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Cognitive demands of the new Queensland Senior Physics, Chemistry and Biology Syllabus: An Analysis Based on the New Taxonomy of Educational Objectives

Abstract.
A syllabus stipulates which knowledge and skills should be taught in a subject, thus signaling what is worth learning. The aim of this syllabus analysis was to determine the cognitive demand of learning objectives in the recently reformed Queensland physics, chemistry and biology syllabi and to analyse whether the development of students' metacognitive and self-system is embedded in the curriculum. Marzano and Kendall's (2007) New Taxonomy of Educational Objectives was used as theoretical framework for the analysis. Results show that cognitive levels of learning objectives are skewed towards the lower order thinking skills retrieval and comprehension in all three sciences. A comparison with the previous syllabi confirmed a reduced emphasis on analysis and knowledge utilisation in the new syllabi. Teaching metacognitive and self-system thinking have been found to be implicit rather than explicit objectives of the new syllabi. There may be a mismatch between publicly portrait goals of science education in Australia and the cognitive demands emphasised in the new syllabi, fuelling the debate about the right balance of lower order and higher order cognitive skills in secondary science. Implications for pedagogy and stakeholders in science education are discussed.

Keywords: curriculum analysis, learning objectives, cognitive skills, science, QCE system

1. Introduction

A syllabus outlines the knowledge and skills students are expected to learn as part of a course. Typically, these educational goals are stated in form of learning objectives, success criteria or curriculum standards. Effective learning objectives should identify content knowledge and how this knowledge should be demonstrated through observable behaviour (Anderson & Krathwohl, 2001; Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). The identified behaviour is commonly a cognitive skill, i.e. mental process, that helps learners organise and integrate their experiences. Thus practically speaking, learning objectives contain a verb describing the intended cognitive skill, plus an object describing the knowledge to be constructed, e.g. students should explain (cognitive skill) how temperature can affect an enzyme's activity (knowledge).

The cognitive skills in learning objectives can be classified using educational taxonomies. Bloom's (1956) Taxonomy, Biggs and Collis's (1982) Structure of Observed Learning Outcomes (SOLO) Taxonomy, Anderson and Krathwohl's (2001) Revised Bloom's Taxonomy, and Marzano and Kendall's (2007) New Taxonomy of Educational Objectives are just a few examples of widely used educational taxonomies[1]. Because such taxonomies provide a consistent language for cognitive skills, they can improve communication between educators, increase comparability of learning objectives and support new curriculum design (Bloom et al., 1956; Marzano & Kendall, 2007). Teachers can use educational taxonomies as a theoretical framework to analyse the cognitive demands of prescribed curricula when designing learning resources in order to ensure that their instructions and assessment are aligned with curriculum objectives (Anderson & Krathwohl, 2001; Bertucio, 2017; Bümen, 2007).

This study employs Marzano and Kendall's (2007) New Taxonomy of Educational Objectives as theoretical lens because this taxonomy underpins the suite of new senior secondary syllabi in Queensland. In the New Taxonomy, cognitive skills 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 to be 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, 2015). Decision making, for instance, requires more conscious thought and awareness than recalling information, which is often executed automatically (Marzano & Kendall, 2007). As opposed to Bloom's Taxonomy, the notion of a cumulative hierarchy of cognitive skills has been removed, so that a student may use a higher order cognitive skill without a lower order one.

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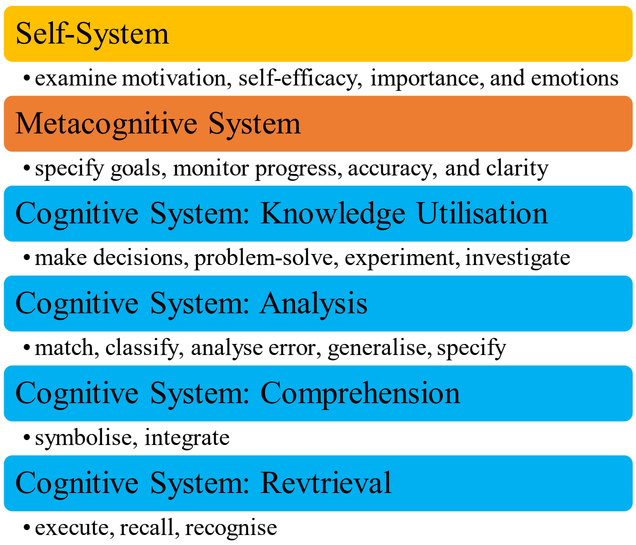
[1] For a comprehensive review of educational taxonomies see Moseley, D., Elliott, J., Gregson, M., & Higgins, S. (2005). Thinking skills frameworks for use in education and training. *British Educational Research Journal*, *31*(3), 367–390.

Marzano and Kendall (2007) argue that learning is a function of more than just cognitive skills. They recognise the influence of a student's 'self' intentionally choosing to learn and to control the learning process. Thus, in the New Taxonomy the cognitive system is influenced by two further systems, the metacognitive system and the self-system (see Figure 1). The metacognitive system describes students' learning goals and students' strategies to accomplish those goals by monitoring their progress, accuracy and clarity of understanding. Teaching metacognitive thinking seem to be effective at enhancing students' cognitive skills long-term and frequently across subject disciplines (Beyer, 2008; Sanz de Acedo Lizarraga, Sanz de Acedo Baquedano, & Rufo, 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 describes students' beliefs and emotions about the importance of knowledge and their own efficacy. It includes students' decision to engage in learning. The introduction of the self-system in 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 processes by determining whether a learning task is worth engaging with. It considers intention an important precursor of learning (Irvine, 2017). As most educational objectives have an affective component, such as implicit values or the goal for students to appreciate taught content (Anderson & Krathwohl, 2001), it seems advisable to include both an affective as well as cognitive component in a taxonomy of educational objectives.

Figure 1. Classification of cognitive skills in the New Taxonomy of Educational Objectives



2. Study Context and Rationale

In 2019, Queensland has undergone a major senior curriculum reform. Key features of the new system are redeveloped syllabi for all senior subjects and new assessment types, including high stakes external examinations in subjects leading to tertiary study pathways. The resulting changes encompass a shift in curricular priorities in terms of knowledge and skills taught (Matters & Masters, 2014). The Queensland Curriculum and Assessment Authority (QCAA) – "a statutory body of the Queensland Government" charged with "a critical role in the design and delivery of education in Queensland" (QCAA, 2019, para. 1) – has prioritised Marzano and Kendall's (2007) New Taxonomy of Educational Objectives as the framework for their new senior syllabi. Each syllabus's learning objectives are prefaced by a ‘cognitive verb’ based on the New Taxonomy. Cognitive verbs provide a description of the depth at which students will be required to understand, and demonstrate their knowledge during assessment (QCAA, 2018b) and thus indicate the cognitive demand of the educational objective. For example, according to the New Taxonomy, “compare” is a level 3 cognitive verb, thus the objective “compare mitosis and meiosis” requires teachers to provide students with opportunities to analyse the processes of mitosis and meiosis.

By communicating which knowledge and cognitive skills students should be taught, the new syllabi send messages about what is worth learning in science. They can directly affect teachers’ pedagogical decisions and hence curriculum implementation (Davis & Krajcik, 2005). Therefore, syllabus analysis or mapping is an important tool for examining the intended curriculum. Before the release of the P-10 Australian Curriculum, Jane, Wilson and Zbar (2011) mapped the knowledge and cognitive demands of the final Australian Curriculum and the former State and Territory curricula in science and other subjects to determine introduced changes. Results could be used to tailor support for teachers implementing the new curriculum. Matters and Masters (2007) reported on content knowledge and achievement standards expected of year 12 chemistry and physics students Australia wide to determine the consistency of expectations. This study is the first in-depth analysis of the reformed Queensland senior science curriculum. It follows research of the cognitive demands of science curricula in the USA (Liu & Fulmer, 2008), China (Wei, 2020), Singapore and Korea (Lee, Kim, & Yoon, 2015). These previous studies supported alignment of prescribed, assessed and enacted curricula and lay foundations for reflections on the congruence of mandated science curricula with publicly proclaimed goals of science education. An analysis of the cognitive demand of the new Queensland biology, physics and chemistry senior syllabus aims to accomplish similar goals. The following research questions were asked:

1. What are the cognitive levels of learning objectives in the new Queensland physics, chemistry and biology syllabus?
2. How is the metacognitive and self-system embedded in the new syllabi?
3. What changes were introduced by the recent senior syllabus reform to the cognitive demands of learning objectives?

3. Methods

Access to the physics, chemistry and biology syllabus was obtained through the QCAA website. The three syllabi were read in full to record their structure and components. Even though this study’s research question is not concerned with the structure of the syllabi, it was necessary to examine it to avoid errors or misconceptions during the interpretation of results. Then, learning objectives were analysed for their cognitive demand at the most specific level provided by the syllabus.

Each analysed syllabus contains broad syllabus objectives, which are not specific to the subject’s content, e.g. “describe and explain scientific concepts, theories, models and systems and their limitations”. These syllabus objectives inform unit objectives, which resemble the syllabus objectives but include broad subject matter to be learnt in the unit, e.g. “describe and explain cells as the basis of life, and multicellular organisms”. Finally, each unit has subject matter content descriptors which describe what students are expected to do (the cognitive verb) and the specific knowledge they are expected to learn, e.g. “recognise the different types of nitrogenous wastes produced by the breakdown of proteins”.

These specific learning objectives were categorised into the four cognitive levels of the New Taxonomy of Educational Objectives (retrieval, comprehension, analysis and knowledge utilisation) by matching cognitive verbs at the start of each learning objective with a list of cognitive verbs belonging to each cognitive level (see Appendix 1 for a list of cognitive verbs used by the QCAA to write syllabus objectives and their corresponding cognitive levels in the New Taxonomy). The frequency of learning objectives in the syllabus written at each cognitive level was reported as percentage of all analysed objectives.

Syllabus objectives, unit objectives or subject matter content descriptors in all three syllabi gave no explicit instructions to develop students' metacognitive and self-system thinking. Therefore, the remaining sections of each syllabus were searched for implicit references to these two systems of the New Taxonomy using a discourse analysis. This methodology allowed the analysis to focus on larger sections of text rather than cognitive verbs only. The syllabi were read in full again and sentences which may refer to the development of students' metacognitive or self-system thinking were recorded. The purpose of this step was not to gather a comprehensive list of sentences referring to the two systems, but to read all potentially relevant text in context of its paragraphs and headings. Thereafter, 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 2 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; e.g. for examining 'value' of knowledge (= self-system), 'merit' was included but 'cost' was not included; and for checking own 'understanding' (= metacognitive system), 'grasp' was included but 'consciousness' was not included. Each syllabus, excluding the glossary, was searched for all keywords using a word-search function and sentences containing a keyword were coded if they addressed metacognitive or self-system thinking. Finally, all coded sentences were read together to double-check that they match the New Taxonomy's definitions of the metacognitive and self-system. Coded sentences that were off-topic were deleted.

Sentences which instructed students to find reliable information or write reasonable descriptions were not coded as metacognitive thinking because the emphasis was not on students monitoring whether their own thinking about information is reliable or reasonable. For example, when students are asked to "draw reasonable conclusions based on their accurate analysis of evidence", they are not encouraged to monitor their own accuracy or clarity of thinking by examining potential misconceptions. In another instance, students are instructed to reflect on the difficulties experienced by scientists in their work. Yet again, this was not coded as metacognitive thinking as students are not asked to reflect on their own difficulties in learning.

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 around the subject matter. However, the QCAA's definition of the cognitive verb 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 value or importance of the content matter to themselves, the verb has not been coded as 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.

Lastly, the previous physics, chemistry and biology senior syllabi were analysed using the same methods as outlined above in order to analyse changes to cognitive demands introduced by the new system. To allow for direct comparison of the old and new syllabi, cognitive verbs in the old syllabi were classified according to the New Taxonomy, even though learning objectives in the old syllabi are not framed by any particular educational taxonomy. As the old syllabi do not specify cognitive verbs in the description of subject matter, the most specific learning objectives available to be analysed were the seven general objectives and their elaborations. The sample units of work in the old syllabi sometimes use cognitive verbs under "suggested learning experiences", however, these were not coded because they constitute an exemplar for teachers rather than a prescriptive component of the syllabus.

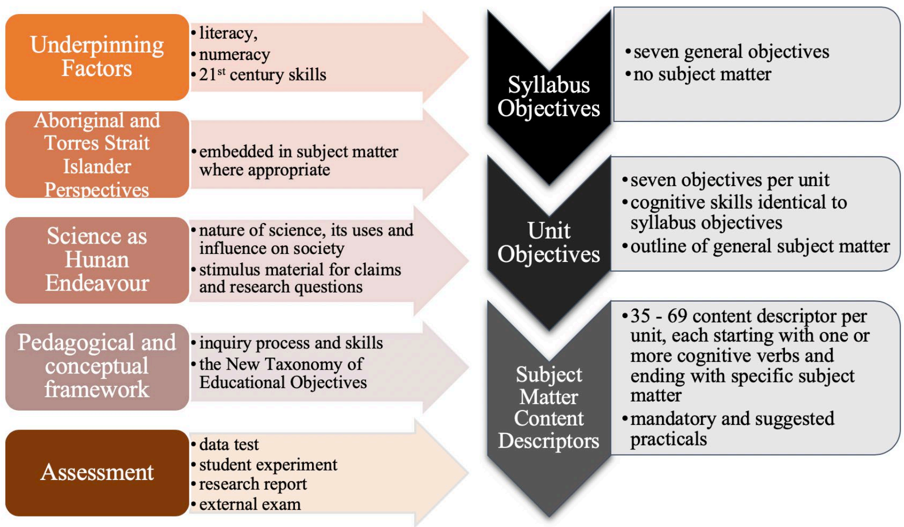
4. Results

4.1. Syllabus structure

The new physics, chemistry and biology syllabi are structured identically. The same seven syllabus objectives outline how students are expected to demonstrate knowledge, i.e. (1) describe and explain, (2) apply, (3) analyse, (4) interpret, (5) investigate, (6) evaluate, and (7) communicate. Since syllabus objectives are identical between the three subject areas, they do no refer to 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 knowledge to be learned 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 general subject matter to be learned in each unit. 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, including all mandatory and suggested practicals students should experience as part of the course.

Whenever appropriate, the learning objectives of each syllabus are meant to 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 provide guidance for any pedagogical approach chosen by schools and are thus not prescriptive. Finally, the three syllabi outline identical types of formative and summative assessment to be delivered: data tests, student experiments, research reports and an external exam weighted at 50%. The structure of the new syllabi is summarised in Figure 3.

Figure 3. Structure of the new physics, chemistry and biology syllabi



Throughout the three syllabi, the importance of cognitive skills is emphasised. The *Teaching and Learning* section of the physics, chemistry and biology syllabus states that "students are required to use a range of cognitive processes in order to demonstrate and meet the syllabus objectives" (e.g. QCAA, 2018a, 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" (e.g. QCAA, 2018a, p. 42). Moreover, the underpinning factor *21st century skills* includes critical and creative thinking. Gonski at 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. Finally, the QCAA's (2018b) *Cognitive Verb Toolkit*, a teaching resource accompanying the release of the new 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" (p.1).

4.2. Cognitive level of learning objectives

The syllabus analysis examined cognitive demands of the 207 physics, 205 chemistry and 158 biology subject matter content descriptors. Some content descriptors contained more than one cognitive verb, in which case all verbs were coded because students should be able to demonstrate subject knowledge through each listed cognitive skill. Table 2 shows the total cognitive verbs coded per subject. This total was used to calculate proportions of cognitive levels in each syllabus.

Table 2. Number of analysed subject matter content descriptors and cognitive verbs:

	Physics	Chemistry	Biology
Subject matter content descriptors	207	205	158
Cognitive verbs in content descriptors	242	381	196

Considering that the QCAA adopted 72 cognitive verbs from the New Taxonomy, each science syllabus only utilises a narrow range of them. That means, similar cognitive verbs are used repetitively to describe learning objectives at each cognitive level. Table 3 shows the cognitive verbs used in each syllabus at each cognitive level. Define, describe, explain, and solve dominate the physics syllabus; recognise, use, explain, and understand the chemistry syllabus; and identify, recall, recognise, explain, and analyse the biology syllabus.

Table 3. Cognitive verbs in subject matter content descriptors by cognitive level

	Physics	Chemistry	Biology
Retrieval	38%	27%	36%
define	17%	0%	4%
demonstrate	0%	0%	2%
identify	2%	3%	10%
recall	13%	3%	7%
recognise	2%	9%	11%
select	0%	0%	1%
sketch	0%	1%	0%
use	2%	11%	3%
Comprehension	24%	32%	33%
calculate	2%	5%	2%
communicate	0%	2%	0%
describe	9%	5%	9%

draw	0%	1%	0%
explain	12%	9%	15%
represent	1%	1%	0%
summarise	0%	0%	1%
symbolise	0%	1%	0%
understand	0%	9%	6%
Analysis	14%	20%	20%
analyse	0%	3%	7%
apply	1%	4%	0%
classify	0%	0%	1%
compare	2%	2%	2%
consider	1%	0%	0%
contrast	2%	0%	1%
deduce	0%	3%	0%
determine	3%	3%	3%
differentiate	0%	0%	1%
discriminate	0%	0%	1%
distinguish	1%	3%	0%
infer	0%	0%	1%
interpret	4%	2%	4%
sequence	0%	0%	1%
Knowledge Utilisation	25%	20%	11%
appraise	0%	0%	1%
appreciate	0%	4%	0%
construct	1%	3%	1%
decide	0%	0%	1%
discuss	0%	1%	1%
evaluate	0%	2%	1%
investigate	4%	1%	2%
justify	0%	0%	1%
predict	0%	5%	5%
solve	18%	4%	0%

Cognitive levels of subject matter content descriptors are skewed towards retrieval and comprehension in all three sciences (see Figure 4). 36% 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. Thus, less than a 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. Cognitive levels of subject matter content descriptors

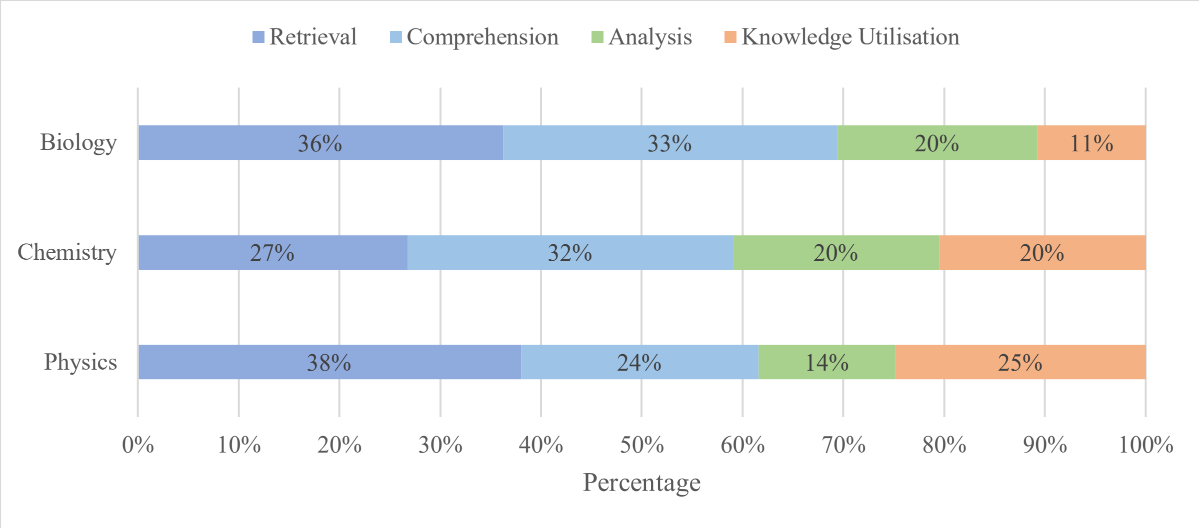


Table 4 and Figure 5 show a more fine-grained analysis of cognitive demands in each syllabus by examining the proportions of learning objectives at each cognitive level for each topic. The curriculum mapping project undertaken by the Australian government to support the development of the Australian Curriculum used topographic graphs like Figure 5 to show the extent of content coverage and the emphasis on different cognitive levels for each topic (Jane et al., 2011)[2]. 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.

Table 4. Cognitive demand of learning objectives by content topic

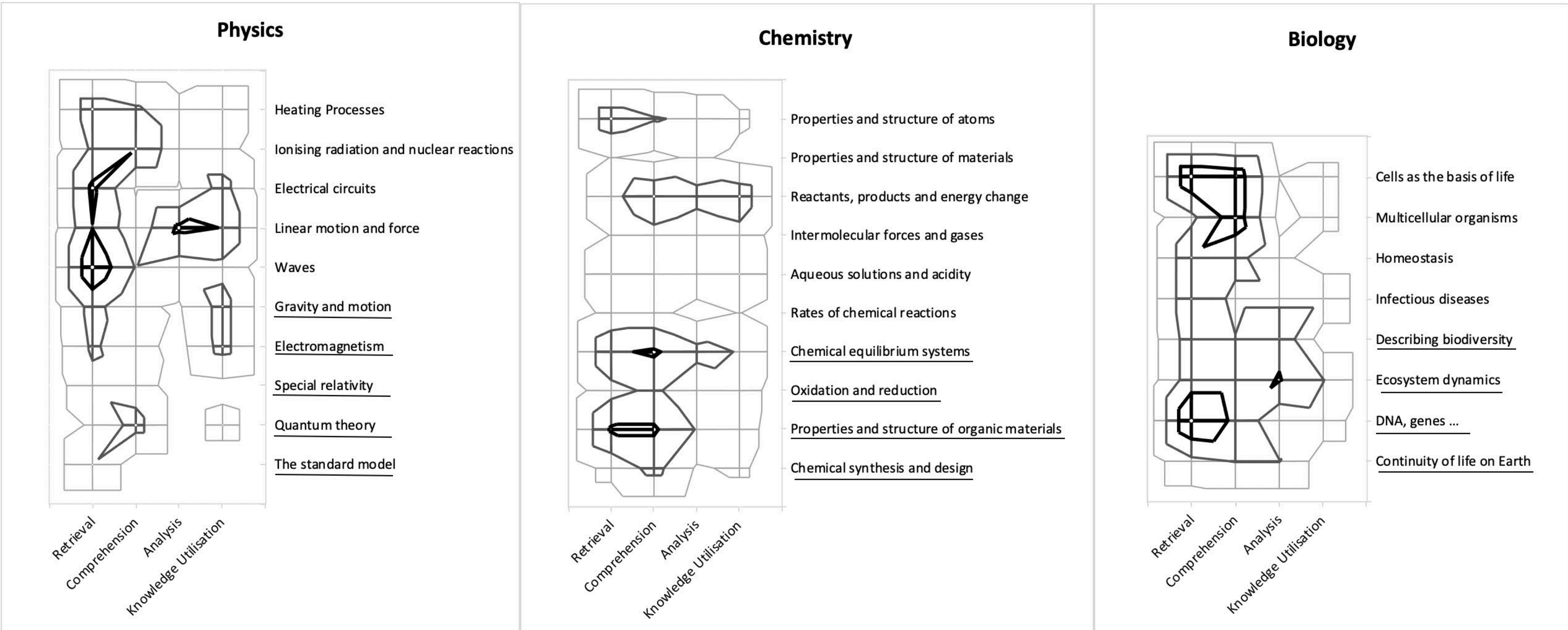
	Content Topic	**Retrieval**	**Comprehension**	**Analysis**	**Knowledge Utilisation**
Physics	Heating Processes	4.1%	3.3%	1.7%	2.5%
	Ionising radiation and nuclear reactions	3.3%	5.0%	1.7%	1.7%
	Electrical circuits	5.4%	0.8%	0.8%	3.7%
	Linear motion and force	5.0%	1.7%	5.4%	5.0%
	Waves	6.6%	2.9%	2.1%	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%

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

	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, genes and the continuity of life	7.1%	4.6%	1.5%	2.0%
	Continuity of life on Earth	2.6%	3.1%	3.1%	0.0%

In physics, most topics emphasise retrieval or comprehension skills, while only some topics emphasise knowledge utilisation and few topics emphasise analysis. For example, gravity and motion, electromagnetism, special relativity, quantum theory and the standard model have few or no subject matter content descriptors at analysis level. Notably, earlier topics seem to have a greater spread across the four cognitive levels than later topics which are assessed on the external exam. In comparison, chemistry has a more even spread of cognitive levels across the subject matter content descriptors of most topics. However, yet again, later topics which will feature on the external exam focus more strongly on retrieval and comprehension e.g. properties and structure of organic materials and chemical equilibrium systems. In Biology, the stronger focus on retrieval and comprehension is most notable. Half of the biology topics have very few or no subject matter content descriptors at analysis or knowledge utilisation level. By contrast, all topics but infectious diseases have a relatively high proportion of subject matter content descriptors at retrieval and comprehension level. The distribution of cognitive levels across the subject matter content descriptors in each science may be one factor why some students perceive physics or chemistry as more challenging than biology and may contribute to the three sciences being scaled differently for the calculation of students' tertiary admission rank (ATAR). Interestingly, while subject matter content descriptors in the three subjects are distributed differently across the four cognitive levels, assessment criteria and marking guides of all subjects' internal assessments are identical.

Figure 5. Emphasis on cognitive levels by content topic.



Note: Underlined topics are assessed on the external exam

4.3. Metacognitive and the self-system thinking in the syllabi

No subject matter content descriptor directs teachers to engage students with metacognitive thinking in either subject. The cognitive verbs used in the prescribed learning objectives focus solely on the four levels of the cognitive system. However, the syllabus discourse analysis showed that there are implicit references to the metacognitive system in other sections of the three syllabi (see Table 5). For example, the pedagogical and conceptual framework as well as the underpinning factor 21st century skills states that physics, chemistry and biology students should specify goals in form of plans and research questions, monitor their own 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. However, no references were found in the three syllabi to the fourth component of the metacognitive system, i.e. students monitoring the clarity of their thinking and understanding.

Similar to the metacognitive system, subject matter content descriptors did not make explicit references to the self-system. Instead, the self-system is an implicit learning goal for students completing the syllabus. 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 5). In addition, 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 become aware of the importance of learned content and skills to their life outside of the classroom and thus develop an appreciation of the subject matter and its impact.

Table 5. Implicit references to the metacognitive and self-system in the syllabi

		Location in Syllabus	Examples:
Metacognitive System	**Specify Goal**	- Elaboration of Syllabus Objectives - Underpinning factors (21st century skills) - Pedagogical and conceptual framework - Assessment objectives - Unit 1 and 2 descriptions (Biology: Unit 3 and 4 descriptions as well)	- 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 (…) take action, set concrete goals and follow the steps necessary to achieve them
	Monitor Process	- Underpinning factors (21st century skills) - Pedagogical and conceptual framework - Unit 1 and 2 descriptions (Biology: Unit 3 and 4 descriptions as well)	- Personal and social skills - self-management: (…) persisting to complete tasks and overcome obstacles; develop organisational skills and identify the resources needed to achieve goals* - 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* - 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	- N/A	- N/A
Self-System	**Examine Importance**	- Rationale - Underpinning factors (numeracy and literacy) - Science as Human Endeavour subject matter - Unit 1 and 2 descriptions (in Biology and Chemistry Unit 3 and 4 descriptors as well) - 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 - character (resilience, mindfulness, open-and fair-mindedness, self- awareness: (…) to know yourself or have a clear understanding of your personality, including strengths and weaknesses*
	Examine Emotional Response	- Underpinning factors (21st century skills) - Unit 1 and 2 descriptions (Biology: Unit 3 and 4 descriptions as well)	- Personal and social skills - self-management: effectively regulating, managing and monitoring emotional responses*
	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 (…)*

*21st century skills are listed in syllabi without explanations; quoted definitions are taken from the QCAA's (2018) Capabilities and Skills Frameworks across Senior Curriculum Phases

4.4. Comparison to previous senior syllabi

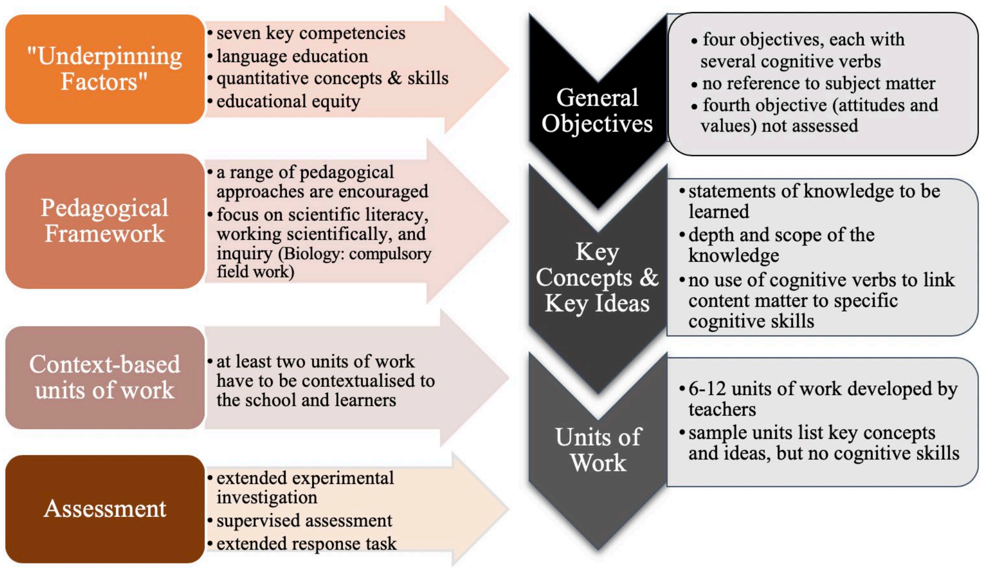
4.4.1. Structure of the previous senior syllabi

Learning objectives and factors underpinning curriculum delivery are structured differently in the old syllabi than in the new syllabi (see Figure 6). The previous 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 1-3 inform the marking criteria of all assessments and the fourth general objective is addressing affective elements of learning, i.e. attitudes and values, and is not assessed.

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

Figure 6. Structure of the previous physics, chemistry and biology syllabi



While the sample units in the appendix of each syllabus do not link specific cognitive verbs with each key concept or key idea, it was expected that teachers choose cognitive skills from the general objectives for students to demonstrate the knowledge they have constructed. The 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 old QCE system. Therefore, this study uses cognitive verbs in the elaborations of general objectives to code cognitive levels of the old syllabi. Notably, the old syllabi do not use a specific educational taxonomy as consistent conceptual framework for cognitive skills in their learning objectives.

Similar to the new syllabi, the old syllabi require student learning of subject matter and skills across all units to be underpinned by certain key competencies, i.e. language education, quantitative concepts and skills, and educational equity. While these factors have different names than the "underpinning factors" of the new syllabi, the content and purpose is very similar. The pedagogical framework of the old syllabi is non-prescriptive, encouraging a range of approaches, from problem-based learning to guided discovery learning to direct instruction. However, an extended appendix on scientific literacy, ways of working scientifically and the compulsory field work component in biology places an implicit emphasis on various models of inquiry learning and practical work. All summative assessment across the three subjects are school based and students are assessed more frequently than in the new system, i.e. 4-6 pieces of assessment per year instead of 3-4. The assessment types of the old system are supervised exams, reports on extended experimental investigations and written extended responses to a stimulus.

Even though the old syllabi are not explicitly framed by a theoretical framework for cognitive skills like the suite of new syllabi, there is evidence that an emphasis on equipping students with a range of cognitive skills exists. For example, the 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 syllabi instruct teachers to scaffold thinking skills and in biology, problem-based learning "where thinking and problem-solving skills are naturally developed" (p.7) is encouraged (Queensland Studies Authority, 2014).

4.4.2. Changes to cognitive demand

To determine the cognitive demand of learning objectives in the old physics, chemistry and biology syllabi, the 46 cognitive verbs in the elaborations of the physics and chemistry general objectives 1-3 and the 24 cognitive verbs in the elaborations of the biology general objectives 1-3 were coded. Since these cognitive verbs are not linked to specific subject matter, no topographic graphs could be created to visualise the cognitive level to which each key concept was intended to be taught.

As opposed to the new syllabi, the cognitive demand of learning objectives in the old syllabus 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 demand 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 7). Thus, >60% of cognitive verbs referred to higher order thinking skills, which is almost the exact opposite of the distribution of cognitive levels in the new syllabi.

Figure 7. Cognitive levels of general objectives in previous syllabi

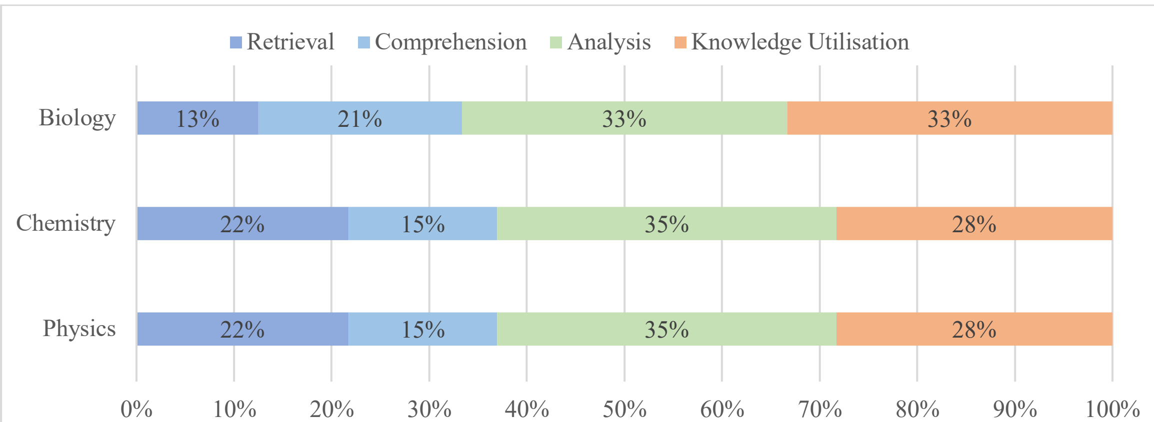
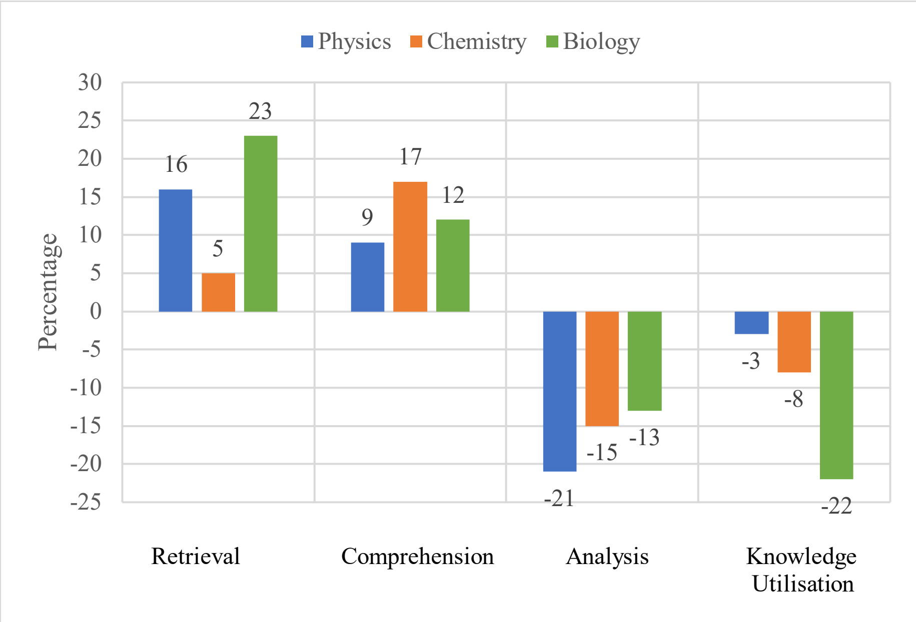


Figure 8 shows the discrepancies in percentages of each cognitive level between the new and old syllabi. The trend is identical for all three subjects, even though its magnitude varies. In physics, the new syllabi place greater emphasis on retrieval (+16%) and comprehension (+9%), much less emphasis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

Figure 8. Discrepancies in cognitive demand (new syllabi – previous syllabi)



4.4.3. Changes to metacognitive and self-system thinking

A noticeable difference between the old and new system is that the old 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 new syllabi do not address these systems in their syllabus objectives. It needs to be noted, however, that the objective addressing students' affective domain is not assessed. The old syllabi also list the development of students' attitudes and values through studying the subject area as one of their global aims.

The old syllabi also have implicit references to metacognitive and self-system thinking in other syllabus components (see Table 6). 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);
- progress from personal inaccurate constructions to explanations based on accepted theories (= monitor accuracy).

There is an emphasis on purposeful context for learning across the three subject areas, resulting in students having the opportunity to explore the significance of taught concepts for themselves (= examine importance). Furthermore, the 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).

Table 6. References to the metacognitive and self-system in the old syllabi

		Location in Syllabus	Examples:
Metacognitive System	**Specify Goal**	- General Objectives - Learning experiences (= 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 - They need to distinguish between a plausible conclusion and one based on pure supposition
	Monitor Clarity	- N/A	- N/A
Self - System Thinking	**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 (… list given) e.g. 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

The old and new physics, chemistry and biology syllabi seem to have a comparable focus on metacognitive thinking. Both syllabus suits direct students to specify goals, especially in the context of planning and designing a scientific investigation. Directives to students 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 more emphasised in the old syllabi than in the new syllabi as it is referred to in both the general objectives and assessment specifications of the old syllabi. Neither syllabus makes implicit nor explicit references to students monitoring the clarity of their thinking.

In regards to self-system thinking, both syllabi prioritise students examining the importance of learned concepts to themselves, even though this theme seems more central in the old syllabi as it is referred to in syllabus aims, the general objectives, assessment specifications and the comprehensive appendix on contexed-based units of work. Students examining their motivation is also more directly referred to in the old syllabi than in the new syllabi, e.g. in the syllabus introductions, the general objectives and the guidance for learning experiences. Examining self-efficacy, however, only has sparring references in both versions of the syllabi. Finally, there is only one very implicit reference to students examining their emotional response in the old syllabi, without clear guidance on how to implement such a learning goal, while the new syllabi direct teachers to teach this skill by developing students' self-management skills.

5. Discussion

The aim of the syllabus analysis was to determine the cognitive demand of learning objectives in the new Queensland senior physics, chemistry and biology syllabi and to analyse whether the development of students' metacognitive and self-system is embedded in the curriculum. The three new 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 rigid curriculum. There may now be a mismatch between some goals of and trends in science education portrait by Australian policy documents and the cognitive demands emphasised in the new syllabus subject matter descriptors. This fuels the ongoing debate about the right 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 metacognitive and self-system thinking have been found to be implicit rather than explicit objectives of the new syllabi. This is not unusual but may lead to reduced implementation of those objectives, even though the engagements of learners with metacognitive and self-system thinking has a positive effect on student outcomes (Hattie, 2008). The following section discusses the implications of those findings for stakeholders in high school science education.

5.1. Highly prescriptive learning objectives

Priestley (2014) argues that there is a trend in many western curricula of the last decade to move towards generic content specification, meaning that teachers are free to mould subject matter to their context and individualise it for their learners. The new Queensland science syllabi seem to defy this trend. In the old syllabi, teachers were given a list of key concept and key ideas and were encouraged to contextualise the subject matter by creating their own units and work programs with a substantial amount of freedom. In contrast to that, the new syllabi have pre-written linear units with a detailed list of subject matter to be covered for each concept. The depth to which subject matter is to be covered is indicated by the cognitive verb at the start of each learning objective. Any learning objective of 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 detailed and clear statements of learning objectives can benefit the quality and alignment of teachers' lessons planning and formative assessment (Blumberg, 2009). It certainly also addresses the criticism of the previous Queensland senior system that schools failed to develop students' foundational knowledge required for many university courses, particularly in mathematics and the natural sciences, and 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 of learners and school contexts cannot be taken into account fully, thus reducing the curriculum that develops 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 (Curriculum to Classroom) has also indicated that a 'one size fits all' approach to curriculum delivery carries its own problems, such as increased levels of stress and covert resistance to change by teachers (Barton, Garvis, & Ryan, 2014).

5.2. Dominance of retrieval and comprehension in learning objectives

One rationale of P-12 education in Australia is to develop skills in learners that will allow them to adapt to rapidly changing economic and social circumstances of our current times (Gonski et al., 2018). These skills are referred to as 'General Capabilities' in the Australia Curriculum, 'Key Competencies' in the old QCE system and 'Underpinning Factors' in the new syllabi. They include so called '21st century skills' like problem-solving or critical and creative thinking, which address higher order cognitive skills such as interpretation, analysis, or evaluation (Boghossian, 2012). In her review of emerging trends in Australian senior science education, Firn (2016) urges syllabus writers to more explicitly identify where and how 21st century skills can be incorporated in the curriculum. Gleeson, Klenowski and Looney (2020) argue that such emphasis on skill development is (a) influenced by globalisation and (b) a common feature of recent curriculum reforms in many countries. A survey of over 500 educators in the USA confirms that skills like creativity and critical thinking are rated as more important than disciplinary or even cross-disciplinary knowledge (Mishra & Mehta, 2017). Similarly, a review of 21st century knowledge frameworks found that across the board, little attention was given to the development of disciplinary content knowledge (Kereluik, Mishra, Fahnoe, & Terry, 2013).

Collectively, this sends the message that new syllabi should value higher order thinking skills like knowledge utilisation and analysis over the teaching of facts or concepts and associated lower order thinking skills like retrieval or comprehension. This seems to be the case in Australian P-10 science education. The Australian Curriculum for science has been shown to have a stronger emphasis on application and a lower emphasis on retrieval of knowledge than previous state and territory curricula (Jane et al., 2011). Moreover, the New Taxonomy of Educational Objectives, which underpins objectives in the new senior syllabi, does not assume that lower order thinking skills are needed as foundation to develop effective higher order thinking skills (Marzano & Kendall, 2007). This is one of the sharpest differences to Bloom's (1956) original Taxonomy for Educational Objectives, which claims that foundational knowledge precedes higher order learning. Some empirical evidence supports this by showing that building foundational knowledge through lower order thinking tasks has no effect on learners' performance on higher order thinking tests and, more importantly, that higher order thinking practice does not affect performance on lower order thinking tests. The cognitive complexity of the practice tasks had to match the cognitive level of the test to have a positive effect on student outcomes (Agarwal, 2019).

Considering the above literature, the results of the syllabus analysis are surprising. In all three subjects, more than half of the subject matter content descriptors address lower level cognitive skills. When compared to their predecessors, all three content areas now place greater emphasis on lower order thinking than on higher order thinking learning objectives. Moreover, 50% of students' final grade is determined by an external exam, which can hinder policy intentions to focus on higher order cognitive skills (Fensham & Bellocchi, 2013).

While this seems to be a contradiction to the publicly advertised aims of science education in Australia, many would argue that it is a deliberate and positive shift. Mishra and Mehta (2017), for instance, 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 and that such a knowledge base enables the learner to view problems in unique ways. During the development of the new 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 weakness of the old senior science syllabi. The government argued that students need foundational knowledge and skills before applying their knowledge during inquiry-based assessment. This resonates with common arguments expressed in the literature before the turn of the century, e.g. that effective problem solving requires content knowledge specific to the problem (DeCorte, 1990) because problem solving involves automatic retrieval of relevant knowledge (Christensen, 1991).

Describing retrieval and comprehension as 'lower order' or 'lower level' cognitive skills can carry a devaluing connotation. Booker (2007) argues 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. In support of this, science and mathematics curricula of countries performing well on international tests, such as Singapore, Finland and Japan, are strongly biased in favour of lower order thinking learning objectives focusing on understanding knowledge or remembering how to perform routine procedures (Lee et al., 2015; Porter, McMaken, Hwang, & Yang, 2011).

5.3. Metacognitive and self-system thinking as implicit curriculum component

The exclusion of metacognitive and self-system thinking learning objectives from subject matter content descriptors, syllabus objectives and assessment criteria of the new senior science syllabi is not out of the ordinary. Despite the positive effect of teaching skills like goals setting or self-regulation on student achievement (Hattie, 2008) and on cognitive development (Bayat & Tarmizi, 2010; Venville & Oliver, 2015), they are rarely addressed explicitly in learning objectives or seen 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 usage of metacognitive knowledge dimensions in 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 emotive skills that cannot be observed directly, i.e. emotional intelligence, resilience or motivation.

Nevertheless, the discourse analysis of the new senior science syllabi shows that, to a certain extent, metacognitive and self-system thinking have become accepted implicit goals of the senior science curriculum. Their value seems to have diminished though in the reformed syllabi as compared to the previous syllabi, which is most clearly evident in their removal from general syllabus objectives. It is also indirectly evident in the removal of the imperative to contextualise prescribed subject matter.

Relying on implicit directions to teach metacognitive and self-system thinking may lead to inconsistent or ineffective implementation of this curriculum component. Marzano and Kendall (2008) argue that teachers require specific strategies or frameworks for teaching metacognitive and self-system skills to students. A curriculum reform in the Northern Territory and South Australia aiming to strengthen students' literacy through the inclusion of metacognition showed that the lack of explicit instructions for teachers on how to include metacognition in lessons lead to poor alignment of the syllabus and classroom learning (Fenwick, 2018). Long term, focusing on the cognitive system while treating the metacognitive and self-system as optional curriculum component may result in lower enrolments of students in senior science subjects for intrinsic reasons (as opposed to selecting the subject as a means for gaining entry to certain university courses) as has become evident in Western Australia after the latest syllabus reform (Kruger, Won, & Treagust, 2013).

5.4. Implications for Pedagogy and Inquiry Learning

The new physics, chemistry and biology syllabi do not endorse a specific pedagogical approach or philosophy. However, the pedagogical frameworks of the three syllabi outline approaches to inquiry learning in great detail. Inquiry-based learning is a pedagogical approach characterised by students posing and investigating questions to develop their understanding of scientific concepts. Inquiry teaching approaches can range from open student-directed inquiry to teacher-guided inquiry with strict parameters. 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 UK, Canada and the USA. They are a core component of schools who have been judged to deliver "effective science programs" in diverse US high schools (Scogin, Cavlazoglu, LeBlanc, & Stuessy, 2018).

It is questionable, however, whether retrieval and comprehension skills which dominate the new syllabi are most effectively taught by inquiry learning. Instead, teachers may choose to adopt a more didactic teaching style faced with a highly prescriptive curriculum content and high stakes external examinations (Kruger et al., 2013). More prescriptive syllabi also lead to more time constraints for teachers, which has been found to be one of the biggest barriers to inquiry learning (Fitzgerald, Danaia, & McKinnon, 2017). Again, there seems to be a potential mismatch between public policy recommendations and the content of the prescribed curriculum.

6. Limitations and Recommendations

This study analysed the cognitive demand of syllabus learning objectives using Marzano and Kendall's (2007) New Taxonomy of Educational Objectives as theoretical framework. While this theoretical framework is highly appropriate for the new 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 learning objectives of the old syllabi. Cognitive verbs in the old 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, cognitive levels were analysed at different levels of detail in the new and the old syllabi. The aim was to analyse the cognitive demand of the most specific learning objectives of each syllabus. While the new syllabi stated a cognitive verb for each subject matter content descriptors, key concepts and key ideas in the old syllabi were presented as a list of nouns without verbs suggesting the cognitive level or depth to which each key concept or idea should be taught. Thus, the syllabi's general objective 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 cognitive demand 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 an easier 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 new prescribed curriculum is only the first step in an educational reform. The senior physics, chemistry and biology syllabus documents are currently interpreted, reformulated and enacted by teachers across Queensland. As Shalem (2013) points out, even well written standards do not dictate appropriate pedagogical practices. Future research should examine the cognitive demand of the enacted curriculum and the pedagogical choices of teachers implementing the new syllabi. It would be informative to research whether the new system has swung from an arguably too open curriculum with a strong focus on higher order thinking skills and inquiry learning to a too rigid curriculum predominantly focusing on lower order thinking and transmission learning or whether it has achieved a healthy balance. In either case, since there is a wealth of research on effectively teaching the newly emphasised retrieval and comprehension skills (e.g. Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Rohrer & Pashler, 2010), it seems advisable to develop professional development for senior science teachers that addresses the changes to cognitive demand of learning objectives in the new syllabi.

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Appendix 1:
Cognitive verbs commonly used for syllabus objectives and their cognitive level

	Retrieval	Comprehension	Analysis	Knowledge utilisation
Category description	Recall of information from permanent memory	Activation and transfer of knowledge from permanent memory to working memory	Reasoned extensions and inferences to go beyond what was directly taught	Application or use of knowledge in specific situations
Sub-components	• recognising • recalling • executing	• integrating • symbolising	• matching • classifying • analysing errors • generalising • specifying	• decision-making • problem-solving • experimenting • investigating
Cognitive verbs	define demonstrate identify name recall recognise retrieve select state use	clarify communicate comprehend describe explain illustrate model represent summarise understand	analyse apply categorise classify compare connect consider contrast critique differentiate discriminate distinguish examine generalise identify infer interpret judge reflect on	create conduct decide determine develop discuss elaborate evaluate investigate justify predict propose solve synthesise

Figure adopted from "Categories of common cognitive verbs" by the QCAA, 2019, retrieved from https://www.qcaa.qld.edu.au/downloads/p_10/ac_categories_cognitive_verbs.pdf

Appendix 2: Discourse analysis key words

	Verbs	Nouns	Adjectives (opposites not included)
Metacognitive System	monitor	metacognition, mindfulness	mindful
	determine	executive control	familiar
	check	thought, thinking	clear, comprehensible
	evaluate	process, procedure, technique, approach, strategy	accurate, right, reliable
	improve	performance, conducting, implementation	correct
	regulate	execution, enactment, carry(ing) out, completion	valid, sound, reasonable
	defend	understanding, comprehension, grasp, awareness, insight,	ambiguous, vague,
	(knowledge)	familiarity	doubtful
	question	clarity, intelligibility, comprehensibility	certain, sure, confused
	analyse	accuracy, rightness, reliability	difficult
	judge	correctness	effective, how well/ good,
	examine	validity, soundness, reasonableness	successful, fruitful
	assess	error, mistake, fallacy, misconception, oversight	intended
	specify	ambiguity, ambivalence, vagueness, doubt	
	establish	certainty, conviction, sureness, assuredness	
	develop	confusion, ignorance	
	set	difficulty, problem, struggle	
	identify	indistinction (*sic)*	
	accomplish	assumption, supposition	
	plan	reasoning, logic, interpretation,	
	rehearse	effectiveness, success,	
	keep track	goal, target, desire, wish, resolve	
	(of), track	objective, purpose, hope	
	review	plan	
	reflect	(needed) resources, materials, aid, help, support, means	
	aspire	milestone	
	achieve	progress, progression, advance(ment), growth, improvement	
		tracking	
		aspiration, ambition, dream, intent(ion), aim	
		reflection	
		accomplishment, achievement	
Self- System	analyse	importance, significance	important, significant
	examine	purpose, worth, motive, impetus	valued, appreciated,
	defend	attitude, viewpoint, perspective, opinion, stance, standpoint,	desired, esteemed,
	identify	position	respected, admired,
	describe	belief, idea, conviction, contention	cherished
	improve	value, merit, utility, desirability, principles, morals, ethics,	able, skilful, adept,
	engage (with/	benefit, appreciation	good, well, better,
	in)	efficacy	intelligent, proficient,
	perceive	ability, capacity, expertise, adeptness, aptitude, mastery	talented
	notice	capability, potential, proficiency, experience, talent,	competent, adequate
	desire	intelligence	emotional (response)
	inspire	power	motivated, inspired,
	appreciate	resources, means	enthusiastic, ambitious,
		competence, competency, adequacy, fitness	driven, determined
		effort (attribution)	interested
		emotion, sensation	engaged, involved,
		feeling, sentiment, sense	personal, own
		motivation, motive, stimulus, inspiration, enthusiasm,	
		ambition, drive, initiative, determination	
		(level of) interest, real-life	
		attention	
		engagement, participation, involvement, association	
		self, individual	
		perception, notion	

Note: black terms 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"; grey terms derived from thesaurus