative assessment tasks were available in the first two years of the reform implementation, as only one cycle of school-based assessments and external examinations had been conducted. For now, the alignment of the assessed with the prescribed curriculum is assumed based on the QCAA's (2018a) senior assessment quality assurance processes, which include an appraisal of assessment items' alignment with syllabus learning objectives as part of judging the assessment's validity. This quality assurance process aims to ensure the comparability of assessment across the state (Matters & Masters, 2014). Once several cycles of external examinations have been released, their cognitive demands could be evaluated in combination with the cognitive demands of school-based assessment as the level of cognitive skills assessed can be a strong influence on the cognitive demands of teacher instructions (Fensham & Bellocchi, 2013).

Finally, the scope of this research project and the timeline of the higher research degree prevented the immediate follow up of unexpected findings. For instance, it was surprising that the described differences between the cognitive demands of textbooks and teacher instructions for physics, chemistry, and biology were minimal. Furthermore, no clear differences were found in the cognitive demands of Year 11 and Year 12 lessons. This is potentially because all reformed Queensland science syllabi have subject matter content descriptors developed from the same seven general syllabus learning objectives. Additionally, all science subjects use the same four types of summative assessment with identical marking criteria in Year 11 and Year 12. Teachers of the three senior sciences are also generally part of the same department and are working under the same Head of Department. Therefore, the culture in that department may perpetuate pedagogical content knowledge and the cognitive demands of the enacted curriculum. It would be informative to replicate this case study in other departments, such as mathematics or the humanities. Differences found between the cognitive demands of the curriculum enacted by teachers at different schools, on the other hand, were larger than expected. This study did not aim to compare schools with different contexts, and these results have not been discussed or examined in depth. However, contextual factors clearly introduce a large variance in the cognitive demands of enacted science curricula at different schools.

8.5. Concluding Remarks

Teaching entails a choice between what knowledge to emphasise (i.e., the what) and which learning activities to facilitate (i.e., the how). The how determines which cognitive skills students use to gain knowledge and the cognitive depth to which they can demonstrate their learning. Cognitive skills are an important aspect of curricula, yet they can be easily overlooked or inadvertently changed while planning for and implementing lessons. The introduction of this thesis outlined a hypothetical scenario in which the cognitive demands of a physics learning objective on projectile motion changed throughout the curriculum implementation process (see Section 1.1.). Educators can reduce such misalignment by considering the cognitive demands of learning objectives and matching them purposefully with appropriate pedagogical choices and planned learning activities. Curriculum alignment is also stronger when educators carefully choose learning resources, including textbook content, that provides opportunities for students to learn the topic using the cognitive skills specified by curriculum writers. Curriculum writers, in turn, could evaluate the cognitive skills they specify to ensure these skills prepare today’s students for tomorrow’s challenges. This study demonstrates how curriculum writers, textbook authors, and classroom teachers all play a role in shaping curriculum priorities and regulating what type of thinking constitutes successful learning at school.

When this research project concluded, a revised version of the Prep to Year 10 Australian Curriculum for science was rolled out (ACARA, 2022). The Australian Curriculum Version 9.0 claims to have reduced subject content knowledge, increased alignment between learning objectives and achievement standards of assessment, and improved links between subject matter content descriptors and General Capabilities, which include 21st Century Skills like critical and creative thinking (ACARA, 2021). It appears that greater selective attention is given to teaching conceptual understanding to a desired cognitive depth, which would be a positive development. On the other hand, the assessment regime of the senior science curriculum and its content-centred nature may have a ripple effect on Year 10 and Year 9, as teachers aim to prepare students for the demands of learning in Year 11 and Year 12. Bellocchi et al.'s (2021) analysis of the revised Australian Curriculum for Year 10 science indicates that chosen cognitive verbs coupled with uncritical knowledge presentation limit opportunities for students to become critical consumers and producers of scientific knowledge, and therefore their opportunities for higher-order thinking. The ongoing evaluation of cognitive demands and their potential impacts on students' learning outcomes and participation in science will be crucial for the future of Australian science education.

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Appendix A.

Summary of the Pilot Study Results

1. Context

The purpose of this pilot study was to assess the effectiveness and quality of the document analysis protocol and lesson observation instrument for the main data collection in 2020. The data collection protocol followed the main study's methods with the addition of semi-structured teacher interviews. This pilot study did not include a textbook analysis. The two participating teachers (physics and chemistry) were observed three times and interviewed once.

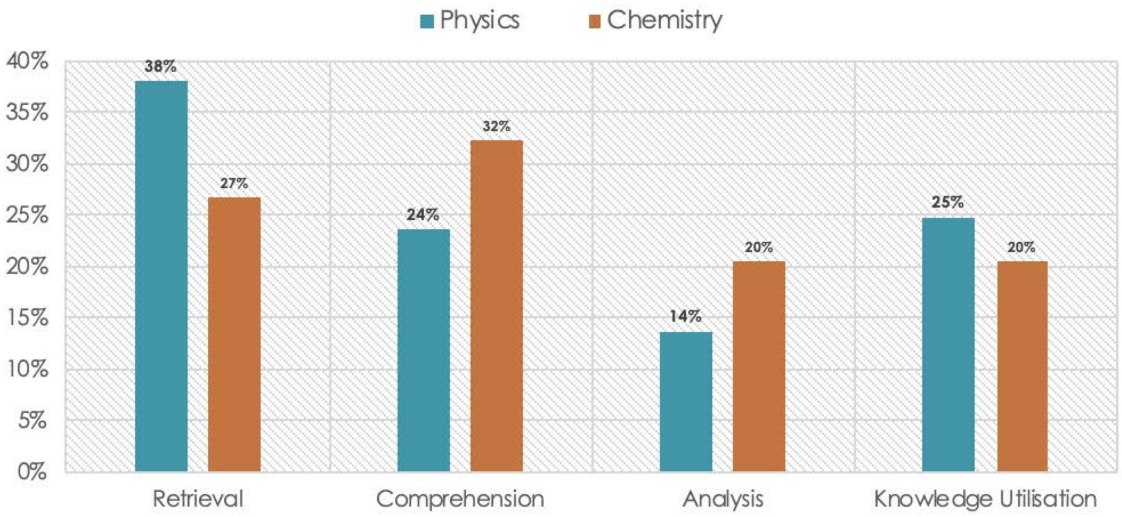
2. Results

2.1. Syllabus Analysis

Figure A1 shows the proportion of cognitive verbs at each cognitive level in the subject matter content descriptors of the physics and chemistry syllabus. The physics syllabus requires students to demonstrate 38% retrieval, 24% comprehension, 14% analysis, and 25% knowledge utilisation. Cognitive verbs in the chemistry syllabus are more evenly spread across the cognitive levels with 27% retrieval, 32% comprehension, 20% analysis, and 20% knowledge utilisation. No subject matter content descriptor makes explicit reference to the metacognitive system or the self-system.

Figure A1

Cognitive Demands of the Prescribed Curriculum



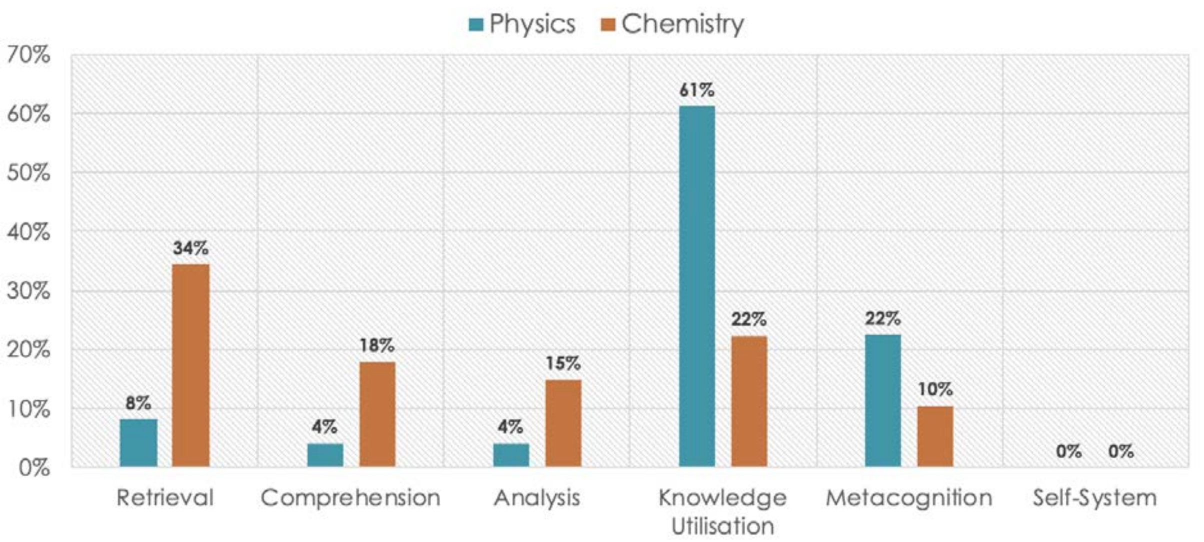
2.2. Lesson Observations

The proportions of teacher instructions at each cognitive level differ from the proportions of cognitive levels in the prescribed curriculum. Most notably, both observed teachers asked students to reflect on their learning goals and their progress with various tasks, which can be classified as metacognitive thinking. Neither teacher encouraged students to consider their motivation or self-efficacy (= self-system thinking), but since only six lessons were observed, generalisations cannot be made from this result. Even though the metacognitive system and self-system are not explicitly referred to in the learning objectives of the syllabi, they have been shown to have a positive impact on student achievement and cognitive development (e.g., Martin et al., 2000; Tornero, 2017; Venville & Oliver, 2015).

Chemistry teacher instructions were more evenly spread across cognitive levels than physics teacher instructions. In physics lessons, there was a very strong emphasis on knowledge utilisation. This may be because observations have taken place exclusively at the end of a unit, when students were given time to creatively apply their knowledge to design an investigation and solve problems as part of their summative assessment. Figure A2 summarises the cognitive demands of observed lessons for each subject.

Figure A2.

Cognitive Demands of the Enacted Curriculum

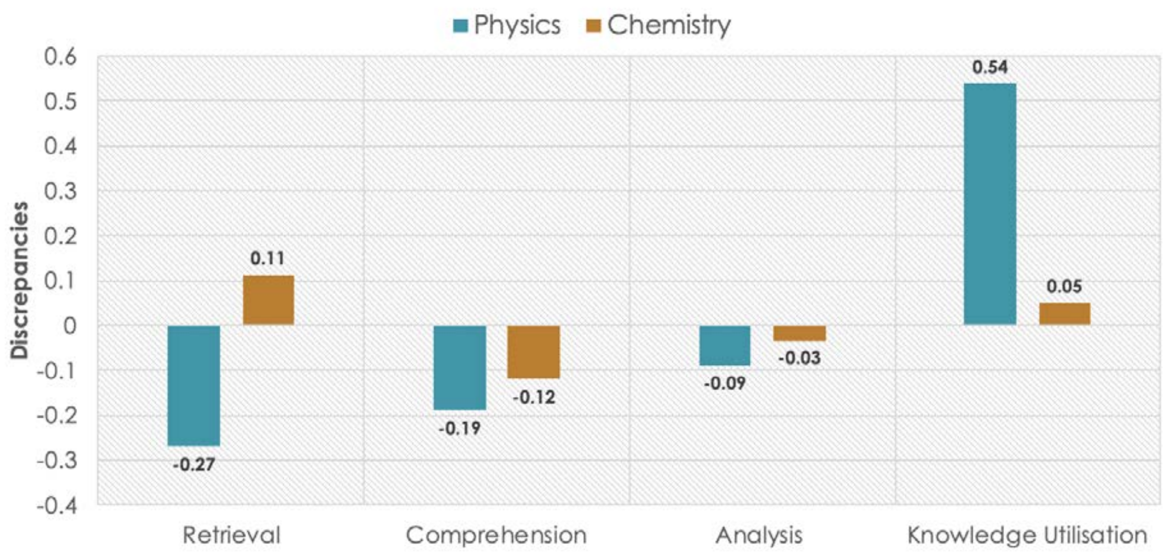


2.3. Curriculum Alignment

Discrepancies between the proportions of cognitive levels in the prescribed and enacted curriculum show which cognitive levels are overrepresented and which ones are underrepresented in observed lessons (see Figure A3). In chemistry, analysis and knowledge utilisation seem well aligned because the discrepancies are low (i.e., -0.03 and +0.05 respectively). Comprehension was underrepresented during observed chemistry lessons (discrepancy: -0.12) at the cost of retrieval, which was overrepresented (discrepancy: +0.11). In physics, teacher instructions in the observed lessons contained less retrieval, comprehension and analysis (discrepancies: -0.27, -0.19, and -0.09 respectively) and much more knowledge utilisation (discrepancy: +0.54) than is mandated by the syllabus. This pattern is contrary to findings overseas where higher-order cognitive skills are usually underrepresented and lower-order cognitive skills overrepresented in the enacted curriculum. (e.g., Khan & Inamullah, 2011; Ulmer, 2005; Zohar et al., 1998). There is some evidence that teachers who have greater knowledge of content matter more frequently teach higher-order cognitive skills (Abdullah et al., 2016) and the observed physics teacher is very experienced. However, it is more likely that the emphasis on knowledge utilisation is biased by the timing of observations, as mentioned above. Porter's Alignment Index for the enacted curriculum and prescribed curriculum across both subjects is 0.31, which is relatively low.

Figure A3

Alignment of the Prescribed and Enacted Curriculum



2.4. Learning Activities at Each Cognitive Level

Teacher instructions and classroom tasks fostering retrieval and comprehension tended to be verbal and required individual work by students (e.g., the teacher verbally directed questions at the whole class and called on individual students). Analysis and metacognitive tasks were also predominantly completed individually, but expected responses tended to be written, such as written responses to textbook questions or questions on a PowerPoint, or non-verbal responses, such as thumbs up/down signalling. Teacher instructions fostering knowledge utilisation, on the other hand, were exclusively linked to collaborative work, such as internet research or the design of an investigation in groups. As recommended by research, instructions at most cognitive levels involved guided practice with teacher feedback (De

Corte, 1990). Even though cognitive verbs were part of the classroom discourse, no explicit modelling of any cognitive skill was observed using visual representations of procedural steps or thinking-aloud practice by the teacher.

2.5. Teacher Interviews

Thematic analysis of the interview transcripts indicated two themes. The first theme found similar factors that influenced the cognitive demands of participants' enacted curriculum. These factors acted as a filter for learning objectives in the prescribed curriculum (Wallace & Priestley, 2017). Both teachers strongly prioritised teaching all content knowledge outlined in the new syllabi and were mindful of preparing their students for the new external examinations by covering all subject matter. According to the interviewed teachers, this focus on content knowledge prevented them from intentionally planning to teach cognitive skills or even planning to teach the content matter at the prescribed cognitive depth. For example, Participant 1 said:

> I would like to put more time into planning and thinking about the cognitions, but I am not. I am just trying to get through the syllabus and do questions that I know will probably be assessed.

In the participants' minds, teaching cognitive skills greatly added to their teaching workload rather than being effortlessly integrated into their current teaching processes. One teacher prioritised cognitive levels in lesson instructions that are likely to match the cognitive levels of questions on the external examination. These projections were based on the teacher's experience with the writing and moderation of assessment between schools in the old Queensland senior system. The participants' teaching habits (i.e., the way they have taught particular content matter in the past 17+ years) and textbook questions or activities were also perceived as factors influencing the cognitive demands of their enacted curriculum. Both teachers heavily relied on newly published textbooks written for the reformed syllabi. Specifically, they used the Cengage Learning Australia Unit 1 and 2 textbook with students and supplemented their lesson planning with content from the Oxford and Pearson Unit 1 and 2 textbooks. The curriculum filters mentioned by these interviewed teachers are not unprecedented, as all factors have been reported in previous studies examining influences on teachers' choices for the enacted curriculum (Remillard & Heck, 2014).

The second theme from the qualitative interviews follows from both participants seeing inherent benefits in the lesson observations and the use of the observation instrument. Teachers perceived the observations as a structured method to highlight the cognitive skills they emphasised or modelled in their teaching. By considering their individual observation results, participants may focus on cognitive skills rather than just content knowledge in their future lesson planning. Further, the school's combined observation results may inform the school of areas for internal professional development. These results reinforced participants' self-reflection on curriculum alignment. For example, the interviewed teacher participants made reflective statements, including:

> I don't feel like I do enough knowledge utilisation.
>
> I am doing a good amount of retrieval, but it is really not that diverse in the way that I do retrieval.
>
> I would like to know some more things [pedagogies] for metacognition.

The benefits of such self-reflection to teachers' professional growth are well established in the literature (Marsh, 2010).

3. Conclusion

The analysis of the pilot study results led to several modifications of the research design and data collection procedures, including the timing of observations, the recording of participant demographics, and the addition of a textbook analysis (see Section 3.2.4.). Overall, the document analysis protocol and observation instrument have proven to be effective data collection methods and the data generated from this pilot hold promise for the value of the main study in 2020.

Appendix B.

Search Keywords for the Analysis of Metacognition and the Self-System

	Verbs	**Nouns**	**Adjectives (opposites not included)**
Metacognition	Monitor Determine Check Evaluate Improve Regulate Defend (knowledge) Question Analyse Judge Examine Assess Specify Establish Develop Set Identify Accomplish Plan Rehearse Keep track (of), *track* Review Reflect Aspire Achieve	Metacognition, *mindfulness* Executive control Thought, *thinking* Process, procedure, technique, approach, strategy Performance, conducting, implementation Execution, enactment, carry(ing) out, completion Understanding, comprehension, grasp, awareness, insight, familiarity Clarity, intelligibility, comprehensibility Accuracy, rightness, reliability Correctness Validity, soundness, reasonableness Error, mistake, fallacy, misconception, oversight Ambiguity, ambivalence, vagueness, doubt Certainty, conviction, sureness, assuredness Confusion, *ignorance* Difficulty, problem, struggle Indistinction Assumption, *supposition* Reasoning, logic, interpretation Effectiveness, *success* Goal, target, desire, wish, resolve Objective, purpose, hope Plan (Needed) resources, materials, aid, help, support, means Milestone Progress, progression, advance(ment), growth, improvement Tracking Aspiration, ambition, dream, intent(ion), aim Reflection Accomplishment, achievement	Mindful Familiar Clear, comprehensible Accurate, right, reliable Correct Valid, sound, reasonable Ambiguous, vague, doubtful Certain, sure, confused Difficult Effective, how well/good, *successful*, *fruitful* Intended
Self- system	Analyse Examine Defend Identify Describe Improve Engage (with/in) Perceive Notice Desire Inspire Appreciate	Importance, *significance* Purpose, worth, motive, impetus Attitude, viewpoint, perspective, opinion, stance, standpoint, position Belief, idea, conviction, contention Value, merit, utility, desirability, principles, morals, ethics, benefit, appreciation Efficacy Ability, capacity, expertise, adeptness, aptitude, mastery Capability, potential, proficiency, experience, talent, intelligence Power Resources, *means* Competence, competency, *adequacy*, *fitness* Effort (attribution) Emotion, sensation Feeling, sentiment, sense Motivation, motive, stimulus, inspiration, enthusiasm, ambition, drive, initiative, determination (Level of) interest, real-life Attention Engagement, participation, involvement, association Self, individual Perception, *notion*	Important, *significant* Valued, appreciated, desired, esteemed, respected, admired, cherished Able, skilful, adept Good, well, better, intelligent, proficient, talented Competent, adequate Emotional (response) Motivated, inspired, enthusiastic, ambitious, driven, determined Interested Engaged, involved Personal, *own*

Note. Search keywords are derived from Marzano and Kendall's (2007, 2008) books *The New Taxonomy of Educational Objectives* and *Designing and Assessing Educational Objectives: Applying the New Taxonomy*. Terms derived from a thesaurus are formatted in italics.

Appendix C.

Principal and Teacher Information Letters and Consent Forms

JAMES COOK UNIVERSITY AUSTRALIA

02/12/2019

Dear INSERT PRINCIPAL'S NAME,

I am a Doctor of Philosophy student at James Cook University researching how cognitive skills of the new senior syllabi are taught in Biology, Chemistry and Physics.

As I am sure you are aware, cognitive skills like recalling, explaining or evaluating play a central role in the new QCE system. The newly developed syllabi seem to value pedagogy which does not focus solely on teaching content knowledge, but also equips students with knowledge processing skills needed in the 21st century workforce. Understanding of cognitive verbs is likely to become a significant component of senior students' preparation for their external examinations and there is a plethora of evidence in educational research showing that teaching of cognitive skills is linked to improved student outcomes. This is why I am very interested in exploring these matters in Far North Queensland. Being a Biology teacher myself, I am focusing on cognitive skills taught in three senior sciences.

I would like your permission to invite the Biology, Chemistry and Physics teachers at your school to participate in my study. Participation would be voluntary and teachers would have the right to stop their participation at any time without explanation. The inconvenience to your school and participating teachers would be low and the study does not have potential for distress to staff or students. I would like to observe three lessons of each participant and record the cognitive level of classroom instructions as well as the pedagogies used to teach cognitive skills in Terms 1-3 of 2020. I would also like to conduct a 45 minute audiotaped interview with each observed teacher at the end of Term 4, 2020.

Of course, the school's name and all participating teachers' identities would stay anonymous. Moreover, the collected data would be limited to this research, although results may ultimately be presented in formats other than my thesis, such as journal articles or academic conference papers. Upon completion of my research, I would share my findings with you, the participants, Education Queensland and Queensland Catholic Education.

My study has the potential to partially evaluate the implementation of the new QCE system by measuring the extent to which cognitive skills taught in classrooms match cognitive skills prescribed by the new senior curriculum. Moreover, results may be able to support teachers to purposefully and effectively teach cognitive skills.

Should you agree to participate, please sign the attached letter of approval and return it via email. Alternatively, feel free to formulate your own letter of approval.

Thank you for your time. If you have any questions about the study, please contact me or my academic supervisor Dr Helen Boon. I would genuinely appreciate your participation.

Sincerely,
Claudia Pudelko

Principal Investigator:
Claudia Pudelko (BEd Honours)
College of Arts, Society and Education
James Cook University
Email: claudia.pudelko@my.jcu.edu.au

Supervisor:
Helen Boon (BSc, PhD, PGCE)
College of Arts, Society and Education
James Cook University
Phone:
Email: helen.boon@jcu.edu.au

If you have any concerns regarding the ethical conduct of the study, please contact:
Human Ethics, Research Office
James Cook University, Townsville, Qld, 4811
Phone: (07) 4781 5011 (ethics@jcu.edu.au)

Dear Claudia Pudelko,

Your request to conduct research on cognitive skills in senior science at INSERT SCHOOL NAME is approved. Participation by teachers remains voluntary.

I understand the aims of this research study and have been provided with a written information letter to keep.

I understand that the research will involve classroom observations and audiotaped teacher interviews and I agree that the researcher may use the results as described in the information letter.

I am aware that I can stop the school's participation in this study at any time without explanation or prejudice and that any information collected will be strictly confidential.

Upon completion of your research, please provide this office with a summary of your findings.

Sincerely,

--- -----------------------------------
(Name Printed) (Date)

(Signature)

JAMES COOK UNIVERSITY
AUSTRALIA

17/08/2020

Dear senior science teacher,

I am a Doctor of Philosophy student at James Cook University researching how cognitive skills of the new senior syllabi are taught in Biology, Chemistry and Physics.

As I am sure you are aware, cognitive skills like recalling, explaining or evaluating play a central role in the new QCE system. The newly developed syllabi seem to value pedagogy which does not focus solely on teaching content knowledge, but also equips students with knowledge processing skills needed in the 21st century workforce. Understanding of cognitive verbs is likely to become a significant component of senior students' preparation for their external examinations and there is a plethora of evidence in educational research showing that teaching of cognitive skills is linked to improved student outcomes. This is why I am very interested in exploring these matters in Far North Queensland. Being a Biology teacher myself, I am focusing on cognitive skills taught in three senior sciences (Chemistry, Physics and Biology).

I would like to invite you to participate in my study. Participation would be voluntary, and you would have the right to stop your participation at any time without explanation. I am mindful to keep the inconvenience to participants low and the study does not have potential for distress to you or students. I would like to observe three of your year 11 and/or year 12 lessons and record the cognitive level of classroom instructions as well as the pedagogies you use to teach cognitive skills.

Of course your identity and your school's name would stay anonymous. The collected data would be limited to this research, although results may ultimately be presented in formats other than my thesis, such as journal articles or academic conference papers. Upon completion of my research, I would share my findings with you and your school, as well as Education Queensland and Queensland Catholic Education.

My study has the potential to partially evaluate the implementation of the new QCE system by measuring the extent to which cognitive skills taught in classrooms match cognitive skills prescribed by the new senior curriculum. Moreover, results may be able to support teachers to purposefully and effectively teach cognitive skills.

Should you agree to participate, please sign the attached informed consent form.

Thank you for your time. If you have any questions about the study, please contact me or my academic supervisor Dr Helen Boon. I would genuinely appreciate your participation.

Sincerely,
Claudia Pudelko

Principal Investigator:
Claudia Pudelko (BEd Honours)
College of Arts, Society and Education
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JAMES COOK UNIVERSITY
AUSTRALIA

INFORMED CONSENT FORM

PRINCIPAL INVESTIGATOR: Claudia Pudelko
PROJECT TITLE: Cognitive Skills in Senior Science
COLLEGE: Arts, Society and Education

I understand the aim of this research study is to investigate cognitive skills taught in Far North Queensland senior science classrooms. I consent to participate in this project, the details of which have been explained to me, and I have been provided with a written information letter to keep.

I understand that my participation will involve three classroom observations and I agree that the researcher may use the results as described in the information letter.

I acknowledge that:

- taking part in this study is voluntary and I am aware that I can stop taking part in it at any time without explanation or prejudice and to withdraw any unprocessed data I have provided;

- any information I give will be kept strictly confidential/anonymous and that no names will be used to identify me with this study without my approval;

(Please tick to indicate consent)

I consent to be observed during three of my lessons ☐ **Yes** ☐ **No**

Name: *(printed)*	
Signature:	**Date:**

Appendix D.
Lesson Observation Instrument

Modified Florida Taxonomy of Cognitive Behaviour

School: Subject, Year level:
Teacher: Unit, Topic:
Date and time:

1. **Retrieval**

	5	10	15	20	25	30	35	40	45	50
1.1 Execute										
1.2 Recall										
1.3 Recognise										

Pedagogies:

2. **Comprehension**

	5	10	15	20	25	30	35	40	45	50
2.1 Symbolise										
2.2 Integrate										

Pedagogies:

3. **Analysis**

	5	10	15	20	25	30	35	40	45	50
3.1 Specify										
3.2 Generalise										
3.3 Analyse errors										
3.4 Classify										
3.5 Match										

Pedagogies:

4. **Knowledge Utilisation**

	5	10	15	20	25	30	35	40	45	50
4.1 Investigate										
4.2 Experiment										
4.3 Problem solve										
4.4 Make decisions										

Pedagogies:

5. Metacognition

	5	10	15	20	25	30	35	40	45	50	Pedagogies:
5.1 Monitor accuracy											
5.2 Monitor clarity											
5.3 Monitor process											
5.4 Specify goals											

6. Self-system thinking

	5	10	15	20	25	30	35	40	45	50	Pedagogies:
6.1 Examine motivation											
6.2 Examine emotional responses											
6.3 Examine beliefs about own ability											
6.4 Examine importance of knowledge											

Notes:

mFTCB Elaboration on Use

Based on "Designing & Assessing Educational Objectives" (Marzano & Kendall, 2008)

Retrieval

1.1. **Execute**

- Perform a procedure, carry out…
- Demonstrate something
- Use, calculate, write, copy, read
- Balance a simple equation or use a formula (may not be able to explain it)

1.2. **Recall**

- produce features of information
- define, state, name, list
- describe
- label a diagram
- fill in blank/ cloze passage

1.3. **Recognise**

- validate correct statements
- true false questions
- select a synonym or word from list, select a label
- identify
- link definition to term (match cards)
- most multiple-choice questions

Comprehension

2.1. **Symbolise**

- construct a symbolic representation
- graphic organiser, mind map, flowchart
- graph or draw a diagram
- make a model
- construct, depict, represent, draw, sketch

2.2. **Integrate**

- identify the structure and critical characteristics of knowledge
- say in your own words, paraphrase
- summarise, write a paragraph about…
- clarify, describe relationships between concepts
- explain, not just how, but "why"
- give examples

Analysis (generate new information)

3.1. **Specify**

- identify specific application or consequence
- apply, find new example
- extrapolate, predict
- deduce, derive, infer, determine
- What would happen if?
- Under what conditions would?

3.2. **Generalise**

- construct generalisation or principles
- draw new conclusion from given facts
- create a rule or theory

3.3. **Analyse Error**

- identify errors, find the mistake
- critique a text or statement
- rephrase so it is true
- state limitations and inaccuracies
- assess, judge, edit, diagnose problem, (argue)

3.4. **Classify**

- identify categories, create categories
- organise, sequence, categorise with clear reasons
- put items or steps into right sequence
- structure, sort, rank

3.5. **Match**

- identify similarities and differences
- differentiate, compare and contrast, distinguish
- select criteria for matching/ reasons for similarities and differences
- Venn diagram or similar
- Find analogy or metaphor

Knowledge Utilisation

4.1. **Investigate**
- conduct investigations
- use secondary sources and people's opinions, historical contexts etc.
- propose and argument or answer, why does this work?
- Create, design, proof
- Research (but don't just summarise)
- Synthesise, theorise
- Identify what is already known and what isn't

4.2. **Experiment**
- generate and test hypotheses
- collect data through observation, test, generate data, survey
- predict, explore
- create or modify methods
- how does this work?

4.3. **Problem solve**
- solve problems, overcome an obstacle
- create, design, develop, generate, devise a strategy
- solve, resolve, figure out
- identify solutions

4.4. **Make decisions**
- identify alternatives
- what is most suitable
- decide, argue, evaluate, justify, (discuss)

Metacognition (executive control)

5.1. **Monitor Accuracy**
- check for correctness
- self-marking, peer-marking
- reflect, how do you know that you are correct?

5.2. **Monitor Clarity**
- What am I confused/ clear about?
- What questions do I need to ask?
- Show of thumbs

5.3. **Monitor Process**
- Is my learning effective? How effective is my plan
- Am I getting closer to reaching my goal?
- What works best for me?
- Traffic lights, WWW + EBI
- Evaluate

5.4. **Specify goals**
- State what you want to learn/ achieve/ acomplish
- Make a plan for accomplishing the goal

Self-system

For all: how logical/reasonable is your thinking about…

6.1. **Examine motivation**
- Reflect on self-system components (emotion, importance and efficacy) and reasons for them
- How interested/ motivated are you? Why?

6.2. **Examine emotions**
- How does it make you feel to learn this?
- Is it exciting? Does it make you feel anxious?
- What are you feeling about…? Why?

6.3. **Examine efficacy**
- Can I learn this? Am I smart enough?
- Can I succeed in this? How well can I do?
- Can I improve?
- Do I have time for this?

6.4. **Examine importance**
- Why is this useful for me to learn?
- What will I use this for? Why are we learning this?
- Will this help me reach my goals?

Appendix E.

Research Approvals

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