Research in Science Education (2022) 52:1603–1622
https://doi.org/10.1007/s11165-021-09988-4

Cognitive Demands of the Reformed Queensland Physics, Chemistry and Biology Syllabus: An Analysis Framed by the New Taxonomy of Educational Objectives

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Accepted: 1 January 2021 / Published online: 19 May 2021

Abstract

Learning objectives outline the knowledge and skills to be taught in a subject, thus signaling what is worth learning and what type of thinking is valued. The aim of this syllabus analysis is to determine the cognitive demand of learning objectives in the recently reformed Queensland physics, chemistry and biology syllabus and to analyse whether the development of students' metacognitive and self-system thinking is embedded in the curriculum. Marzano and Kendall's (2007) New Taxonomy of Educational Objectives was used as a 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, with less than 50% of learning objectives at analysis or knowledge utilisation level. Teaching metacognitive and self-system thinking were found to be implicit rather than explicit objectives of the new syllabi. There may be a mismatch between the policy 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 · Cognition · Secondary/high school · Syllabus analysis

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1. Educational Objectives and their Cognitive Demands

Educational objectives, sometimes called aims, goals or success criteria, are explicit statements describing what students are expected to learn as a result of a course or subject (Marzano and Kendall 2007). 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 grade level, e.g. Singapore or Australia. Typically, these learning objectives identify content knowledge and a cognitive skill that helps learners organise and integrate their experiences (Bloom et al. 1956). Thus, most learning objectives contain a cognitive verb describing the intended cognitive demand of the learning objective, plus the knowledge to be constructed, i.e. students should evaluate (cognitive verb) the properties and structure of ionic, covalent and metallic compounds (knowledge).

By communicating which knowledge and cognitive skills students should be taught, learning objectives send messages about what is worth learning in a subject and why the subject is taught. One such rationale of education in Australia is to develop skills in learners that will allow them to adapt to 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 (Preschool to Grade 10) and 'Underpinning Factors' or '21st Century Skills' in the senior syllabi (Grade 11 and 12). They include higher order thinking skills like problem-solving or critical and creative thinking. Gonski and colleagues (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. That is a view supported by 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 cross-disciplinary knowledge (Mishra and Mehta 2017). In her review of emerging trends in Australian senior science education, Firn (2016) urged syllabus writers to more explicitly identify where and how 21st Century Skills can be incorporated in the curriculum.

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 Preschool to Grade 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). To date, however, the cognitive demand of current Australian science curricula in Year 11 and 12 have not been analysed. This is a crucial gap in the literature around Australian science curricula because such an analysis of curriculum policies and documents can expose which cognitive skills are emphasised in each subject area.

Cognisant of the importance of analysing the prescribed curriculum, this study is 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 Grade 10 (Jane et al. 2011) and on knowledge and achievement standards expected of Grade 12 chemistry and physics students in Australia (Matters and Masters 2007). International research has analysed the cognitive demands of science curricula in the USA (Liu and Fulmer 2008), China (Wei 2020), Singapore and Korea (Lee et al. 2015). These previous studies supported alignment of prescribed, assessed and enacted curricula, and results were used to tailor support and professional development for teachers. Analysing the cognitive demand of curriculum documents also allows for reflections on the congruence of science curricula with proclaimed goals of science education (e.g. Liang and Yuan 2008). The study described here aims to accomplish similar goals, and thus inform decision making of curriculum developers and science educators, by asking the following research questions:

(1) What are the cognitive demands of learning objectives in the reformed Queensland physics, chemistry and biology syllabus?
(2) How is the metacognitive and self-system embedded in the new syllabi?

Study Context

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 and 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 (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 – 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 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 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). A syllabus analysis can uncover the type of cognitive skills that are prescribed by the reformed senior syllabi and the emphasis placed on the metacognitive and the self-system. It allows for evaluation of the type of thinking that is expected and valued in the new senior science syllabi.

Theoretical Framework

Cognitive skills in learning objectives can be classified using educational taxonomies. For example, 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 and Krathwohl 2001). This study employs Marzano and Kendall (2007)

New Taxonomy of Educational Objectives as the theoretical lens for analysing cognitive demands of learning objectives because the New Taxonomy underpins the suite of all senior secondary syllabi in Queensland, Australia. Each syllabus explicitly details the New Taxonomy's structure and adopts its terminology of cognitive verbs for learning objectives. 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, e.g. Anderson and Krathwohl (2001) Revised Bloom's Taxonomy or Biggs and Collis (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 re-classified based on taxonomies other than the one used for writing the objectives.

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 and Dubas 2015). Decision making, for instance, requires more conscious thought and awareness than recalling information, which is often executed automatically (Marzano and 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. A student may, for example, calculate acceleration using Newton's second law to problem solve in an unknown situation before being able to explain that acceleration occurs due to unbalanced forces. Thus, the student applies knowledge (level 3) before truly understanding it (level 2).

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. In the New Taxonomy the cognitive system is influenced by two further systems, the metacognitive system and the self-system (see Fig. 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 seems to be effective at enhancing students' cognitive skills long-term and frequently across subject disciplines (Beyer 2008; Acedo et al. 2010). Hattie (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 and

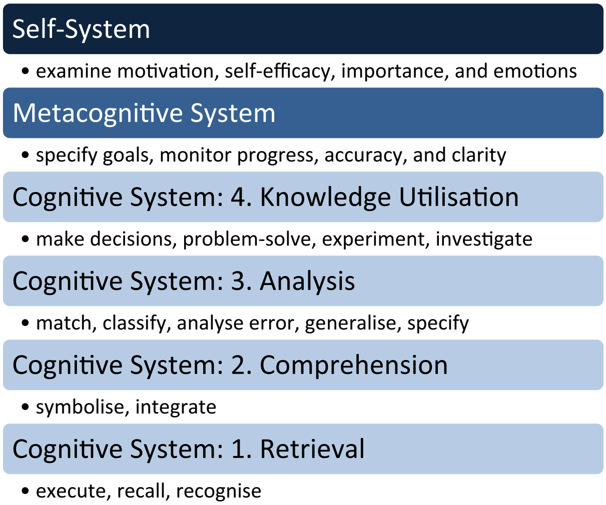

Fig. 1 Structure of the new taxonomy of educational objectives

their motivation. 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). The *Australian School Science Education National Action Plan 2008–2012* argues that such focus of learning on the relevance to students' concerns is a core characteristic of an ideal science curriculum (Goodrum and 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).

Methods

To proceed with the analyses proposed in this study, the physics, chemistry and biology syllabi were accessed through the QCAA website. The three syllabi were read in full to record their structure and components. To investigate the first research question, learning objectives were analysed for their cognitive demand at the most specific level provided. 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

Table 1 Examples of learning objectives at each cognitive level

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

Cognitive verbs used to classify each objective are italicized

each cognitive level published by the QCAA.[1] Table 1 shows examples of learning objectives matched to their cognitive level. 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, to answer research question two, the remaining sections of each syllabus were searched for implicit references to these two systems of the New Taxonomy. The analysis entailed (1) identifying, (2) selecting, and (3) appraising text passages to classify syllabus excerpts as references to metacognitive 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 Table 4 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.

(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 metacognitive 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.

[1] The full list of cognitive verbs can be accessed at https://www.qcaa.qld.edu.au/downloads/p_10/ac_categories_cognitive_verbs.pdf

Results synthesise how these text passages embed the metacognitive and self-system in the new science syllabi.

Results

Cognitive Levels 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. A total of 242 cognitive verbs were coded for physics, 381 for chemistry and 196 for biology. This total was used to calculate proportions of cognitive levels in each syllabus.

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 2 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.

Cognitive levels of subject matter content descriptors are skewed towards retrieval and comprehension in all three sciences (see Fig. 2). 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 3 shows 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 Fig. 3 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 (see Appendix Table 5 for exact percentages for each topic).

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 analysis level. Notably, earlier topics seem to have a greater

[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.

Table 2 Proportion of cognitive verbs in subject matter content descriptors

	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%

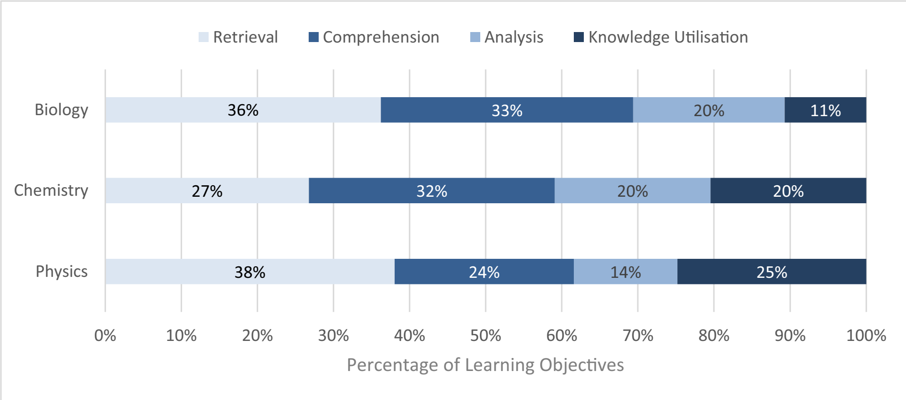

Fig. 2 Cognitive levels of subject matter content descriptors

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 can 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' Australian Tertiary Admission Rank (ATAR). Interestingly, while subject matter content descriptors in the three subjects are distributed unequally across the four cognitive levels, assessment criteria and marking guides of all subjects' internal assessments are identical.

Metacognitive and Self-system Thinking in the Syllabi

No subject matter content descriptor directing teachers to engage students with metacognitive thinking in the subjects was identified. The cognitive verbs used in the prescribed learning objectives focus solely on the four levels of the cognitive system. However, there are implicit references to the metacognitive system in other sections of the three syllabi (see Table 3). For example, the pedagogical and conceptual framework as well as the underpinning factor i.e., 21st Century Skills, states that physics, chemistry and biology students should specify goals in the 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. No references were found in the three syllabi relating to students monitoring the clarity of their thinking and understanding.

Fig. 3 Emphasis on cognitive levels by content topic. Note: Underlined topics are assessed on the external exam

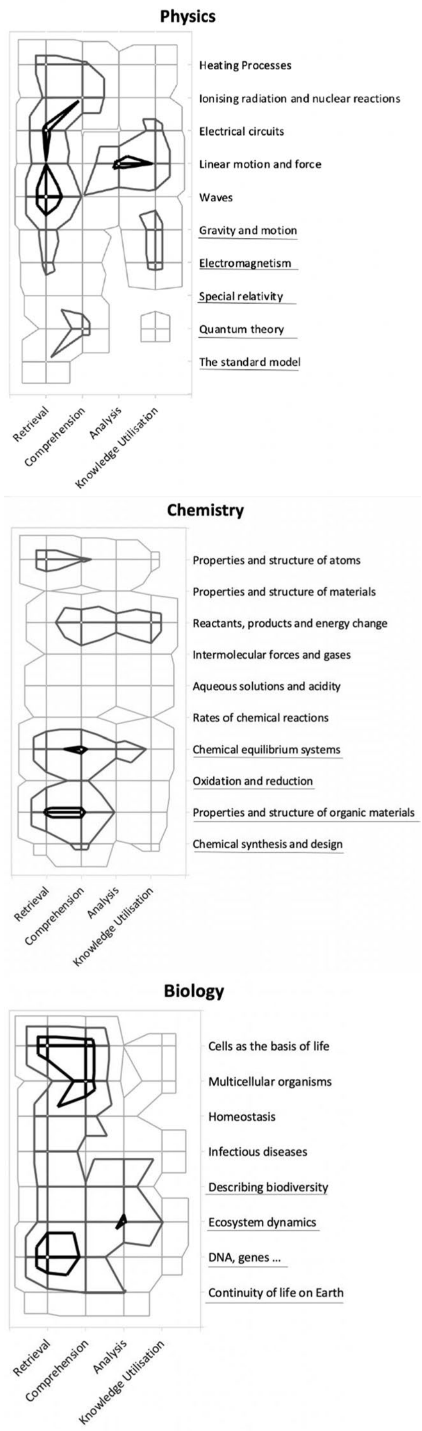

Table 3 Implicit references to the metacognitive and self-system in the three syllabi

		Location in Syllabus	Examples:
Metacognitive System	Specify Goal	- Elaboration of syllabus objectives - Underpinning factors (21st Century Skills) - Pedagogical and conceptual framework - Assessment objectives - Unit 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*
	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* - 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

Table 3 (continued)

		Location in Syllabus	Examples:
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*
	Examine Emotional Response	- Underpinning factors (21st Century Skills) - Unit descriptions	- 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 sourced from the QCAA's (2018a, b) Capabilities and Skills Frameworks across Senior Curriculum Phase

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 3). 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.

Discussion

The new physics, chemistry and biology syllabi have been found to be dominated by learning objectives addressing retrieval and comprehension of knowledge. Directives to teach metacognitive and self-system thinking are present, but they are implicit rather than explicit learning objectives. The following section discusses the implications of those findings for stakeholders and pedagogy in science education.

Dominance of Retrieval and Comprehension in Learning Objectives

Considering an increased focus on 21st Century Skills in science education internationally and the goals of science education in Australia outlined in the introduction, the results of this syllabus analysis are surprising. In all three subjects, more than half of the subject matter content descriptors address lower level cognitive skills. Moreover, 50% of students' final grade is determined by an external exam, which, in some circumstances, may hinder intentions to focus on higher order cognitive skills in the classroom (Fensham and Bellocchi 2013). Research on the enacted curriculum through classroom observations or teacher surveys is needed to determine if this is the case in Queensland.

While a focus on retrieval and comprehension seems to be a contradiction to aims of science education in Australia, some scholars 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 previous 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 and Masters 2014). The government responded by arguing 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 strong 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 might entail 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 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 et al. 2011). However, Hollins and Reiss (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 be less focused 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 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 recall of knowledge (Hollins and Reiss 2016). The previous Queensland senior science syllabi had 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, research is needed on 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.

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 and Tarmizi 2010; Venville and 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 and Kendall 2008). An analysis of 15 different chemistry syllabi in Turkey showed that the cognitive domain dominates learning goals (Pekdağ and 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 affective skills that cannot be observed directly, i.e. value systems 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 importance seems to have diminished though in the reformed syllabi as compared to the previous syllabi, which had an explicit, yet not assessed, learning objective addressing students' affective domain and instructing teachers to develop students' attitudes and values surrounding their learning in the subject. The previous suit of senior science syllabi also mandated to contextualise prescribed subject matter in teacher designed units (e.g. Queensland Studies Authority 2007).

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, a focus on the cognitive system while treating the metacognitive and self-system as an 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 was observed in Western Australia after the last syllabus reform (Kruger et al. 2013).

Implications for Pedagogy

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 (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 et al. 2018).

It is questionable, however, whether retrieval and comprehension skills which dominate the new syllabi are commonly taught by inquiry learning. Instead, teachers may choose to adopt a more didactic teaching style and to prioritise the delivery of content knowledge over the development of cognitive skills when faced with a highly prescriptive curriculum 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 et al. 2017). Again, there seems to be a potential mismatch between policy recommendations in Australia and the content of the prescribed curriculum.

Independent of the pedagogical approach, teachers could benefit from professional learning about best practice for teaching the different cognitive skills, metacognition and self-system thinking outlined in the science syllabi. Researchers have attempted to specify teaching practices that produce particular cognitive learning outcomes (Anderson and Krathwohl 2001), but have not succeeded in providing a universal answer. Nevertheless, Beyer (2008) review of pedagogical interventions for cognitive skills and De Corte (1990) review of pedagogies to teach problem-solving both conclude 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 context, and (d) metacognitive reflection on thinking procedures are particularly useful for effective cognitive skills curricula.

Limitations and Recommendations

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 and 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, the analysis of cognitive skills in the reformed science syllabi can support 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 new syllabi are currently interpreted, reformulated and enacted by teachers across Queensland. As Shalem et al. (2013) points out, even well written standards do not dictate appropriate pedagogical practices. Thus, 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 et al. 2013; Rohrer and Pashler 2010), professional development for senior science teachers that addresses the changes to cognitive demand of learning objectives in the new syllabi is imperative.

Conclusion

The aim of the syllabus analysis was to determine the cognitive demand of learning objectives in the reformed Queensland senior physics, chemistry and biology syllabi and to analyse whether the development of students' metacognitive and self-system is embedded in the curriculum. Results show that learning objectives in the new syllabi emphasise lower order cognitive skills like retrieval or comprehension over higher order cognitive skills like analysis or knowledge utilisation, which seems to contradict goals of science education in Australian policy documents. 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). Research is needed on potential effects of the reformed syllabi on the engagement of students with the sciences beyond the secondary level.

Appendix

Table 4 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	

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

Table 5 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 forc22e	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, 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%

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