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The Intellectual Demands of the Intended Primary Science Curriculum in Korea and Singapore: An analysis based on revised Bloom's taxonomy

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The Intellectual Demands of the Intended Primary Science Curriculum in Korea and Singapore: An analysis based on revised Bloom's taxonomy

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While there has been a remarkable worldwide convergence in the emphases of primary science curricula over the last four decades, the cognitive and knowledge demands that they make on learners have not been well-researched. Without knowing what these intellectual or epistemic requirements are when learning science in school, issues concerning curricular alignment and access to abstract disciplinary knowledge are also likely to occur. To highlight the value of such forms of analyses, we examine the intended primary science curricula from Korea and Singapore using revised Bloom's taxonomy, as well as describe some of their general features for teaching. The results contribute insights into the complexities of the science curriculum among two similar yet different educational systems that have performed well in international science achievement tests at primary levels.

Keywords: *Intended curriculum; Revised Bloom's taxonomy; Primary science*

1. Introduction

Speaking with reference to primary education in the developing world, policy researchers Benavot and Kamens (1989, p. 3) once reported that 'with all the interest in providing an instructionally effective and financially efficient educational environment, it is surprising how little is said (or known) about one of the most important components of schooling in the modern world: the curriculum'. Science educators, however, have more reasons to be optimistic for despite the presence of various country-specific emphases in aims, topics, coverage, and teaching methods (Schmidt et al., 2001),

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primary science curricula have experienced a remarkable worldwide convergence over the last four decades. These commonalities have included a focus on life-relevance, enjoyment, and fun during science learning; engagement with diverse young learners; and the provision of multiple hands-on, problem-solving activities among other positive features (see Atkin & Black, 2003; Jenkins, 2003; McEneaney, 2003; Sinnema & Aitkin, 2013). While planning such accessible, coherent, and interesting curricula that nurture scientific literacy is beyond dispute (Porter, 2006), our claim in this paper is that few studies have examined arguably one of the most fundamental aspects within any curriculum—the cognitive and knowledge demands that it makes on learners.

Knowing the latter provides valuable information on what to teach (i.e. the intended curriculum) as well as predicts how teachers would teach (i.e. the enacted curriculum) and what is typically assessed (i.e. the tested curriculum) in the totality of a child's experiences in school (Anderson et al., 2001; Martone & Sireci, 2009). More so when it was reported that curriculum change in recent years has been increasingly influenced by prescriptive (inter)national standards and frameworks in science as opposed to school-based curriculum developments (Elyon, 2014; Harlen, 2014). Australia presents an exemplary case study: In 2013 the first national curriculum for various subjects was inaugurated, including science teaching from foundation years to Grade 10. Earlier stakeholder feedback had reported that the 'problem identified for primary schools was more to do with the absence of science being taught rather than with the relevance of what is being taught' (Framing Paper Consultation Report, 2009, p. 11). Using different words, many Australians were therefore adamant that the 'conceptual understanding underpinning the [science] topic needs describing'. These concerns were eventually addressed by the government through a set of achievement standards that characterized what was termed the 'quality of learning' in each grade, namely, 'the extent of knowledge, the depth of understanding and the sophistication of skills' (Overview, n.d., ¶ 2). Even among jurisdictions that loosely regulate what primary science teaching should look like in classrooms, an intent for learning is always at work with regard to the levels or quality of intellectual/epistemic work expected from learners. Because this fundamental exercise in curriculum theorizing has not often been carried out or at least not made publicly available in many educational systems, a number of issues can accrue that hinder widespread, successful instruction in the subject.

A major threat, understandably, is the increased likelihood of misalignments concerning pedagogy, subject matter, and assessment that has prompted some researchers to conclude that 'primary science education in many countries is in a parlous state' (Mulholland & Wallace, 1996 cited in Lewthwaite & Fisher, 2005). Indeed, the relatively poor performance among American students in mathematics and science has frequently been attributed to the extensive coverage of topics at the expense of deep conceptual understanding (Schmidt et al., 2001). Insofar as diversity and choice have been long-standing prerogatives when planning curricula in the USA, this situation perhaps reinforces our contention even more starkly about knowing what are the epistemic demands required of learners. Debates concerning so-called powerful knowledge for improving access to sophisticated disciplinary knowledge by all students have likewise exacerbated this urgency to scrutinize the levels or quality of intellectual work in school subjects (Young, 2007). It is a well-known fact that apart from textbooks, teachers will normatively seek guidance from the intended curriculum for the sequence, depth, coverage, and structures of knowledge for instruction. And among advocates of powerful knowledge, the curriculum is practically synonymous with school knowledge. Hence, the opportunities afforded for imparting specialized or abstract concepts (i.e. powerful knowledge)—a non-negotiable obligation of formal schooling as well as an entitlement for all students—resonate with our imperative here to understand the intellectual demands of primary science curricula. Finally, given the tight coupling between curriculum making and student achievement in almost every school subject, it is therefore obvious that 'acts of curricular intentionality are worth investigation in themselves … .goals and sequences of intended student experiences … must be investigated' (Schmidt, Raizen, Britton, Bianchi, & Wolfe, 2002, p. 180), and we might add with very good reason, the intellectual demands as well.

Recognizing the importance of investigating cognitive and knowledge demands in curricula as critical educational goals, we thus attempt to analyze and compare the intended primary science curriculum in Korea and Singapore. In both nations, primary science instruction occurs from Grades 3 to 6 and is regarded as an important school subject with mandatory hours of teaching between 1.5 and 3 hours per week. Teachers here follow a textbook-based national curriculum with a large number of content standards or learning objectives that are typically considered to be isomorphic with teaching intentions (e.g. Hogan et al., 2013; Wee, Kim, Cho, Sohn, & Oh, 2011). And because students here have performed well in international tests such as the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMMS), it was therefore felt worthwhile to examine what were the general features of their intended primary science curricula, especially the intellectual demands made on young learners. To enable us to achieve this task, we adopted a widely used instrument—revised Bloom's taxonomy (RBT) (Anderson et al., 2001).

These findings can help science educators partially account for the performance of science learners here without resorting to speculation involving non-educational reasons such as culture (see Meyer & Benavot, 2014) in both of these countries where Science, Technology, Engineering and Mathematics (STEM) education and human capital development are given high prominence. We expect to find similarities and differences between the emphases of learning objectives in their respective curricula, although what is perhaps more interesting is how both states have done well in international tests *despite* these differences. Speaking in the context of secondary school children, researchers in the past have already tried to explain the strong showing in TIMMS by Korea and Singapore that implicates the possession of a scientifically updated and rigorous science curriculum (e.g. Law, 2002; Morris & Marsh, 1992). Our study is also significant because of the introduction of topographical maps as analytic tools during curriculum research (Porter, 2006) together with the extreme paucity of research in English concerning the Korean primary science curriculum and to a lesser extent that from Singapore.

Of course, such an examination of the intended science curriculum cannot causally account for learning and achievement nor predict how science will be taught by any one teacher—the distinction between the programmatic and classroom curriculum (Doyle, 1996). (To be fair, during the iterative process of teaching where cognitive demands would just as likely surpass or fall below their stated levels in the curriculum, was a reality familiar to the authors of the revised taxonomy). Excellent teaching can moreover proceed despite uneven or patchy curricula materials, and vice versa. Neither are we fully able to adjudicate important structural variations between the two states such as the presence of exit-examinations at Grade 6 in Singapore that are absent in Korea, nor imagine if Korea could minimize its population of rural schools. We also acknowledge that the RBT represents a particular albeit well-supported version of epistemic knowledge distinct from what has been articulated in the PISA tests or in the American *Next Generation Science Standards*, for example. Nonetheless, this is likely to be the first recent analysis using a familiar instrument on the intended primary science curriculum that clearly specifies what children ought to know and do in primary science from both of these high-performing countries. Such in-depth considerations about intellectual value are surely essential when one embarks on critiquing the merits of school curricula or reform programmes, though again, researching the former is not as widespread as commonly believed. It is hoped that our research would encourage others to analyze the intellectual demands of curricula in their own jurisdictions for all the aforementioned rationales outlined earlier.

Our research questions are therefore as follows: What are the general features of the intended primary science curriculum in Korea and Singapore? What are the cognitive demands and levels of knowledge required of learners in primary science here? In what follows, we briefly review research on the cognitive demands of learning using taxonomies such as RBT before describing the methodological decisions we employed for the coding process in our research.

2. Analysis of Learning Using Taxonomies and Research Methodology

2.1. *Assessing Cognitive Demands through Taxonomies of Learning*

To achieve desired goals, outcomes, and quality of education, the curriculum is regarded as one of the most fundamental means to guide teachers' pedagogical decisions/actions. Analyzing the cognitive demands in a curriculum can therefore map out what children are expected to learn and be able to do throughout their period of formal schooling. Accordingly, there have been various attempts to analyze these demands in terms of the distribution of levels of knowledge and competencies in subject-specific domains such as Klopfer's model, Bloom's taxonomy, and the Structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs, 1995), which we now briefly describe.

Klopfer's model (1971) was designed to overcome criticisms concerning the generalized format of the original version of Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956) by developing domain-specific cognitive dimensions of science such as science inquiry and attitudes of science. However, the knowledge dimension here was too broadly categorized in a one-dimensional structure, which separated it from inquiry processes; thus, it was unable to unpack the complexity of knowledge and cognitive processes (Wee et al., 2011). Bloom's taxonomy was recently revised to overcome such limitations of one-dimensional categorizations, generalizations of cognitive dimensions, and difficulties of coding cognitive levels based on rigid hierarchical categorizations (Anderson et al., 2001; Krathwohl, 2002). The revision accordingly proposed a two-dimensional approach to map cognitive development (i.e. adding knowledge dimensions and cognitive process) and also suggested verb forms (understand, explain, infer, create, etc.) to describe the cognitive processes with greater clarity. Since then, RBT has been used internationally in mathematics and science curriculum research (e.g. Ari, 2011; Porter, 2006), although this literature has been extremely limited with regard to elementary science.

The SOLO taxonomy has been another significant tool to comprehend cognitive development among children. This model proposes several dimensions of cognition; pre-structural, uni-structural, multi-structural, relational, and extended abstract to understand the complexity and non-linearity of children's cognitive development. It is particularly useful for evaluating the growth of students' cognition in classrooms (Biggs, 1995). That is, it assesses what levels of cognition students develop over time when mastering certain concepts. For instance, teachers can evaluate whether a learner can list the stages of life cycle of a butterfly (uni-structural) before being able to explain the complexity and interrelation of life cycles and habitats (relational). Thus, this tool is more appropriate to assess the outcomes of children's cognitive development in classrooms (Brabrand & Dahl, 2009), rather than analyzing intended cognitive demands in curriculum. Two caveats, however, need to be underscored regarding all such evaluations of cognitive/knowledge demands (from learning objectives) in curricula or tests: first, they do not translate directly into theories of teaching and instead can have detrimental effects if misinterpreted (Booker, 2007; Torrance, 2007). Second, these forms of analyses are consistent with a systematic philosophy of curriculum that privileges the role of subject matter as canonical, expert knowledge to be received by a (passive) learner. Others have criticized this stance as a content-product, reified model of science education (e.g. Bencze & Alsop, 2009) that is perhaps most faithful to the Latin origins of the word curriculum (*currere*), which is to run along a track (course). Aware of the strengths and limitations of RBT (see Schneider, 2014; Tekkumru-Kisa, Stein, & Schunn, 2015), we have chosen RBT as a useful method to examine the intellectual demands of the intended primary science curriculum in Korea and Singapore.

2.2. *Inter-rater Reliabilities and Methodological Decisions for Coding*

Relevant official curriculum documents from both countries were subjected to routine documentary analysis while their explicit learning objectives were coded using RBT.

We coded each learning objective along two dimensions: four possible levels of knowledge and six possible levels of cognitive processes. Two of the researchers (second and third authors) independently coded the Korean data, and the first author and a research assistant independently coded the learning objectives from Singapore. In Singapore, affective learning outcomes were ignored; only the cognitive and experimental/practical (i.e. process skills) learning outcomes were considered. Some objectives had two command verbs (e.g. 'Identify the organs in the human digestive system [mouth, gullet, stomach, small intestine, and large intestine] and describe their functions') which we then coded based on the more demanding learning goal according to RBT. Within-country inter-rater kappa values and percentage agreements showing coding reliabilities are shown in Table 1. Kappa values were satisfactory for Korean coders, whereas these values were low for Singapore, which was mainly due to differences in classifying a number of learning objectives that focused on process skills. In either case, consensus by discussion was eventually obtained for all remaining disputed items.

Based on a random sample (10%) of the learning objectives, coders from each country then coded items from the other state to ascertain consistency in our understandings of RBT. Seventeen Korean learning objectives were translated into English and nine objectives from Singapore were analyzed directly: While Korean researchers could code learning objectives from Singapore in a very similar manner as those from the latter, the reverse was not true (see Table 2). Again, this discrepancy by the Singaporean team was largely attributed to differences in coding learning objectives that seemed to warrant procedural knowledge together with the application of cognitive skills.

Following Porter (2006), we produced topographical maps that displayed in graphical form how well cognitive/knowledge demands in a curriculum match (or do not) across given content standards. These representations have been widely used in mathematics, although thus far only in the area of high-school physics (Liu et al., 2009). They seem promising for curriculum research and will thus be introduced to readers in this journal.

Table 1. Within-country inter-rater values of kappa and percentage agreement based on learning objectives from the intended primary science curriculum from Korea (*n* = 168) and Singapore (*n* = 83)

	Within-country kappa values		Within-country percentage agreement (%)	
	Cognitive levels	Knowledge levels	Cognitive levels	Knowledge levels
Korea	0.62 (substantial agreement)	0.59 (moderate agreement)	74	82
Singapore	0.17 (slight agreement)	0.29 (fair agreement)	54	60

Table 2. Cross-national inter-rater values of kappa and percentage agreement based on random samples of seventeen and nine learning objectives from Korea and Singapore respectively

	Cross-national kappa values		Cross-national percentage agreement (%)	
	Cognitive levels	Knowledge levels	Cognitive levels	Knowledge levels
Coding of Singaporean objectives	0.67 (substantial agreement)	1.00 (perfect agreement)	78	100
Coding of Korean objectives	0.11 (slight agreement)	0.09 (slight agreement)	47	53

3. Findings

3.1. *General Features of Primary Science Curricula in Korea and Singapore*

Korea and Singapore (Organisation for Economic Co-operation and Development [OECD], 2010) share many similar visions and approaches toward science teaching and learning. Due to the limitations of natural resources, both countries have recognized the importance of scientific literacy as one of the key drivers of economic competitiveness and sustainability. Scientific and technological innovations are believed to be able to help overcome challenges (e.g. social equity and environmental problems) now and in the near future. Accordingly, there have been various attempts to reform primary science curriculum such as teaching via inquiry or the Science, Technology, Engineering, (Arts) and Mathematics [STE(A)M] approach in common with international trends (Chin & Poon, 2014, Ministry of Education, Science and Technology Korea [MEST], 2011). In recent years, interdisciplinary STEM approaches that emphasize creative problem-solving and collaborative knowledge building have also been encouraged (Ministry of Education, Science, and Technology [MEST] & Korea Foundation for the Advancement of Science and Creativity [KOFAC], 2012). Yet, this emphasis has not been officially reflected in the current Korean curriculum, although major science curriculum reforms are under way in Korea. In 2014, a curriculum vision statement of scientific literacy based on the OECD PISA was inserted into the primary science syllabus in Singapore for the first time, although this has not been operationalized directly via any learning objective (Curriculum Planning & Development Division [CPDD], 2013).

Compared to other developed countries such as the USA, Canada, or Finland (Kim, Lavonen, & Ogawa, 2009), primary science curricula in Korea and Singapore are highly centralized: There are mandatory learning outcomes, suggested pedagogies, and teaching hours (Lee, Park, Lee, & Han, 2005). Based on the national curriculum, textbooks and teacher's guidebooks have been developed and/or authorized by the government (Lim et al., 2007; Wee et al., 2011) to ensure their close alignment, a practice that has been in place for at least 20 years (Harlen, 1994). Most elementary students are thus likely to learn the same units using the same textbooks over a similar timeline. Accordingly, teachers' pedagogical decision-making and instruction are strongly influenced by what is included/prescribed in textbooks, which are tightly aligned with the curriculum and testing issues. This attention towards alignment is more distinctive in Singapore because of the Primary School Leaving Examination (PSLE), for based on the results of this Grade 6 exit examination, admission to secondary schools is determined.

Science as a distinct school subject is taught to 9–12-year-olds in elementary schools in both countries. The content and learning outcomes are clustered into two main groups: Grades 3–4 and 5–6. In Korea, content and big ideas in science are organized into two clustered dimensions: Matter and Energy and Life and Earth, which represent Chemistry/Physics and Life sciences/Earth/planetary science. In Singapore, a thematic approach has been adopted where learning objectives are organized into five integrated themes (Diversity, Interactions, Systems, Cycles, and Energy). This was thought to be able to 'communicate a more coherent and integrated understanding of science that bridged the life science-physical science divide' (Chin & Poon, 2014, p. 33). In both states, descriptions of learning objectives, skills, and attitudes are often integrated with content knowledge (Yoon, Kang, & Kim, 2011). For instance, on a topic of plant life cycles in Grades 3–4 science in Korea, one learning objective states that 'Through comparing the lifecycles of various plants, students understand plants have different patterns of lifecycles'. A science process skill (comparing) is thus integrated with a scientific concept (life cycles) in one learning objective.

3.2. *Cognitive Demands and Levels of Knowledge from the Intended Curriculum Based on RBT*

3.2.1. *Overall profile of learning objectives.* Tables 3 and 4 show the profile of the primary science intended learning objectives from both countries classified according to the two dimensions in RBT. Korean learning objectives on the cognitive dimension were skewed toward Remember and Understand (87.3%), whereas in Singapore they

Table 3. Total number of learning objectives ($n = 168$) from Korea classified according to the dimensions of knowledge and cognitive processes in RBT

	Remember	Understand	Apply	Analyze	Evaluate	Create	Number of knowledge items
Factual	22 (13.1)	4 (2.3)	0	0	0	0	26 (15.5)
Conceptual	31 (18.4)	84 (50.6)	4 (2.3)	0	0	4 (2.3)	123 (73.2)
Procedural	3 (1.8)	2 (1.1)	13 (7.7)	0	0	1 (0.4)	19 (11.3)
Metacognitive	0	0	0	0	0	0	0
Number of cognitive items	56 (33.3)	90 (54.0)	17 (10.0)	0	0	5 (2.7)	168

Percentages shown in brackets (%).

Table 4. Total number of learning objectives ($n = 83$) from Singapore classified according to the dimensions of knowledge and cognitive processes in RBT

	Remember	Understand	Apply	Analyze	Evaluate	Create	Number of knowledge items
Factual	11 (13.3)	1 (1.2)	0	0	0	0	12 (14.5)
Conceptual	0	49 (59.0)	0	0	0	0	49 (59.0)
Procedural	0	0	22 (26.5)	0	0	0	22 (26.5)
Metacognitive	0	0	0	0	0	0	0
Number of cognitive items	11 (13.3)	50 (60.2)	22 (26.5)	0	0	0	83

Percentages shown in brackets (%).

were skewed toward Understand and Apply (86.7% total). In Singapore, Conceptual and Procedural items predominated (85.5% of total), while in Korea the Conceptual category alone accounted for 73.2% of all knowledge objectives from that country.

One apparent commonality in both states was the association of most objectives with the Conceptual and Understand categories. In the earlier iteration of Understand in Bloom's taxonomy that was termed 'comprehension', this was acknowledged as 'probably the largest general class of intellectual abilities and skills emphasized in schools and colleges' (Bloom et al., 1956, p. 89). Neither country had any items in the Metacognitive domain, nor did any item require thinking beyond Apply, except five items in the category of Create in Korean science curriculum. These five items are described as follows:

- Students construct a toy utilizing the properties of magnets (Grades 3–4).
- Students look for examples of how magnets are used in their everyday lives and devise new ways of using magnets (Grades 3–4).
- Students devise ways to project sound to a further distance (Grades 3–4).
- Students devise ways to compare the relative concentrations of solutions (Grades 5–6).
- Students devise tools that include the use of lenses (Grades 5–6).

In the category of Create, learners are expected to devise novel or different ways or tools by adapting scientific knowledge, which are often challenging tasks. Thus, almost all the intended learning objectives for primary science in Korea and Singapore are tightly clustered between Remember/Factual and Apply/Procedural, which we believe is philosophically defensible for elementary science curricula.

A final pattern that emerged was the very strong correlation of objectives in Singapore along the RBT dimensions; Factual with Remember, Conceptual with Understand, and Procedural with Apply, whereas they are less correlated in the Korean curriculum. Several learning objectives in the latter show factual knowledge with Understand or conceptual knowledge with Remember.

Table 5. Number of learning objectives in the Knowledge domain from Korea and Singapore sorted according to their grade levels

	Grade	Factual	Conceptual	Procedural	Metacognitive	Total
Korea	3–4	13 (16.7)	58 (73.4)	7 (9.0)	0	78
	5–6	13 (14.4)	65 (72.2)	12 (13.3)	0	90
Singapore	3–4	8 (25.0)	16 (50.0)	8 (25.0)	0	32
	5–6	6 (11.8)	31 (60.8)	14 (27.5)	0	51

Percentages shown in brackets (%).

3.2.2. *Profile of learning objectives across lower and upper grades.*

We also compared the coding results between lower (Grades 3–4) and upper primary (Grades 5–6) levels. When we separated the learning objectives according to the two grade divisions in the curriculum in each country, we observed that students in Singapore experienced a 59% increase in the number of learning objectives from 32 to 51, while Korean students experienced a 15% increase from 78 to 90 objectives over the same period. The rate of increase in the total number of learning objectives is related to the number of science classes between Grades 3–4 and Grades 5–6. In Korea, there are three science lessons (120 minutes) per week in both lower and upper grades. In Singapore, science instruction per week increases from 90 minutes in Grades 3–4 to about 150 minutes in Grades 5–6. Thus, the increase in coverage of learning objectives seems apropos with the increases in instructional time. The distribution of knowledge levels and cognitive demands is likewise interesting because a child in Singapore would experience an 11% increase in Conceptual items and a 13% decrease in Factual learning objectives when moving to upper primary (see Table 5). There were practically no differences between the Cognitive demands between upper and lower primary learning objectives (and in Korea too) (see Table 6).

3.2.3. *Comparison of learning objectives in common subject matter groupings.*

Although both states had country-specific ways of classifying their learning objectives (i.e. topics in Korea vs themes in Singapore), we were able to identify common subject matter groupings for reorganizing similar topical objectives as shown in Tables 7–9 (areas

Table 6. Number of learning objectives in the cognitive domain from Korea and Singapore sorted according to their grade levels

	Grade	Remember	Understand	Apply	Analyze	Eval.	Create	Total
Korea	3–4	23 (29.5)	42 (53.8)	10 (12.8)	0	0	3 (3.8)	78
	5–6	33 (36.7)	48 (53.3)	7 (7.8)	0	0	2 (2.2)	90
Singapore	3–4	4 (12.5)	20 (62.5)	8 (25.0)	0	0	0	32
	5–6	6 (11.8)	31 (60.8)	14 (27.5)	0	0	0	51

Percentages shown in brackets (%).

Table 7. The reorganization of similar learning objectives from Korea and Singapore across six common subject matter groupings

Content areas	Number of learning objectives from Korea	Number of learning objectives from Singapore
Light	4 (5.6)	3 (4.0)
Heat and temperature	5 (7.0)	10 (13.3)
Magnets and electricity	8 (11.3)	10 (13.3)
Structure and function	32 (45.1)	30 (40.0)
Ecosystems and environment	12 (16.9)	8 (10.7)
States of matter/water	10 (14.1)	14 (18.7)
Total	71 (100)	75 (100)

Percentages shown in brackets (%).

of topical divergence are described in the next section). Items in these similar subject areas were thus categorized into light, heat and temperature, magnets and electricity, structure and function, ecosystems and environment, and states of matters including

Table 8. The distribution of learning objectives in the common content areas from Korea and Singapore sorted according to cognitive processes

Country	Content areas	Remember	Understand	Apply	Analyze	Eval.	Create
Korea	Light	2 (2.8)	2 (2.8)	0	0	0	0
	Heat and temperature	1 (1.4)	3 (4.2)	1 (1.4)	0	0	0
	Magnets and electricity	2 (2.8)	2 (2.8)	2 (2.8)	0	0	2 (2.8)
	Structure and function	10 (14.1)	19 (26.8)	3 (4.2)	0	0	0
	Ecosystem and environment	6 (8.5)	6 (8.5)	0	0	0	0
	States of matter/ water	2 (2.8)	7 (9.9)	1 (1.4)	0	0	0
	National total	23 (32.4)	39 (54.9)	7 (9.9)	0	0	2 (2.8)
Singapore	Light	0	2 (2.7)	1 (1.3)	0	0	0
	Heat and temperature	2 (2.7)	7 (9.3)	1 (1.3)	0	0	0
	Magnets and electricity	4 (5.4)	2 (2.7)	4 (5.4)	0	0	0
	Structure and function	1 (1.3)	20 (26.7)	9 (12.0)	0	0	0
	Ecosystem and environment	0	7 (9.3)	1 (1.3)	0	0	0
	States of matter/ water	1 (1.3)	10 (13.3)	3 (4.0)	0	0	0
	National total	8 (10.7)	48 (64.0)	19 (25.3)	0	0	0

Percentages shown in brackets (%).

Table 9. The distribution of learning objectives in the common content areas from Korea and Singapore sorted according to knowledge levels

Country	Content areas	Factual	Conceptual	Procedural	Metacognitive
Korea	Light	1 (1.4)	3 (4.2)	0	0
	Heat and temperature	1 (1.4)	3 (4.2)	1 (1.4)	0
	Magnets and electricity	2 (2.8)	4 (5.6)	2 (2.8)	0
	Structure and function	4 (5.7)	26 (36.6)	2 (2.8)	0
	Ecosystem and environment	2 (2.8)	10 (14.1)	0	0
	States of matter/water	2 (2.8)	7 (9.9)	1 (1.5)	0
	National total	12 (16.9)	53 (74.6)	6 (8.5)	0
Singapore	Light	2 (2.6)	0	1 (1.3)	0
	Heat and temperature	4 (5.4)	5 (6.7)	1 (1.3)	0
	Magnets and electricity	4 (5.4)	2 (2.7)	4 (5.4)	0
	Structure and function	1 (1.3)	20 (26.6)	9 (12.0)	0
	Ecosystem and environment	0	8 (10.7)	0	0
	States of matter/water	1 (1.3)	10 (13.3)	3 (4.0)	0
	National total	12 (16.0)	45 (60.0)	18 (24.0)	0

Percentages shown in brackets (%).

water. According to this scheme, it meant that 42.2% of Korean and 90.4% of Singaporean learning objectives found commonalities with those in the other country. The category ‘structure and function’ garnered the highest number of common learning objectives because there are many similarities in the biological sciences in both curricula, whereas there are greater dissimilarities in the areas of physics, chemistry, and earth/planetary sciences. We initially attempted to divide ‘structure and function’ into subsections such as animals/plants or functions/structures; however, the two curriculum had different approaches toward the study of living beings and we abandoned this idea.

The profile of knowledge and cognitive processes in these similar topical areas are shown in Tables 8 and 9 and in topographs (Figures 1 and 2). When Tables 8 and 9 are represented by topographs as in Figures 1 and 2, respectively, it allows a clearer visualization of their similarities in the six common subject matter groupings (Porter, 2006).

As seen in Figure 1, the absolute differences between the distribution of learning objectives (cognitive processes) were greatest in the content area of structure and function. Specifically, Korean learning objectives in the Remember category were in the calculated alignment ratio between 0.10 and 0.15 (the green region); that is, they were 10%–15% more frequent than those in Singapore (Table 8 shows that it is 12.8%). The other five common subject areas generally experienced minimal divergences of 0.00–0.05 (i.e. 0%–5% in the blue regions) (see Liu et al., 2009 for details on these calculations). The Porter Alingment Index was calculated to be 0.71, which means that the degree of alignment for both countries in these six groupings along their cognitive dimensions was high (Porter, 2006).

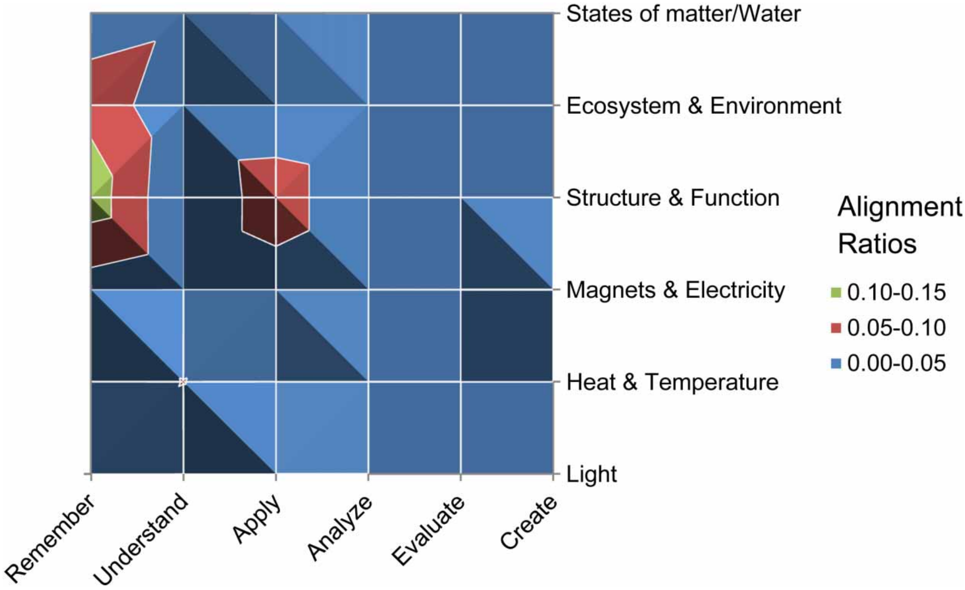

Figure 1. Topograph showing the distribution of learning objectives from Korea and Singapore in the six common subject matter groupings along their cognitive processes

In Figure 2 and Table 9, it can be observed that with respect to the content area of structure and function, there were 0.08–0.10 (i.e. 8%–10%) (light blue region) more learning objectives in the Conceptual domain in Korea, whereas the Singapore curriculum had greater representation by the same amount in the Procedural domain. As with the previous topograph, other content areas in the Knowledge dimension did not experience much divergence between the two countries. The Porter Alingment Index was 0.69 for the knowledge dimension. In conclusion, it is interesting that when we reorganized common topical learning objectives into six common subject matter groupings, the learning objectives from Korea (42.2% of total national objectives) and Singapore (90.4% of total national objectives) were extremely close in terms of their knowledge and cognitive demands that were visually confirmed by the topographs. Indeed, nine-tenths of the content areas from Singapore could be located within the Korean curriculum, though the reverse did not apply.

3.2.4. *Comparison of dissimilar content areas from Korea and Singapore.* We examined those remaining learning objectives that seemed unique to each country; Tables 10 and 11 show that Korea had 97 learning objectives (57.7% of total learning objectives) that are country specific, whereas Singapore had 8 (9.6%) that found no counterparts in Korea. Many of these Korean objectives belonged to the earth/planetary sciences category as well as certain chemistry and physics topics that are only taught in lower secondary grades (Grade 7–8) in Singapore. These topics in physics in the Korean curriculum are in the areas of speed, characteristics of sound, and usage of lenses.

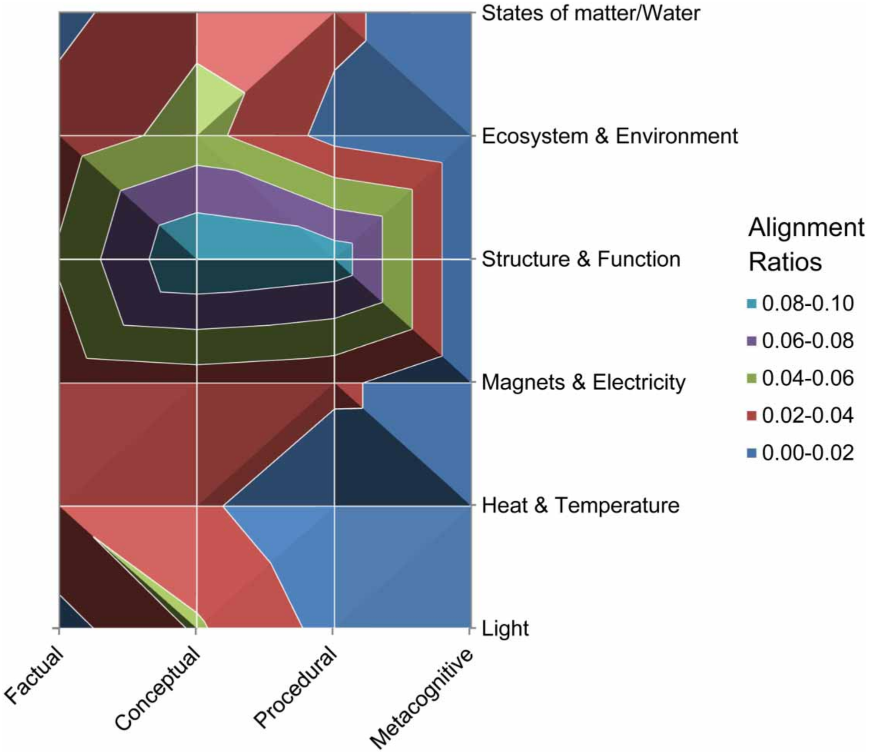

Figure 2. Topograph showing the distribution of learning objectives from Korea and Singapore in common subject matter groupings along their knowledge levels

Chemistry topics included gases and liquids, separation of mixtures, solution and dissolution, acids and bases, various gases (e.g. oxygen and carbon dioxide), and combustion and extinguishment. Earth/planetary science topics included the earth and moon, changes in the earth's surface, volcanoes and earthquakes, geological strata and fossils, weather and our lives, the solar system and stars, movement of the earth

Table 10. The distribution of learning objectives in the dissimilar content areas from Korea sorted according to cognitive processes

Country-specific topics	Remember	Understand	Apply	Analyze	Eval.	Create	Totals (%)
Physics	5	8	1	0	0	2	16 (16.5)
Chemistry	6	15	8	0	0	1	30 (30.9)
Earth/planetary sciences	22	28	1	0	0	0	51 (52.6)
Totals	33 (34.0)	51 (52.6)	10 (10.3)	0	0	3 (3.1)	97

Percentages shown in brackets (%).

Table 11. The distribution of learning objectives in the dissimilar content areas from Korea sorted according to knowledge levels

Country-specific topics	Factual	Conceptual	Procedural	Metacognitive	Totals (%)
Physics	2	11	3	0	16 (16.5)
Chemistry	3	19	8	0	30 (30.9)
Earth/planetary sciences	10	39	2	0	51 (52.6)
Totals	15 (15.5)	69 (71.1)	13 (13.4)	0	97

Percentages shown in brackets (%).

and the moon, and seasonal changes. In Singapore, learning objectives regarding energy (kinetic energy, potential energy, interconversion of energy, etc.) and forces (effects of forces, different kinds of forces, etc.) were absent in the Korean curriculum. While it is difficult to come to firm conclusions with respect to Singapore, it is fair to claim that similar to the learning objectives in the shared common content areas, most Korean learning objectives fell into the Conceptual and Understand categories. These country-specific Korean learning objectives were also nearly divided equally among lower (*n* = *48*) and upper primary (*n* = *49*) levels.

4. Conclusion and Discussion

4.1. *Summary of Findings*

In our analysis of the national primary science curricula from Korea and Singapore, we found that both states had placed strong emphases on learning science via inquiry beginning from Grade 3. Complementary resources for teaching are abundant and are used widely to teach content, process skills, as well as values and attitudes in science. Such efforts could be more earnest in Singapore because of the major exit exams at the end of Grade 6. Although there are twice as many learning objectives in Korea (*n* = 168) as compared to that in Singapore (*n* = 83), Tables 3 and 4 show that the categories of Understand and Conceptual in RBT hosted the largest number of items in both states. In addition, there was a wider spread of objectives in Korea across the taxonomy, although there were hardly any beyond Apply and neither country had any item requiring Metacognitive knowledge. Students in Singapore experience a 59% increase in learning objectives as they move from the lower to upper primary, whereas their Korean counterparts experience a 15% increase (Tables 5 and 6). This situation seems commensurate with the increase in science instructional time (90 minutes to about 150 minutes) in Singapore, but without any increase in time (120 minutes in all grades) in Korea. It is also interesting to note that learners in Singapore experienced 11% more Conceptual items when they moved to upper primary, while Korean learners experienced 7% more Remember objectives over the same time period. When the learning objectives in both countries were reorganized into six common subject matter groupings, there were a large number of similarities in terms of the profile of cognitive processes and knowledge demands (Tables 7–9) that we represented visually using topographs in Figures 1 and 2. According to this scheme, it meant that 42.2% of Korean and 90.4% of Singaporean learning objectives found commonalities with those in the other country; content from Singapore could largely be subsumed into the Korean curriculum. But Korea had 97 additional learning objectives (57.7% of total learning objectives) that found no counterparts in Singapore, which belonged to the earth/planetary sciences as well as to chemistry and physics topics (Tables 10 and 11). Similar to the learning objectives in the shared common content areas, most of these dissimilar Korean objectives fell into the Conceptual and Understand categories.

With respect to the cognitive demands in the learning objectives, there are fewer items classified under Procedural and Apply in the Korean curriculum compared to that in Singapore (Tables 3 and 4). One likely reason is that within each unit in the Korean curriculum, there are usually three to four inquiry activities introduced separately from the intended learning objectives. The former recommend activities and instructional inputs for classroom implementation that are typically associated with procedural knowledge and application of skills. This unique feature in Korea might have accounted for this difference; these activities were separate from the learning objectives and thus excluded from coding in our study. On the other hand, learning objectives in Singapore that are grouped under 'skills and processes' in the curriculum are routinely expected to be taught and tested.

In Korea, there was an increase in lower cognitive processes (e.g. Remember) in upper grades; that is, Remember increased from 30% to 37% (Table 5). The second and third authors suggest that this could have been due to the emphasis on content knowledge in upper grades, which require the recall of specific scientific information. Here, there are many science topics with heavy/complex content such as lenses, various gases, and solutions requiring greater attention to the acquisition of facts. For instance, one objective in *Various Gases* (Grades 5–6) stated that students will be able to *know* the characteristics of carbon dioxide and oxygen. Accordingly, students are expected to remember the properties of carbon dioxide (e.g. heavier than air) and oxygen (e.g. essential for combustion) as essential facts. In this learning objective, the verb 'know' in Korean was coded as Remember because students will need to recall or remember the characteristics of different gases. There are several other learning objectives that include the verb 'know' in the Korean curriculum to describe/emphasize science concepts, definitions, and terms, which we also coded as Remember. Again, this deliberate choice in our coding could have potentially resulted in more instances of Remember.

Nonetheless, it is noted that the levels of knowledge and cognitive process skills in both curricula are focused on the lower levels of knowledge and skills in both curricula. Most of the learning objectives are clustered in the dimensions of Conceptual and Understand or below those levels. On the other hand, there were no learning objectives in the dimension of Metacognitive knowledge, Analyze, and Evaluate and we observed only five items in the Create dimension in the Korean curriculum. Despite Bloom's earlier comments on 'understand/conceptual' as the most prevalent grouping to be found within school contexts, the paucity of items testing higher order thinking/

knowledge raises some concerns about developing scientific literacy in Korea and Singapore as we explain next.

4.2. *Implications for Alignment, Knowing Abstract Knowledge and Scientific Literacy*

Performing such analyses of the cognitive processes and knowledge demands of the intended curriculum is necessary to ensure the alignment of teaching and testing. Although Korea does not require an exit exam at the end of primary schooling, the exit examinations in Singapore are confidential in nature and thus not open to curriculum alignment testing (e.g. through topographs). It is hoped to be able to conduct this important procedure once confidentiality constraints are removed in the next few years.

More significantly, our analyses using RBT has a number of important implications for learning abstract disciplinary knowledge and scientific literacy in general. The final goals of science education often focus on educating students to become scientifically literate citizens who can make critical decisions and contribute toward solving complex problems in the future. While having scientific conceptual knowledge is fundamental to the former, this does not solely depend on 'knowing' or 'understanding' conceptual knowledge as we have shown to be the predominant emphases in the intended curriculum in both states. As such, the goals of quality science education as espoused in the respective curricula and their intended learning objectives might show some degree of contradiction.

Some educators might argue that the current study has only analyzed the elementary science curriculum; thus, these lower intellectual demands are age-appropriate or expected. Moreover, we did not analyze how learning objectives are further developed throughout middle and high schools as part of the spiral curriculum, which we accept as a limitation. However, international research on students' reasoning and argumentation has underscored the importance of evaluating evidence and making conclusions in problem-solving contexts and also students' learning abilities and readiness to develop higher cognitive levels such as analyze, evaluate, and create at elementary levels (Duschl, Schweingruber, & Shouse, 2007). This critical aspect of learning might be ignored when conceptual knowledge and understanding skills are over-prioritized in school science. In this sense, the degree to which children learn abstract disciplinary knowledge, at least in these two countries that we have surveyed here, might therefore not satisfy those who insist upon such forms of important knowledge/reasoning to be taught widely in schools.

Even though there are more learning objectives in Korea compared to that in Singapore, we do not imply that students in Korea learn more content than Singaporean students. More than a third of the learning objectives in Singapore appear 'nested' with three or more sub-concepts or cases to be learnt. For instance, under the learning objective of 'investigate the factors which affect the rate of evaporation and communicate findings: wind, temperature, exposed surface area', we have three conditions related to learning about the rate of evaporation. Similarly, when pupils are asked to 'differentiate among the terms organism, population and community', there are three definitions regarding understanding the basic units of ecological analyses: 'a) An organism is a living thing, b) a population is defined as a group of plants and animals of the same kind, living and reproducing at a given place and time', and 'c) a community consists of many populations living together in a particular place'. While all these kinds of 'nested' or linked learning objectives in Singapore were counted as one in this study and are regarded as such by local teachers, their equivalents are normally stated as separate learning outcomes in Korea. Hence, the differences in total numbers of learning objectives in these two countries seemed to result mainly from such structural considerations, not so much from the actual quantity of knowledge or cognitive process that students have to master.

The dissimilar topics in the two curricula are also worth noting. It was reported that there are more topics taught in Korea compared to Singapore; especially, earth/planetary science components are absent in Singapore although they occupy about 30% of the Korean curriculum. Decisions to include topics depend heavily on the particular contexts in each nation. For example, there is not much demand for knowledge about earth/planetary science in Singapore due to the relatively stable geological/climatic conditions and flat landscape there. In Korea, however, 70% of the land is covered with mountains with fossil-bearing strata, hence demanding general knowledge about the former. This contextualization or enculturation of the curriculum thus brings forth a country-specific form of scientific literacy. In Korea, the science curriculum has been divided and taught in four dimensions (physics, chemistry, biology, and earth science) for decades and the proportion of each science in the curriculum is equally divided, which is not mirrored in Singapore which lacks this historical legacy.

Finally, it is interesting to realize that testing in TIMMS includes topics in the earth/planetary sciences, human health, rusting, mixtures, dissolving substances, and rainbows, among others, topics that are not directly reflected in the Singapore primary curriculum (see TIMMS, 2013). Despite this lack of official coverage in schools, students in Singapore have consistently performed well in TIMMS. We wonder if the primary science curriculum here had allowed more time for the development of reasoning skills (Davie, 2012) or if it instead permitted the consolidation of taught content knowledge in science. Thus, we believe that it is vital to investigate the dynamic interplay of content matter and intellectual demands made on students during teaching. Future research might also examine how intended primary science curricula are enacted in classrooms and how sociocultural aspects of educational practice (students' work habits, after-school activities, etc.) complexly mediate the development of scientific literacy.

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