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How Complex or Abstract Are Science Learning Outcomes? A Novel Coding Scheme Based on Semantic Density and Gravity

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Abstract
There has been a longstanding interest in the kinds of scientific knowledge that primary science learners must know and be able to do, which comprise the intellectual demands in this subject. These prescriptions chiefly take guidance from national curriculum documents, especially in the form of their learning outcomes (LO) or learning standards. Using the concepts of semantic density (SD) and semantic gravity (SG), we formulate a novel coding scheme for primary science LO based on Semantics and Legitimation Code Theory. We demonstrate how SD and SG provide insights into the levels of complexity and abstraction respectively from a mix of qualitative and quantitative criteria that we devised. We empirically test the utility of this coding scheme by comparing present reformed primary science LO with their previous versions across three East-Asian regions. It was shown that their LO were not significantly different over versions in terms of SD/SG, had typically one to two learning points, favoured more context-dependent expressions, and were predominantly coded as SD-SG+. This research provides a complementary method of determining the intellectual demands of science curricula in terms of complexity and abstraction of LO that has implications for science teaching as well as the improvement of epistemological access for learners.

Keywords Semantic density · Semantic gravity · Learning outcomes · Primary science

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Introduction and Rationales of Study

Among science educators, there has been a longstanding interest in the kinds of scientific knowledge that primary science learners must know and be able to do. Known sometimes as its intellectual demands (Lee et al. 2015), these desired forms of knowing and doing in school subjects are usually expressed as learning outcomes (LO) or learning standards that are found within the intended curriculum. It is also widely acknowledged that what is officially prescribed determines what should be taught even if not successfully accomplished within each classroom. Some might see these lengthy lists of LO as an attack on the professionalism of teachers especially in systems that hold dear to the Bildung-Didaktik tradition. In contrast, in developing countries or in systems that take reference from the Anglo-American tradition, these LO seem to offer transparent, ready-made guidance about what and how to teach (Wang et al. 2019).

Our previous research has extensively examined the intellectual demands in elementary science curricula across East-Asian regions together with their associated policy and educational structures (Lee et al.2017; Lee and Tan 2018). Thus far, revised Bloom's Taxonomy (RBT) has been our tool of choice as it afforded two useful classifications: (1) six levels of cognitive processes and (2) four levels of knowledge domains. Moreover, we had consistently made the claim that knowing what these intellectual demands were was an essential part of the mandate to secure for young people what sociologists have termed powerful knowledge (e.g. Young 2007). These are the kinds of abstract, theoretical knowledge contained in academic disciplines like science or the humanities. They stand in contrast to learning about the world through ad hoc, everyday experiences/situations that are usually unable to furnish suitable opportunities to learn powerful knowledge. A social justice agenda was implicit in our past endeavours for we argued that only by engaging with powerful knowledge could there be opportunities for learners' future contributions or engagement with society, which has often been termed knowledge of the powerful. These questions concerning what passes for knowledge in schools are not merely academic; governments have been challenged to examine whether schools and their curricula really need to "up the intellectual ante" (Luke 2010, p. 59; Yates and Collins 2010) just as there is widespread insistence on teacher specialisation/certification in teaching primary science and mathematics (Mills et al. 2020). Clearly, knowledge matters, and in significant ways throughout the organisation of effective teaching and learning.

This current project extends our previous work as we now wish to interrogate a different form of intellectual demand present in curricula, specifically the levels of complexity and abstraction of LO. We have attempted to create a new classification scheme that we then put to the test by comparing LO from reformed primary science curricula with their previous versions across three East-Asian regions. If we can achieve a reasonably reliable and valid means of coding, we claim that this will be a distinct contribution for science curriculum research as well as be able to inform classroom instruction. In what follows, we describe the theoretical frameworks behind our study before explaining the details of our coding methods.

Conceptual Framework—Legitimation Code Theory to Understand Knowledge and Knowers

In this paper, we have created a novel coding scheme for examining the levels of complexity and abstraction in primary science LO. Although the routine meanings of complexity and abstraction do overlap—texts that are difficult to understand often possess multiple and/or interlinked meanings (Granito et al. 2015)—they can also be analytically differentiated through semantic gravity (SG) and semantic density (SD) in research. We will explain these terms shortly, but for now, complexity refers to the density of ideas or meanings whereas abstraction concerns the degree of dependency on the context to derive meaning. Both SG and SD are sub-concepts or dimensions belonging to a conceptual framework known as Legitimation Code Theory (LCT) that draws inspiration from sociology and systemic functional linguistics (see Garraway and Bozalek 2019). LCT has been used to investigate both *knowledge* (the objects of knowing) and *knowers* (the agents who learn) as it "enables knowledge practices to be seen, their organizing principles to be conceptualized, and their effects to be explored" (Maton 2014 p. 2–3).

In any social practice, there are acceptable, expert ways of performance versus those that are regarded as unacceptable or incorrect forms. These kinds of tacit, evaluative principles or rules-of-the-game are known as legitimation codes that are enacted by its primary agents in each specific practice. For example, in formal schooling, which is a field of knowledge-building practices, we might regard the daily conduct of lessons with teachers and students as its main agents that maintain that very structure. For the purposes of this study, the intended primary science curriculum with its LO is regarded as a field of practice (as it specifies what knowledge is valued or legitimate in a community), and the science teachers who take guidance from it are its primary agents of implementation.

Because LCT enables links to be made between disciplinary structures of knowledge as well as the sociology of knowledge, researchers can make a distinction between (1) epistemic relations (i.e. how social practices create, endorse and adopt new knowledge) and (2) social relations (i.e. how social practices (re-)define identity and expertise among its agents). Indeed, these two relations are mutually constitutive; one affects or determines the other in profound ways. LCT therefore supplies researchers with flexible, dynamic concepts (e.g. classification, framing, discourse, recognition and realisation rules that are not covered here) to understand all manner of texts (including social practices such as speech, writing) such as curricula documents. For these reasons, it has been used in diverse fields such as education, medicine, business and law (Maton et al. 2016).

Very often, users of LCT seek to investigate "what is possible for whom, when, where and how, and who is able to define these possibilities, when, where and how" (Maton 2014, p. 18) by scrutinising how these legitimation codes vary across knowledge practices and how they are competently appropriated by agents (or not). Why is this important? Assuming that these codes can be made known, they can then be critiqued and thus LCT is a practical theory that can help improve these same practices.

With respect to learning science, unless students can understand what these different kinds of legitimation codes are and how they can personally use or create them, it is unlikely that students will become or see themselves as successful learners; they will lack "epistemological access" to science (Luckett and Hunma 2014). This means that while students might be attending school, their access or engagement with scientific knowledge might actually be curtailed due to say linguistic differences or deficits in requisite school science experiences. Students as well as their teachers must therefore understand what these specialised codes are and what really "counts" in the disciplines. Only when students appropriate the former as their own and therefore "learn," epistemological access can be successfully accomplished. When we adopt LCT to scrutinise our teaching and learning, it offers insights into what kinds of tacit knowledge(s) is at play while simultaneously helping learners gain access to these privileged forms of knowing. In essence, LCT is a recent attempt to operationalise at the level of pedagogy what had merely been theorised by sociologists of education like Basil Bernstein. LCT is thus concerned with improving equitable access to valuable knowledge as well as increasing participation in these very processes whereby this knowledge is legitimated (Garraway and Bozalek 2019).

The complete LCT “toolkit” has five complementary sub-components; we are concerned only with studying the organisation of knowledge in the intended school curricula, which is the purview of the LCT Semantics dimension that comprises SG and SD codes (Doran 2017). Note again that how knowledge is understood here (based from sociological and linguistic perspectives) is different from the idea of knowledge in RBT (derived from psychology) (Anderson et al. 2001). Through Semantics, researchers thus have a different (i.e. not decided by unitary cognitive or knowledge levels) but complementary means of coding LO based on their degrees of abstraction in SG and of complexity in SD codes. Coding by RBT does not consider questions of complexity directly; this might be reasonably inferred if we detect cognitive and knowledge levels that are simultaneously coded high on their respective categories. Likewise, how abstract an LO is cannot be precisely fixed through RBT, which is why it is felt that Semantics can offer an alternative approach towards the coding of LO.

There are some other possible advantages of coding LO via Semantics. For example, coding with RBT assumes a hierarchy within predetermined cognitive processes and knowledge types; items coded as Evaluate are assumed to encompass all previous four although not the highest cognitive process of Create, for instance. Researchers using Semantics, on the other hand, have flexibility in creating purpose-built measures for each of their SG and SD dimensions. They can, in theory, define anything from two to an infinite continuum of strengths/categories if this meets the objectives of their research. There are also expected pairings of codes in RBT (e.g. Remember: Factual; Understand: Conceptual; Apply: Procedural), but no such expectations in outcomes exist when coding with Semantics. The actual intellectual demands of LO during classroom instruction (i.e. the implemented curriculum) are affected by learners’ prior knowledge; they might be higher or lower depending on their past experiences, training or background knowledge. This issue has been long acknowledged among users of Bloom’s Taxonomy (Anderson et al. 2001) and there is no reason to doubt that a similar situation exists for LO coded by Semantics too. This shortcoming, however, does not apply to the current study as we attempt to code LO from the intended curriculum.

One Aspect of LCT—Semantics for Evaluating the Organisation of Knowledge

We now elaborate the theory behind SD and SG that are part of Semantics (Georgiou et al. 2014; Rata et al. 2019). All social practices (e.g. curricula) can be characterised by these two codes that can strengthen or weaken independently of one another. Together, these codes help us understand two aspects of knowledge practices—their complexity and abstraction of meaning.

Semantic Density for Understanding Complexity of Meaning

Complex concepts generally comprise combinations of two or more basic concepts usually of adjective-noun or noun-noun lexical forms (e.g. “pyroclastic flow” “enzyme-substrate complex”) (Kelter and Kaup 2019). Complexity in SD also denotes how many concepts/ideas/

meanings/symbols are captured within or linked/condensed with a certain term/word/formula/practice. Items with weak or low SD (denoted as SD−) would have ideas that are more standalone, relatively simpler, and with fewer associated meanings; red blood cell, phospholipid, diffraction grating, bar magnet, electron cloud, the Grignard reaction would be possible examples of these in science according to Semantics. These terms might appear complex at a lexical level (i.e. they are compound terms), but in Semantics, they are considered terms with low SD as they have a specific referent; they possess fewer ideas or meanings associated with them. On the other hand, items with strong or high SD (i.e. SD+) are highly relational with multiple/generic meanings; cells, respiration, climate change, oxidation, friction, evolution and light can all qualify as items with high SD. Comparing three representations (liquid; water; H_2O), the first would possess the strongest SD code with multiple meanings (i.e. there are many different kinds of liquids) whereas the last has the least ambiguous meaning (i.e. one particular type of liquid with fixed chemical formula H_2O). It goes without saying that chemists who speak different languages are able to understand each other fairly well if their discussions operate at this low/weak level of SD using chemical equations!

Of course, decisions about the condensation of meanings are never fully objective or fixed (and thus a source of miscommunication in everyday life). They depend on the types of practice or knowledge objects, the group of terms that are being compared, a person's background, and its context in the original text (Blackie 2014; Maton 2014). To a novice, a rainbow might imply a relatively low SD, but to a physicist, this might be much more semantically dense as it brings to mind a number of associations regarding light, dispersion and so forth. In addition, many concepts in science are already highly condensed with multiple nominalisations (e.g. fractionation, diffraction, hydrogenation). Since we are dealing with science LO, we must remember that we are comparing relative degrees of density here among terms that are already condensed compared with everyday talk.

Semantic Gravity for Understanding Abstraction and Context Dependency of Meaning

When we say that a concept or meaning is abstract, it normally refers to it being a prototype that aggregates normative features associated with it (e.g. different kinds of felines are still cats) or something that lacks a sensorial, physical referent in the world (e.g. curiosity, honour) (Granito et al. 2015; Hayes and Kraemer 2017). These notions influenced by Piagetian thought have guided science educators for a long time (e.g. Karplus 1977). Following the latter sense of abstraction, how far away or close a meaning/concept/phrase/practice is tied to or dependent on the context is the essence behind SG. When something has a weak or low SG (denoted as SG−), it implies that these have abstract or context-independent meanings at a higher level of classification that can be understood or applied widely across other situations or disciplines. In science, notions such as acids, bases, salts, speed, vectors, using a formula like $Q = \mathrm{mc}\theta$, evolution, and homeostasis can qualify as general concepts with low SG as they can be used across different topics to explain different phenomena. Meanings of these terms here (SG−) are thus "distant from their point of application" and "more situated in, dependent upon, and order by a system of ideas, theory, discipline or multi-disciplinary fields" (Shay 2016 p. 773), which implies that the meaning of the same term can make sense within different types of contexts.

On the other hand, items that have strong or high SG (denoted as SG+) have their meanings closely tied to specific contexts of use or origin; words such as hydrogen sulphate, chloroplast, mitochondrion, calculating acceleration given known numbers are some possibilities here. The important point to consider is that we must consider the *relative* degrees of context dependency within a set of terms that are being compared; in a chemistry lesson, “acids” would be regarded as possessing more generic/abstract meanings with less context dependency (SG−) than mentioning a very specific type of acid such as “hydrogen sulphate” (SG+). An actual demonstration of the dissolving of salt in water would be likewise considered as SG+ whereas the chemical equation “NaCl(s)➔ NaCl(aq)” or using the technical term “dissolution” would have meanings with low SG (Blackie 2014).

We reiterate that deploying semantic codes in a study involves tailoring them in a principled manner that answers the research question. Examples of SD and SG can easily be multiplied here, but it is necessary to note that they are

> neither definitional nor definitive. *The forms taken empirically by different strengths of semantic gravity and semantic density are different in each object of study and for each form of data.* No empirical example is the definition of any specific strength of semantic gravity or semantic density. Accordingly, much research in LCT is devoted to developing ‘translation devices’ or multi-level typologies that translate between concepts and different objects of study (Maton 2019, p. 3, italics ours).

SG and SD in (Science) Education Research

During lessons on thermal physics, it was reported that students would be better served had they been given opportunities to work on questions with a range of SG rather than mainly dwelling in the realm of abstractions, that is, items with low SG (Georgiou 2016). By alternating between abstract theory and concrete practice, it would have helped learners better understand the knowledge structures of thermal physics. Indeed, for many students there was what was called an unhelpful “Icarus Effect” whereby they felt compelled to endorse or cite difficult physics theories in their answers without really comprehending or being able to make appropriate links in their explanations (Georgiou et al. 2014). On the other hand, quantification or the actual working out of mathematical problems in physics (and science in general) can be used for learning abstract theories (i.e. building knowledge) as it grounds knowledge in real-world problems and thus strengthens semantic gravity. All this means that learners can benefit greatly when they exposed to a mix of high and low SG subject matter—both are required (Doran 2017)!

Much of Semantics research in (science) education has underscored how cumulation or meaningful learning occurs when there are recurring back-and-forth movements/changes or what has technically been called semantic waves (Maton 2020). This allows learners in a lesson/unit/curriculum to experience a spectrum of meanings when there are appropriate and periodic shifts in:

- abstract (SG-) ← → concrete (SG+) codes
- simple (SD-) ← → complex (SD+) codes.

It has also been observed that teachers often unpacked new theoretical concepts with more everyday meanings and with real-life contexts, which definitely assisted in helping student understanding. However, a return or upward semantic shift sometimes failed to occur where these concepts could be “repacked” back to its more complex and dense meanings to help learners see their place within disciplinary structures (Maton 2014).

Researchers can furthermore have a useful heuristic when SG and SD are made to form two orthogonal axes known as a semantic plane. Figure 1 below is an example from Rootman-le Grange and Blackie (2018) who analysed chemistry examination questions this way. Different kinds of texts can thus be located in one of these four quadrants, which then afford different meanings for interpretation as legitimate practice. When chemistry items were located at (SG− − SD++) quadrants, for example, it implied that these questions required context-independent, abstract knowledge that also held multiple or complex meanings, which generally makes it harder for students to answer. The semantic plane is thus a useful heuristic for researchers to locate the gradations of strengths of the codes within any practice, including the LO within national curricula as we have done here (Maton 2020).

Semantics has also been adapted to analyse Biology textbooks for their epistemological access (Kelly-Laubscher and Luckett 2016), difficulties when transitioning to university Biology from High School (Mouton and Archer 2019), difficulties in chemistry teaching (Blackie 2014), and investigating the types of knowledge found in student-made science concept maps (Kinchin et al. 2019). In this journal, Semantics was recently used by Buxton et al. (2019) to ascertain the degree of complexity and abstraction in assessment questions including the responses offered by secondary school bilingual learners. Some students were found to be successful when they used part of the question stem as resources to scaffold their answers although many were also stuck and could neither articulate more generalised or specialised ways of explaining (i.e. no semantic waving). What unites many of these studies is that they all sought to interrogate the knowledge structures that learners needed to navigate

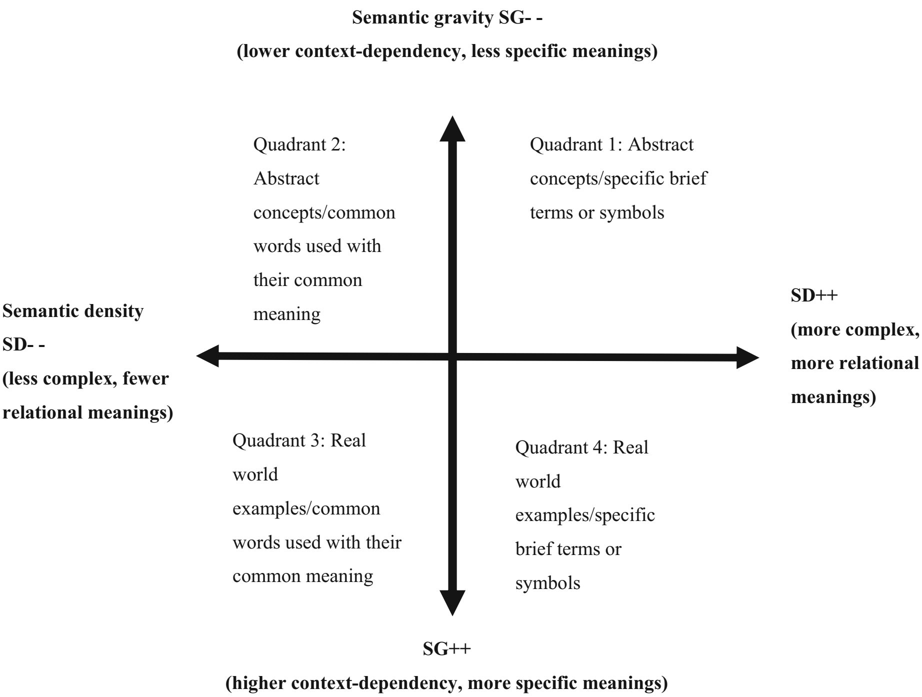

Fig. 1 Example of a semantic plane used for classifying chemistry examination questions (adapted from Rootman-le Grange and Blackie 2018)

as they encountered theoretical knowledge from schools/curricula and how that interacted with their everyday practical knowledge.

Neither one of the four quadrants in Fig. 1 ought to characterise the predominant type of instruction within a course; instead, there are good reasons for learning to encompass more than one quadrant as we have just explained. Semantics thus offers educators a chance to break free of just valorising either abstract/academic (quadrant 1 in Fig. 1) or practical knowledge (quadrant 3), but also to consider opening opportunities for learning science through "rarefied" (quadrant 2) and "wordly" ways of knowing (quadrant 4) (Maton 2020). Indeed, all knowledge or ways of knowing (i.e. within a social practice) inevitably contain different combinations or strengths of SD and SG that we can interrogate to improve epistemological access for all students. Such a stance is even more valuable than trying to pinpoint how strong or how weak is an item in terms of its SD or SG. It was such potential in Semantics that inspired us to embark on this study.

Devising Semantic Codes for LO

While we understood the fundamental theory behind Semantics, there had to be a translational process of adapting it to our research context, a process called an external language of description. Rather than a weakness, we see this as something positive as the research tools can now be customised to serve a specific need. We had to make a number of defensible assumptions and rework Semantics to code science LO without violating any of its principles underlying these sub-concepts. For example, Semantics was never meant to be used as a strict typology although we have created four coding levels representing a gradation of strengths for SG and SD. This was a compromise for greater resolution in our coding rather than just having dichotomous or three levels per dimension. Our study also involved coding the primary science LO, which are from state curricula. As purposefully developed specifications inherently abstract in terms of disciplinary knowledge (science) and definite because they explicitly spell out what is to be taught or attained (these are LO), there were therefore a number of considerations before we derived the final coding scheme shown in Table 1.

SD Codes—Mixing Quantitative and Qualitative Criteria

Semantics research allows coding at various levels such as at word/symbol (e.g. Doran 2017), clause/phrase/sentence/paragraph (e.g. Buxton et al. 2019; Kelly-Laubscher and Luckett 2016) and even larger units where written texts such as lesson plans or concept maps and observations of behaviours are mixed (e.g. Blackie 2014; Kinchin et al. 2019; Maton 2019; Mouton and Archer 2019). We followed Rootman-le Grange and Blackie (2018) to code at the sentence

Table 1 A new coding scheme for primary science LO with four levels of SD and SG

SD−−	SD−	SD+	SD++
No scientific concepts/phenomenon mentioned	1–2 learning points in the LO	3–4 learning points in the LO	> 5 learning points in the LO
SG−−	SG−	SG+	SG++
Verb and noun: not specific, context-independent	Verb: more specific and context dependent Noun: not specific, context-independent	Verb: not specific, context-independent Noun: more specific and context dependent	Verb and noun: more specific and context-dependent

level as this was deemed appropriate for LO as well as being aligned with our previous coding research based on RBT. A mix of qualitative and quantitative criteria can be used to distinguish the strengths of SD/SG and thus we have adapted this fact to create codes for SD in Table 1 (see Wiemer-Hastings and Xu 2005). Given that SD is a code for complexity, SD−− (the weakest level) was defined as having no scientific concepts/phenomena mentioned (least complex code) in an LO. It was, of course, impossible to have SD−− expressed as having no learning points, which would have been a logical contradiction for an LO. What we had in mind for characterising SD−− were LO that could be taught by a teacher not trained in science as they described learning outcomes using unspecialised, ordinary language that did not make explicit reference to scientific phenomena, events or objects. Some examples of these uncommon LO can be found from Hong Kong: "Observe phenomenon in daily life; Develop healthy living habits; Understand the need to save energy."

We then specified three additional codes in this dimension (i.e. SD−, SD+, SD++) based on the number of science learning points specified for instruction in each LO. These general learning points are often found in the noun phrase of an LO and represent the main ideas that a student will know or be able to accomplish after instruction. This is a bespoke adaptation of Semantics theory as all science LO are inherently complex compared to ordinary speech. We have, nonetheless, tried to have a gradated and reasonable increase in complexity in how we have conceptualised it that ranged from SD−− (the least complex) to SD++ (most complex) codes for an LO. Additional examples of how we determined the learning points within an LO and our justifications are shown below in Table 2.

SG Codes—Examining Verb and Noun Phrases in LO

When using SG theory to code for science LO, it initially seemed intuitive to analyse each LO for their number and/or degree of abstract or concrete concepts, but this quest proved very subjective as a general theory of abstraction is still elusive (Borghi et al. 2017). Given that LO are usually prefaced with a verb phrase followed by a noun phrase, we derived four codes for SG based on the combinations of how specific or context-dependent these verbs and nouns

Table 2 Examples of the number of learning points found within an LO for differentiating SD−, SD+ and SD++ codes

Examples of LO	Number of learning points in the LO
Understand the types of mammals (e.g. lion, dogs, cats)	1: types of mammals (ignore examples)
Know that lions or tigers eat meat and are warm blooded	2: (lions/tigers) eat meat and are warm blooded
Describe the characteristics of air such as its colour, state, odour etc.	3: The factors of colour, state and odour affecting air. Ignore "etc."
Recognise or list some broad groups of living things. - plants (flowering, non-flowering) - animals (amphibians, birds, fish, insects, mammals, reptiles) - fungi (mould, mushroom, yeast) -bacteria"	4: (recognise/list) four broad groups of living things (ignore category examples)
Describe the characteristics of living things. - need water, food and air to survive - grow, respond and reproduce	6: All these six characteristics have to be known

were within each LO as shown in Table 1. Hence, we used SG−− to code those LO that had both their verbs and nouns that were not specific as well as being context-independent. SG−− thus refers to LO that contain the most generic learning outcomes or ideas that can be applied across many different contexts. Such LO often used everyday language that we likewise disregarded the number of learning points inside them.

We moreover regarded verbs such as "Explain, Describe, Know" as context-independent command verbs that have similar sense meaning across many contexts and conditions—they are generic cognitive processes. Likewise, the noun phrases in LO coded with SG−− spoke of learning science in very generic, context-independent terms that also often employed non-scientific language (but not always, e.g. "Describe biological evolution"). But when LO were prefaced by "Explain using the given formula…" or "Based on the data tables below…" these were now considered as context-dependent verb phrases because they were accompanied by instructions for some specific tasks, condition or procedure in the LO. These are additional pedagogic instructions associated with such verb phrases.

How did we derive the rest of the SG codes? We defined SG++ codes as having both verb and noun phrases that were specific, and context-dependent—such LO are regarded as very concrete in what they want students to learn and how to do it. Most noun phrases in LO are indeed specific or delimited as they usually make reference to some object, event or phenomenon to learn in the science curriculum. The noun phrase in an LO is by definition about learning some target knowledge in school and cannot exist in a vacuum—just learn "something"! Whether this biased our coding to favour noun phrases as content-dependent is moot, but we tried to devise our SD and SG codes that could be coded reliably and objectively as far as possible.

The polar ends in our SG coding scheme were defensible, but it was harder to characterise the two middle codes of SG− and SG+. A judgment call was made to classify SG+ as possessing non-specific verbs and more context-dependent nouns. This was felt to be an arbitrary separation with SG− although we now managed to obtain four levels of differentiation for SG based on the context dependency of their verb and noun phrases. (Another coding rule we adopted was that if two command verbs were present in an LO, this was regarded as having specific, context-dependent verbs.) Table 3 shows some examples of our SG coding with selected LO from Hong Kong. Because we coded for the abstraction of verb/noun phrases only *within* an LO and not between LO, this bypassed some of the uncertainties in Semantics where the meaning of a term is dependent on the actual pool of terms being compared.

Table 3 Examples of a range of SG coding based on selected science LO from Hong Kong

SG−−	Observe phenomenon in daily life
	Develop healthy living habits
	Develop caring attitudes towards living things and the environment
SG−	When using science and technology focus on safety issues
	Based on their common characteristics or unique features, classify objects
SG+	Identify some characteristics of weather changes
	Understand the need to save energy
	Appreciate the existence of different kinds of living things
SG++	Use the senses to identify the characteristics and changes of common materials
	Make use of common materials and design products
	Design and conduct simple scientific inquiry

Interrater Reliabilities and Sample Data

We coded only primary science LO in the cognitive domain; these were obtained from online official curriculum documents from Hong Kong (in English), mainland China and Taiwan (both originally in Chinese, but translated into English by the authors). The kappa interrater reliabilities from both researchers as coders varied from 0.38 to 0.71 (fair to substantial agreement) for SD for current and past curriculum across the three regions while coding for SG ranged from 0.59 to 0.87 (moderate to almost perfect agreement). It was found that coding for SD was poorer due to greater uncertainties in determining the learning points within an LO although the kappa values were still acceptable here.

Findings—Testing our Coding Scheme

Based on this new coding scheme, Tables 4, 5, 6, 7, 8 and 9 show the profiles of SD and SG codes across current reformed as well as their previous primary science LO across the three East-Asian regions.

The predominant code occupying a third to nearly half of all LO in every past and present curricula (save one) in the three regions was SD−SG+. This meant that LO in these curricula typically consisted of one to two learning points as well as having less specific, context-independent verb phrases linked with more concrete, context-dependent noun phrases. In addition, hardly, any LO from mainland China (Tables 6 and 7) or Taiwan (Tables 8 and 9) were coded as SG−− or SG− while those from the current Hong Kong curriculum had about 10% of LO belonging to these two categories. Most LO in these three regions were located at SG+ or SG++ levels, which perhaps stood to reason as LO are meant to describe in some detail what scientific ideas/processes to learn and how to achieve them. In Hong Kong (Tables 4 and 5) and mainland China, SG+ codes for abstraction in their past and current versions of their curricula were predominant. The reverse was true in the current version of the Taiwanese curriculum where LO coded as SG++ were the most frequent in percentage terms in that, and with reference to the other two regions.

Table 4 Overall profile showing the number of LO ($n = 53$) across SD and SG codes in the current curriculum from Hong Kong (% in brackets)

						Subtotals (%)
	3 (5.7)	3 (5.7)	Abstract, context independent SG- -	0	0	**6 (11.4)**
	2 (3.8)	3 (5.7)	SG-	0	0	**5 (9.5)**
	SD- - Less Complex	SD-		SD+	SD++ More complex	
	1 (1.8)	24 (45.3)	SG+	4 (7.5)	1 (1.8)	**30 (56.4)**
	0	10 (18.9)	SG++ Concrete, context dependent	2 (3.8)	0	**12 (22.7)**
Subtotals (%)	**6 (11.3)**	**40 (75.6)**		**6 (11.3)**	**1 (1.8)**	

Table 5 Overall profile showing the number of LO ($n = 57$) across SD and SG codes in the previous curriculum from Hong Kong (% in brackets)

						Subtotals (%)
	2 (3.5)	1 (1.8)	SG- - Abstract, context independent	0	0	**3 (5.3)**
	0	0	SG-	0	0	**0**
	SD- - Less Complex	SD-		SD+	SD++ More complex	
	3 (5.2)	27 (47.3)	SG+	5 (8.8)	1 (1.8)	**36 (63.1)**
	2 (3.5)	12 (21.1)	SG++ Concrete, context dependent	4 (7.0)	0	**18 (31.6)**
Subtotals (%)	**7 (12.2)**	**30 (70.2)**		**9 (15.8)**	**1 (1.8)**	

It was observed that less than 12% of LO were coded either as SD–– or SD++ that probably reflected how LO often contained at least one scientific term although not usually expressing more than five learning points within a single LO too. LO coded as SD– were in fact the most popular code for complexity, which garnered around 64–75% across the three regions regardless of curricular version. SD+ codes specifying covering three to four learning points in an LO were the next most common complexity category keeping to a tight range of about 10 to 22% in all curricula, past and present.

Because the primary science LO from Hong Kong were subsumed in the subject of General Studies, some of them were phrased more generally and thus coded as SG–– and SG–, which

Table 6 Overall profile showing the number of LO ($n = 206$) across SD and SG codes in the current curriculum from mainland China (% in brackets)

						Subtotals (%)
	0	1 (0.4)	SG- - Abstract, context independent	0	0	**1 (0.4)**
	0	0	SG-	0	0	**0**
	SD- - Less Complex	SD-		SD+	SD++ More complex	
	2 (1.0)	84 (40.8)	SG+	19 (9.2)	10 (4.9)	**115 (55.9)**
	1 (0.4)	53 (25.8)	SG++ Concrete, context dependent	26 (12.6)	10 (4.9)	**90 (43.7)**
Subtotals (%)	**3 (1.4)**	**138 (67.0)**		**45 (21.8)**	**20 (9.8)**	

Table 7 Overall profile showing the number of LO ($n = 162$) across SD and SG codes in the previous curriculum from mainland China (% in brackets)

						Subtotals (%)
	0	0	SG- - Abstract, context independent	0	0	**0**
	0	0	SG-	0	0	**0**
	SD- - Less Complex	SD-		SD+	SD++ More complex	
	12 (7.4)	74 (45.7)	SG+	11 (6.8)	3 (1.9)	**100 (61.8)**
	6 (3.7)	31 (19.1)	SG++ Concrete, context dependent	20 (12.3)	5 (3.1)	**62 (38.2)**
Subtotals (%)	**18 (11.1)**	**105 (64.8)**		**31 (19.1)**	**8 (5.0)**	

gave some assurance that the results from Hong Kong were not a defect of our coding scheme. The primary science LO from the current as well as the previous curriculum from mainland China yielded rather similar coding patterns; SD−SG+ codes predominated (41–46%) followed by SD−SG++ codes at around 19–26%. However, and like the situation in Taiwan, there seemed to be a 10% decrease in LO coded as SD−− in their current as compared to their earlier version. A wider spread of codes (albeit with low frequencies in SG−− and SG−) was maintained in Hong Kong that seemed even more well dispersed in the current version of its curriculum.

Table 8 Overall profile showing the number of LO ($n = 248$) across SD and SG codes in the current curriculum from Taiwan (% in brackets)

						Subtotals (%)
	0	0	SG- - Abstract, context independent	0	0	**0**
	0	1 (0.5)	SG-	0	0	**1 (0.5)**
	SD- - Less Complex	SD-		SD+	SD++ More complex	
	0	32 (12.9)	SG+	2 (0.8)	3 (1.2)	**37 (14.9)**
	0	153 (61.7)	SG++ Concrete, context dependent	42 (16.9)	15 (6.0)	**210 (84.6)**
Subtotals (%)	**0**	**186 (75.1)**		**44 (17.7)**	**18 (7.2)**	

Table 9 Overall profile showing the number of LO ($n = 114$) across SD and SG codes in the previous curriculum from Taiwan (% in brackets)

						Subtotals (%)
	1 (0.8)	0	SG- - Abstract, context independent	0	0	**1 (0.8)**
	0	0	SG-	0	0	**0**
	SD- - Less Complex	SD-		SD+	SD++ More complex	
	6 (5.3)	40 (35.1)	SG+	2 (1.8)	4 (3.5)	**52 (45.7)**
	5 (4.4)	33 (28.9)	SG++ Concrete, context dependent	13 (11.4)	10 (8.8)	**61 (53.5)**
Subtotals (%)	**12 (10.5)**	**73 (64.0)**		**15 (13.2)**	**14 (12.3)**	

While the previous curriculum from Hong Kong and mainland China did not differ significantly from their current versions, there were noticeable shifts in the coding profile for Taiwanese LO. In their previous curriculum, there were about equal frequencies of SG+ and SG++ codes, which then changed strongly in favour of SG++ codes in the present version. In the light of this fact, SD−SG++ codes were the most common now in Taiwan and was the highest in percentage terms (62%) for any single code across all three regions. In other words, the present reformed primary science curriculum here is considered to be extremely concrete in how LO spell out instructional goals and tasks in the noun phrase (with 1–2 learning points). This aspect likely adds greater clarity for Taiwanese teachers in knowing exactly what to teach according to LO specifications.

In a nutshell, most LO in our sample were coded into four main groupings: SD−SG+ (the most prevalent), SD−SG++, SD+SG+ and SD+SG++. This meant that these LO required students to cover between one to four learning points in an LO that were characterised by either context-dependent or context-independent verbs linked with more concrete, context-dependent nouns. These then are the overall intellectual demands of their curriculum as how we have defined it according to Semantics in this paper.

Conclusion and Discussion

In this paper, we offered a complementary way to understand the nature of intellectual demands in curricula through a new coding scheme for the levels of complexity and abstraction of LO (see Table 1). Putting this new classification to the test by coding a total of 840 (past and current) primary science LO from three East-Asian regions, the authors obtained acceptable to good kappa interrater reliabilities. It is felt that the latter added credibility to the conceptualisation of the SD/SG codes here, which was derived from Semantics that is one key aspect of Legitimation Code Theory.

Our findings showed that the overall profiles of complexity and abstraction in the LO from Hong Kong (see Tables 4 and 5) and mainland China (Tables 6 and 7) were not significantly different over time. At least in terms of complexity and abstraction, there were few discernible changes in their LO from previous and current curricula. The overwhelming majority of LO from all three regions were located at SG+ and SG++ abstraction levels while no more than 12% of LO were ever represented at the SD−− and SD++ complexity categories regardless of curriculum version. The current reformed curriculum in Taiwan (Table 8) had more SD−SG++ codes that surpassed all other codes everywhere in frequency although a third to nearly half of all LO in each past and present curricula (save one) belonged to SD−SG+ codes. It was found that the next most common category coding for complexity was SD+ that ranged from 10 to 20% in all curricula, past and present. In summary, LO (past and current) in these three East-Asia regions were expressed using more concrete, context-dependent meanings in their noun phrases (especially SG+) with mainly one to two learning points (SD−) as how we had scoped these dimensions here.

What then are the implications of these findings for science instruction in these East-Asian regions? As the intellectual demands of their curricula have been viewed through the lens of LCT and Semantics here, it gives us a handle into where and how teachers might wish to refocus their instruction in terms of the two dimensions of complexity and abstraction. Based on the semantic plane (see Fig. 1), teachers should no longer be confined to teaching using just dichotomous notions about abstract-concrete or complex-simple dimensions. We can recommend, for example, teachers attempting to imagine how teaching a science concept might change if the verbs or nouns in an LO were to switch from being concrete and context-dependent to less context-dependent or abstract, and vice versa. At present, most of the LO coded in this study were more concrete in nature and thus teachers should be mindful of the need to move from using everyday terminologies/contexts to expand the frequency of abstract concepts/meanings for a topic. Recall that the latter are what some sociologists of education deem as non-negotiable entitlements of formal education—learning the theoretical concepts and structures of a discipline (Young 2007). Such recommendations likewise apply for students who could be encouraged to offer their responses to questions that vary along the dimensions of abstraction, which in this case might be about increasing the opportunities for applying more abstract, content-independent meanings in primary science.

Knowing where and how to move across contexts in the semantic plane for teachers is critical as it enables cumulative knowledge building to occur. Learners too can build on and integrate knowledge more holistically if this is followed. In this way, epistemological access through the process of semantic waving is enhanced. Given that these are national curricula of primary science, some might argue that it might be hard to vary the semantic density of any LO as these are, after all, mandated requirements. Yet, at salient moments in the curriculum, the professional judgement of a teacher can justifiably override these apparent constraints. In reality, teachers are already adding or removing learning points in their classroom teaching to cater to their students' interests, motivation or ability to learn new or challenging concepts. Finally, now that we know the semantic profiles of these primary science curricula, we think that they can better inform science teacher training as novice teachers ponder the intellectual demands of their LO in terms of complexity and abstraction that has been reported for the first time.

We invite other researchers to refine our coding scheme; we have explained how we had to make certain assumptions as we adapted and reworked these Semantics codes specifically for LO. Thus far, we have empirically tested their utility among three East-Asian regions, but future research might involve coding LO from educational systems that have expressed their learning intentions in different ways or are guided by different educational philosophies (see Wang et al. 2019). Other important questions might include: Would greater degrees of complexity and abstraction in science curricula, for example, lead to greater achievement or perhaps turn-off students? And what are the implications with respect to appropriate teacher training in science content knowledge if there are changes in complexity and abstraction of curricula? Because the current primary science curricula from mainland China and Taiwan have explicitly highlighted Science and Technology LO (including learning progressions), further examination of their substantive learning content is needed to ascertain whether the current versions are indeed more intellectually challenging or "tougher."

We acknowledge that not being able to discern significant shifts in the Hong Kong and mainland China curriculum might be attributed to limitations of our coding scheme too; we have defined complexity as the number of learning points that might not vary too greatly among LO while abstraction in our SG codes took advantage of various context dependencies in verb-noun combinations. There are also more potential coding combinations in RBT compared to our coding scheme; 24 (i.e. 6×4) in RBT versus 16 (4×4) in what we have proposed here. While some might lament the potential loss of sensitivity, we stand by our customised definitions of SD/SG as we believe they have proven adequate to ascertain the intellectual demands of LO in a complementary way compared to popular methods like RBT or Webb's Depth of Knowledge.

It is hoped that we have introduced a relatively straightforward and objective way to understand some of the intellectual demands of science curricula. Curricula and their LO are truly important official documents that influence science instruction for so many students around the world. Knowing how complex/abstract are their LO have implications for the learning and accessing of scientific knowledge for all students. As such, we insist that knowing this information will always be a fundamental condition for better science instruction.

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