Title	The intellectual demands and coherency of topics of reformed primary science curricula from three East-Asian regions
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Abstract: The intended curriculum is arguably one of the most important components within any national educational system although those in primary science have not been subject to extensive research scrutiny. Based on reformed primary science curricula from Hong Kong, mainland China, and Taiwan, we compared them on two key features: (1) levels of knowledge and cognitive processes from their learning outcomes, and (2) coherency of topics that influence the ease, meaningfulness and quality of learning in the subject. In the former, we coded their intellectual demands (i.e. what learners must know & do) using revised Bloom' Taxonomy while for the latter we investigated the coverage, focus, sequence, and emphasis of topics across grades. We found that curricula from Hong Kong and mainland China generally focused on the first two levels of knowledge domains and cognitive processes while Taiwanese learning outcomes were predominantly coded as Apply. Different aspects of coherency in the intended curriculum revealed which topics were covered, their focus and sequencing across grade divisions as well as their emphasis of topics. Our empirical research therefore adds to the small number of comparative studies in primary science curricula. It can also practically assist policy- and curriculum-making in these regions as they seek to understand and develop quality curricula in primary science.

Keywords: intellectual demands, coherency, primary science, revised Bloom's Taxonomy, intended curriculum

Introduction

The intended curriculum is arguably one of the most important components within any national educational system. It offers planned opportunities for learning abstract disciplinary knowledge in various subjects like science even if these goals might not be concretely realised after every lesson (DeBoer, 2011). It is, however, surprising that intended primary science curricula have not been subject to as extensive comparative scrutiny as one might expect (Lloyd, Cai, & Tarr., 2017; Stacey et al., 2018). Research here has been limited in number as well as in scope; for example, comparing the UK curriculum with high-performing states (e.g., DoE, 2011; Ruddock & Sainsbury, 2008) or Taiwan with other regions (Lu & Lien, 2016).

In recent years, there have been renewed attention in analyzing primary science curricula within East-Asia (e.g., Authors1&3). This interest by science educators is not misplaced given the strong performance by a number of East-Asian states in international achievement tests in science and mathematics. Finding the reasons for these successes is both complex and elusive (Lau & Lam, 2017), but it is not unreasonable to think that factors related to having a centralised or well-planned curriculum might play an important role (see Kim, 2019).

Most curricula can be organized either by a top-down approach that is aligned with the structures of learning within a discipline (e.g., in *Biological Sciences Curriculum Study*) or a bottom-up one that is designed with a learner's logical development of learning in mind (e.g., in *Science: A Process Approach*) (Posner, 2004). In whichever approach, we concur with Wang and McDougall (2019) that different curriculum designs may affect the progression or learning of knowledge by students, and ultimately their achievement in a school subject. Building on their empirical research on the organization of intended mathematics curricula, this study compares the learning outcomes (LO) and topics in reformed primary science curricula from three East-Asian regions—Hong Kong, mainland China, and Taiwan. We thus want to understand two important features of their intended curriculum: First, their intellectual demands, that is, what learners must know and do (c.f. Authors1). Rigor in the curriculum is not a trivial matter; the apparent lack of cognitively rich and challenging subject matter prompted a former government advisor to question if the Australian curriculum would “up the intellectual ante in primary classrooms” (Luke, 2010, p. 59).

Second, we want to examine their coherency that has been described as the “sensible connection and co-ordination between topics that students study in each subject within a grade as they advance through the grades” (Newmann, Smith, Allensworth, & Bryk, 2001, p. 298). There are multiple aspects and definitions of coherency in the literature, but coherency is widely regarded as a precursor of ease, meaningfulness, and quality of learning in school subjects (Fortus & Krajcik, 2012). In this research, we specifically examine four aspects of coherency in the intended curriculum: coverage, focus, sequencing, and emphasis of primary science topics.

Determining both the intellectual demands and coherency provide insights into the opportunities to learn vital concepts in these reformed curricula—they indicate excellence in an intended curriculum. As Schmidt, Wang, and McKnight (2005, p. 527) put it, what is at stake is “not merely whether there are content standards, but the quality of those standards.” The findings here allow for a better understanding of what passes for primary science education in these regions and have longer-term implications for the development of scientific literacy here. Our research questions are thus: (1) What are the levels of knowledge and cognitive processes (i.e. the intellectual demands) from their LO?, and (2) How coherent are the topics in terms of their coverage, focus, sequencing, and emphasis from these reformed primary science curricula in Hong Kong, mainland China, and Taiwan?

Rationales of Study

We now briefly describe three interrelated rationales for comparing the intended curriculum and some background to the regional primary science reforms before we embark on specific details of our theory and research methods. Our first justification is that the intended curriculum influences in a very significant way how teaching and learning is conducted in every classroom (Kim, 2019). For example, shallowness as well as extensive coverage of mathematics and science topics in the American curriculum were reported as major factors in the relatively poor performance of students there (Schmidt et al., 2001). Canadian students, on the other hand, were reportedly exposed to lower than expected intellectual demands in their science curriculum that stunted their development of scientific literacy (Fitzpatrick & Schulz, 2015). It is interesting though not unexpected to note that in East-Asian states such as

Singapore, the intended primary science curriculum is largely similar to the taught as well as tested curriculum because of high-stakes examinations there (Hogan et al., 2013).

The second rationale is that major educational reforms in East-Asia have occurred and that it is imperative to know their affordances for scientific achievement and literacy from these curricula. We are not implying that one region is better than another, but instead insist that knowing this information (i.e. their rigor & coherency) enables researchers to understand their *own* regions more clearly. Wei and Ou (2019) who employed a similar methodology found that junior-high science curricula from these same East-Asian regions that share a Confucian cultural heritage were remarkably alike in focusing on lower-level cognitive and knowledge demands, which we are eager to verify if this is also true. Moreover, no research has compared aspects of coherency in science curricula from East Asia as far as we know. Third, our study concerns primary science education, which is the foundation for learning science in schools and for many in the Global South likely to be the only formal period of encountering this subject. Our study thus attempts to mitigate this lack of research into science curricula during this important phase of education.

Backgrounds to Recent Primary Science Curriculum Reforms

Hong Kong. In the 1980s, the primary science curriculum in Hong Kong replaced Nature Study and Rural Study that then became an integrated curriculum (incorporating health & social studies) known as General Studies in 1994. A decade later, the goal of science education was crystallised to develop scientific literacy through acquiring scientific knowledge and understanding, process skills, values and attitudes for the development of the whole person (CDC, 2002). The new 2017 reforms still required students to study science from Grade 1, but extended that by the learning of STEM topics and taking an integrative/applied approach towards knowledge and skills (CDC, 2017). Like other regions, science education here has now emphasised scientific literacy and interdisciplinary learning (So, Wan, & Chen, 2018). Schools have been advised to devote 12-15% of curriculum time to General Studies. Hong Kong had a colonial legacy and its educational policy is still influenced by the UK although it is also trying to establish its own curricular systems (Wei & Ou, 2019).

Mainland China. The *Outline of Curriculum Reform of Basic Education* in 2001 proposed a series of measures to revise K-12 education such as compulsory learning of science from Grades 3-6. As the focus shifted from nature studies to science education, its goals too changed from "scientific knowledge" to "scientific literacy" objectives (Wei & Thomas, 2005). The current revisions in 2017 thus emphasised learning core competencies of the 21st century that for science included: scientific concepts and applications, scientific thinking and innovation, scientific inquiry and communication, and scientific attitudes and responsibilities (MOE China, 2017). The 2017 curriculum also proposed learning science beginning from Grade 1 because "science is now regarded as a fundamental school subject" (MOE China, 2017, p.1, our translation) sharing equal status with Chinese language and mathematics at the national policy level. It is noteworthy that science, technology and engineering (STE) have been added as new topics. Due to social and political changes in the last hundred years, mainland China has placed emphasis on economic and global competitiveness in line with the pragmatic tradition of traditional culture such as emphasizing application or usefulness of science. This is reflected in the science curriculum with statements such as "for citizens to improve their quality of life and enhance their ability to participate in social and economic development" (p. 1), and "science and technology promote the development of productivity and the prosperity of economy" (MOE China, 2017, p. 1, our translation) in its curriculum.

Taiwan. The *General Curriculum Guidelines for the Twelve-year Basic Education* policy was issued in 2014 for implementation by 2019 in Taiwan. It focused on the student as a lifelong learner who developed "core competencies" in three categories: spontaneity, communicative interaction, and social participation (MOE Taiwan, 2014). "Core Competency" underscores how learning should not be limited to subject knowledge and skills, but should focus on the combination of learning and life with promoting whole person development of learners through practice. They serve as the main thrusts to guide the development of the science curriculum. The Ministry in 2018 released the *National Basic Education Curriculum for 12 Years: National Primary and Secondary Schools and Ordinary Senior Secondary Schools (Area of natural sciences)* that specified that science would be taught from Grade 3. In addition, the goals of science curriculum were to: Inspire enthusiasm and potential of scientific inquiry; construct scientific literacy; learn science and the applications of technology as lifelong practices; foster the values of caring for society and environmental protection; and the ability to take action, and prepare for career development (see MOE Taiwan, 2018).

Theoretical Frameworks for Analysis

i. Revised Bloom's Taxonomy (RBT). RBT can assess two components of the rigor or intellectual demands of LO, which are six levels of cognitive processes (Remember, Understand, Apply, Analyze, Evaluate, & Create) and four knowledge levels (Factual, Conceptual, Procedural, & Meta-cognitive) (Anderson, et al., 2001). As LO are typically written with a verb and noun phrase (e.g., "Draw the forces acting on a falling object"), the command verbs are coded according to the cognitive processes while the noun phrase can fall into one of four knowledge levels. This widely-used classification in curriculum research has been helpful to distinguish between low and high levels of cognitive processes and knowledge, and their relationships with student learning in science (e.g., Fitzpatrick & Schulz, 2015). Using RBT to investigate rigor is not without criticism; for example Tekkumru-Kisa, Stein, and Schunn (2015) argue that how an LO is implemented in a science classroom might not reflect its actual cognitive demand as it depends on past learning experiences of the learner. Greater prior knowledge or giving scripted tasks for students can potentially push down the intellectual demands of an LO, which was a shortcoming known to its developers (Anderson, et al., 2001). However, this particular criticism does not apply to this study as we confine ourselves to code LO from the intended curriculum.

ii. Coherency of topics. Coherence has historically been regarded as a fundamental and necessary property of a curriculum even though Sikorski and Hammer (2017) insist that a curriculum is by itself unable to make meaningful connections for students, who are the true clients of a curriculum. Most people agree that coherence implies both a vertical and horizontal organization; the former describes the sequencing of content across time whereas the latter is concerned with making links or integrating content that is taught simultaneously (Posner, 2004). Sometimes, there are variations in conceptualizing coherence as it can be customized for different research purposes. For example, Shin, Choi, Stevens, and Krajcik (2019) separated coherence into three components: the first concerned establishing suitable learning goals; the second was about coordinating intra-unit coherence between goals, instruction, and assessment, and finally inter-unit coherence was for building more complex scientific ideas over time.

Schmidt et al. (2005, p. 528) regarded content as coherent if "they are articulated over time as a sequence of topics and performances consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content from which the subject-matter derives." These highly influential researchers explained how a coherent curriculum that facilitates access to understanding by learners must be mindful of its (1) focus (i.e. coverage, sequencing of topics, sufficient time for instruction etc.) and (2) rigor that is "how deeply into the structure of the discipline one moves and by what grade level one moves to that depth" (p. 529). But unlike Schmidt et al. (2005), we determined rigor by grade levels/divisions and in the overall curriculum by using RBT instead of considering rigor as the deepening of knowledge within a certain topic. This is because primary science comprises of four different sub-disciplines (Physics, Chemistry, Earth Science, Biology) with very different topics whereas the disciplinary structures are much more unified or linear in the case of mathematics. Thus, data about the intellectual demands (i.e. rigor) we report here come from making sense of the LO profiles from RBT and not in terms of tracking the depth of knowledge in topic sequences across grade levels (c.f. Wang & McDougall, 2019).

In this study, we define coherence in terms of four aspects: coverage, focus, sequencing, and emphasis. Similar to Wang and McDougall (2019), we regard coverage as the selection and number of specific primary science topics intended to be taught in a curriculum. Focus is likewise defined as the number of topics covered within a grade or grade division; larger numbers of topics indicate low focus, and vice versa. For sequencing of topics, we want to determine when topics appear and stop (i.e. duration or span across grade levels that overlaps with ideas about coverage) and whether more LO appear in upper or lower grade divisions in a topic.

For emphasis, there are two aspects in this study: First, we determine the relative emphasis of a topic within a region—more LO in a topic means that there is greater emphasis. Second, we check for similar topics across the three regions to find overall patterns that could promote the learning of content knowledge. According to Schmidt et al. (2005), more soundly-planned ("spiral") curricula where students progress from learning simpler before more challenging topics are to be found among regions that scored well in TIMSS. One characteristic of a quality intended curriculum with hierarchical progression (i.e. learning more/harder concepts in upper grades) is when a "upper triangular" appearance (◥) of coverage (implying emphasis) can be spotted. This means that some "buttress topics" will persist across grades where teaching deepens the concepts (the horizontal side of the triangle) whereas more difficult topics are both fewer and appear only in later grades (the vertical side).

Methods

i. Data Sources. The primary science LO (only cognitive domain) for this study were obtained from the official reformed curriculum documents; we found 53 LO from Hong King, 206 from mainland China, and 248 from Taiwan. The details of these reformed science curriculum documents are listed in Table 1.

Table 1. The sources of LO from reformed curriculum documents in primary science from the three East-Asian regions.

Title	Data	Region	Year of release
Science Education: Key Learning Area Curriculum Guide (Primary 1 – Secondary 6)	LO in the cognitive domain from Key Stage1 - 2 (Primary 1-3, 4–6)	Hong Kong	2017
Full-time Compulsory Primary Science Curriculum Standards	LO in the cognitive domain from the content standards	Mainland China	2017
National Basic Education Curriculum for 12 Years: National Primary and Secondary Schools and Ordinary Senior Secondary Schools (Area of natural sciences)	Description of learning content (LO) in Appendix IV: Stage of National Primary Education	Taiwan	2018

ii. Coding and interrater reliability for RBT. Due to space constraints, readers are advised to consult our previous work (Authors1) and others (Wei & Ou, 2019; Wei, 2019) for details of the coding procedures of LO with RBT. We translated all the LO from mainland China and Taiwan into English to code in a common language as the LO from Hong Kong were already in English. Any LO that had two or more command verbs were coded for the most demanding learning goal, which similarly applied to coding the noun phrase(s) in an LO. The interrater reliability from Cohen's kappa and percentage agreements were obtained from both researchers as coders. Kappa for knowledge levels (from 0.23 to 0.40) and cognitive processes (from 0.46 to 0.49) ranged from weak to moderate. All disagreements in the coding by the two researchers were then resolved to achieve final consensus.

iii. Allocating LO into topics for coherency. Each LO from the three regions were allocated to a topic from a list of 40 typical primary science topics from Schmidt et al. (2005, p. 545) because coherency is determined at the level of topics, not LO. Analysis of topics within and between regions was thus based on this "standard" list of topics (see Table 5 later). We added a new topic of STE (Science, Technology & Engineering) to capture LO that spoke about these issues; they were not tied to any specific disciplines, but were related to understanding technology and tools, designing/modifying experiments, use of proper representations, appreciating the enterprise, exploration or history of science and so forth. During our allocation, 11 LO from mainland China belonged equally well to two topics, which amounted to a 14% (11/77 total #topics in China) inflation in the number of topics in our data had we strictly confined one LO to one topic. Likewise Taiwan had six dual-topic LO causing a 9.5% inflation (6/63 total #topics in Taiwan) while Hong Kong had a single LO behaving in this manner. While this might have compromised the final outcomes in some way, we believe that force-fitting (or removing) about 9-14% of these dual-topic LO was an even more undesirable option.

iv. Finding coverage, focus, sequencing, and emphasis of topics. For coverage, we counted the topics in each region that corresponded to the list of common primary science topics from Schmidt et al. (2005). Next, how many topics were covered within a grade division defined how high or low was its focus. For sequencing, we checked topics for their duration or span across one, two or three grade divisions depending on the region. Any developing trends/patterns by the number of LO appearing in each topic across all grade divisions was determined by a notation: 0 = "0" (no LO in this topic at all grades); F – "Flat" (similar number of LO in this topic appearing across grades), R – "Rise" (rise in LO numbers about this topic), D – "Drop" (drop in LO numbers in this topic across grades), and H – "Hill" (peculiar only to mainland China as it had 3 levels; the highest number of LO in this topic located in middle grades).

To find the emphasis, the total number of LO within a region was first divided to obtain three number ranges: L-"Low" (lowest third), M-"Medium"(middle), and H-"High"(highest third). In mainland China, for example, the topic with the highest number of LO had 35 LO and the lowest had none. Thus, we considered a topic here with Low emphasis as those having between 0-11 LO (the first one third of 35), Medium with 12-23 LO, and High with 24-35 LO to give an indication of their relative emphasis. Finally, as a collective indicator of emphasis across *all three* intended curricula, we compared which science topics were covered by them to observe whether we could find any desirable "upper triangular" structure or buttress topics.

Findings

A) Overall profiles of cognitive processes and knowledge levels from RBT in the reformed curricula.

Table 2 shows the overall RBT profile of the reformed primary science curricula from all three regions bearing in mind that LO from Hong Kong are considerably fewer in number compared to the other two regions. Only LO from Hong Kong and mainland China contained LO in all six cognitive processes and in both regions Remember was the largest category there. However, Taiwan had the largest proportion of LO in any cognitive category in Apply (78.2%) while mainland China had the least in this category compared with the other two regions. While the first two categories typically occupy the largest two groupings in the Cognitive dimension, this was only true of mainland China and Hong Kong. Understand is usually the predominant category in schools and colleges (Bloom et al., 1956), but this was not true in the overall profile in these three regions. With regard to the expected Cognitive:Knowledge pairings (e.g., Remember:Factual, Understand:Conceptual, Apply:Procedural), only the LO from mainland China and to a lesser extent Hong Kong seemed to follow this pattern. Among Taiwanese LO, 44% were phrased such that the goal of learning was conceptual knowledge even though the command verb was categorized as Apply (e.g., "Through inquiry activities, understand the principles of insulation and heat dissipation that are found in everyday life", "Use various phenomena or examples to understand how seawater flow can affect weather changes"). Thus, these kinds of LO deviated from the typical Apply:Procedural pairings according to Anderson et al. (2001). Few LO appeared beyond Apply in all three regions in these reformed curricula just as most of the Knowledge dimensions were located in Conceptual that is not unexpected for school curricula worldwide.

Table 2. Overall profile of all the reformed primary science LO coded using revised Bloom's Taxonomy across the three regions. (% of the LO are in brackets)

	Knowledge	**Cognitive**						
		Remember	Understand	Apply	Analyze	Evaluate	Create	Number of Knowledge LO
Hong Kong (n=53)	Factual	6(11.3%)	1 (1.9%)	0	0	0	0	7(13.2%)
	Conceptual	11(20.8%)	10(18.9%)	4(7.5%)	1(1.9%)	0	1(1.9%)	27(50.9%)
	Procedural	3(5.7%)	0	12(22.6%)	0	0	3(5.7%)	18(34.0%)
	Metacognitive	0	0	0	0	1(1.9%)	0	1(1.9%)
	Number of Cognitive LO	20(37.7%)	11(20.8%)	16(30.2%)	1(1.9%)	1(1.9%)	4(7.5%)	53
Mainland China (n=206)	Factual	68 (33.0%)	5(2.4%)	2(1.0%)	0	0	0	75 (36.4%)
	Conceptual	16(7.8%)	67(32.5%)	11(5.3%)	2(1.0%)	2(1.0%)	1(0.5%)	99(48.1%)
	Procedural	5(2.4%)	3(1.5%)	15(7.3%)	0	1(0.5%)	6(2.9%)	30(14.6%)
	Metacognitive	0	0	0	0	2 (1.0%)	0	2(1.0%)
	Number of Cognitive LO	89(43.2%)	75(36.4%)	28(13.6%)	2(1.0%)	5(2.4%)	7(3.4%)	206
Taiwan (n=248)	Factual	10(4.0%)	5(2.0%)	34(13.7%)	0	0	0	49(19.8%)
	Conceptual	6(2.4%)	22(8.9%)	109(44.0%)	2(0.8%)	0	0	139(56.0%)
	Procedural	4(1.6%)	0	51(20.6%)	2(0.8%)	0	3 (1.2%)	60(24.2%)
	Metacognitive	0	0	0	0	0	0	0
	Number of Cognitive LO	20(8.1%)	27(10.9%)	194(78.2%)	4(1.6%)	0(0.0%)	3(1.2%)	248

i.Regional profiles of cognitive processes and knowledge levels by grade levels

In terms of cognitive processes between lower and higher grades, Hong Kong was relatively similar as was mainland China although in the latter more higher-order LO (e.g., Evaluate, Create) appeared (in % terms) in Grades 5-6 than in other regions (Table 3). The profile for Taiwan was quite consistent across grade levels with an overwhelming emphasis on Apply in both.

Table 3. Overall profile of RBT cognitive processes in the LO sorted according to their grade levels across the three regions. (% of the LO are in brackets)

	Grade	**Remember**	**Understand**	**Apply**	**Analyse**	**Evaluate**	**Create**	**Total**
Hong Kong (n=53)	1-3	10 (40.0%)	4 (16.0%)	8 (32.0%)	0	1 (4.0%)	2 (8.0%)	25 (47.2%)
	4-6	10 (35.7%)	7 (25.0%)	8 (28.6%)	1 (3.6%)	0	2 (7.1%)	28 (52.8%)

Mainland China (n=206)	1-2	19 (50.0%)	9 (23.7%)	8 (21.1%)	0	1 (2.6%)	1 (2.6%)	38 (18.4%)
	3-4	37 (39.8%)	39 (41.9%)	14 (15.1%)	1 (1.1%)	1 (1.1%)	1 (1.1%)	93 (45.1%)
	5-6	33 (44.0%)	27 (36.0%)	6 (8.0%)	1 (1.3%)	3 (4.0%)	5 (6.7%)	75 (36.4%)
Taiwan (n=248)	3-4	12 (11.3%)	10 (9.4%)	82 (77.4%)	1 (0.9%)	0	1 (0.9%)	106 (42.7%)
	5-6	8 (5.6%)	17 (12.0%)	112 (78.9%)	3 (2.1%)	0	2 (1.4%)	142 (57.3%)

Table 4. Overall profile of RBT knowledge levels in the LO sorted according to their grade levels across the regions. (% of the LO are in brackets)

	Grade	Factual	Conceptual	Procedural	Metacognitive	Total
Hong Kong (n=53)	1-3	4(16.0%)	12(48.0%)	8(32.0%)	1（4.0%）	25(47.2%)
	4-6	3(10.7%)	15(53.6%)	10(35.7%)	0	28(52.8%)
Mainland China (n=206)	1-2	20(52.6%)	12(31.6%)	5(13.2%)	1(2.6%)	38(18.4%)
	3-4	29(31.2%)	49(52.7%)	14(15.1%)	1(1.1%)	93(45.1%)
	5-6	26(34.7%)	38(50.7%)	11(14.7%)	0	75(36.4%)
Taiwan (n=248)	3-4	25(23.6%)	51(48.1%)	30(28.3%)	0	106(42.7%)
	5-6	24(16.9%)	88(62.0%)	30(21.1%)	0	142(57.3%)

In all three regions, Factual knowledge shifted towards Conceptual in the upper grades with the difference most pronounced in Taiwan (Table 4). Even though it is normative for Procedural to appear with Apply, LO requiring the use of procedural knowledge was highest in Hong Kong (in % terms) compared with other two regions that reflected the strong hands-on learning emphasis of its curriculum.

B) Coherency of topics in the reformed curricula from the three regions

i. Coverage. Table 5 shows the selection and number of primary science topics (by grade division & number of LO within) in the three regions. Mainland China and Taiwan covered a total of 39 and 37 topics respectively out of 41 that are more twice that of Hong Kong with only 17. It is again to be remembered that the primary science curriculum in Hong Kong is part of General Studies rather than a standalone school subject. Thus, we can observe a contrast where topics such as magnetism, habitats and niches, biomes and ecosystems, explanations of physical change, and types of forces are not covered in Hong Kong, but are emphasised in Taiwan, for example.

ii. Focus. Table 5 shows that Grades 1-2 cover 17 topics in mainland China, which is less focused (i.e. more topics/grade) than Grades 1-3 in Hong Kong with 15 topics. Teachers from Taiwan and mainland China are also expected to handle nearly equivalent number of topics (between 30-32) in grade divisions 3-4 and 5-6. Yet, their differences in terms of the number of LO within each grade division are stark: 13% (106/93) more for Grades 3-4 and 89% (142/75) (see Table 3) more for Grades 5-6 respectively in the Taiwanese curriculum compared to mainland China. And, there is a lower focus of science topics in the upper grades in Taiwan and mainland China compared to Hong Kong as they are standalone subjects there.

Table 5. Overall profile of number of LO in 41 primary science topic across grade levels in the three regions (adapted from Schmidt et al. 2005).

	Hong Kong (n=53)				Mainland China (n = 206)					Taiwan (n=248)			
Common Science Topics	LO in Grade 1-3	LO in Grad e 4-6	Total LO across grades (Relative Emphasis)	Trend pattern across grades	LO in Grade 1-2	LO in Grade 3-4	LO in Grade 5-6	Total LO across grades (Relative Emphasis)	Trend pattern across grades	LO in Grade 3-4	LO in Grade 5-6	Total LO across grades (Relative Emphasis)	Trend pattern across grades
Organs, tissues	1	2	3(L)	R	1	4	3	8(L)	H	0	6	6(L)	R
Physical properties of matter	2	2	4(L)	F	3	7	1	11(L)	H	10	6	16(H)	D
Plants, fungi	1	0	1(L)	D	3	6	4	13(M)	H	11	2	13(M)	D
Animals	1	0	1(L)	D	3	7	3	13(M)	H	6	8	14(H)	R
Classification of matter	1	1	2(L)	F	2	2	0	4(L)	D	3	3	6(L)	F
Rocks, soil	0	0	0(L)	0	0	6	1	7(L)	H	1	2	3(L)	R
Light	0	0	0(L)	0	0	1	5	6(L)	R	2	7	9(M)	R
Electricity	0	0	0(L)	0	0	4	0	4(L)	H	3	1	4(L)	D
Life cycles	1	1	2(L)	F	0	2	0	2(L)	H	1	0	1(L)	D
Physical changes of matter	1	1	2(L)	F	1	3	2	6(L)	H	3	1	4(L)	D
Heat and temperature	1	0	1(L)	D	0	2	2	4(L)	R	2	0	2(L)	D
Bodies of water	0	0	0(L)	0	0	1	1	2(L)	R	0	0	0(L)	0
Interdependence of life	5	2	7(M)	D	1	2	3	6(L)	R	6	2	8(M)	D
Habits and niches	0	0	0(L)	0	1	3	1	5(L)	H	4	7	11(M)	R
Biomes and ecosystems	0	0	0(L)	0	0	1	0	1(L)	H	1	11	12(M)	R
Reproduction	0	0	0(L)	0	0	2	2	4(L)	R	0	1	1(L)	R
Time, space, motion	0	0	0(L)	0	1	7	0	8(L)	H	1	0	1(L)	D
Types of forces	0	0	0(L)	0	2	1	0	3(L)	D	3	10	13(M)	R
Weather and climate	1	2	3(L)	R	3	4	2	9(L)	H	8	4	12(M)	D
Planets in the solar system	2	2	4(L)	F	1	4	1	6(L)	H	5	2	7(M)	D
Magnetism	0	0	0(L)	0	5	0	0	5(L)	D	2	8	10(M)	R

Earth's composition	0	0	0(L)	0	0	0	4	4(L)	R	2	4	6(L)	R
Organism energy handling	0	0	0(L)	0	0	0	2	2(L)	R	2	1	3(L)	D
Land, water, sea resource conservation	0	2	2(L)	R	0	2	5	7(L)	R	1	1	2(L)	F
Earth in the solar system	0	0	0(L)	0	1	2	6	9(L)	R	0	0	0(L)	0
Atoms, ions, molecules	0	0	0(L)	0	0	0	0	0(L)	0	0	2	2(L)	R
Chemical changes of matter	0	1	1(L)	R	0	0	1	1(L)	R	2	7	9(M)	R
Physical cycles	0	0	0(L)	0	0	0	2	2(L)	R	0	1	1(L)	R
Land forms	0	0	0(L)	0	0	1	1	2(L)	R	4	1	5(L)	D
Material and energy resource conservation	1	1	2(L)	F	0	1	4	5(L)	R	5	1	6(L)	D
Explanations of physical changes	0	0	0(L)	0	0	6	0	6(L)	H	9	11	20(H)	R
Pollution	0	0	0(L)	0	0	0	1	1(L)	R	3	0	3(L)	D
Atmosphere	0	0	0(L)	0	0	0	1	1(L)	R	0	0	0(L)	0
Sounds and vibration	0	0	0(L)	0	0	3	0	3(L)	H	2	4	6(L)	R
Cells	0	0	0(L)	0	0	0	1	1(L)	R	0	1	1(L)	R
Human nutrition	1	1	2(L)	F	0	0	1	1(L)	R	0	1	1(L)	R
Building and breaking	0	0	0(L)	0	0	0	0	0(L)	0	0	0	0(L)	0
Energy types, sources, conversions	2	2	4(L)	F	1	2	2	5(L)	R	2	10	12(M)	R
Dynamics of motion	0	0	0(L)	0	0	1	1	2(L)	R	1	1	2(L)	F
Organism sensing and responding	0	0	0(L)	0	1	1	2	4(L)	R	3	0	3(L)	D
Science Technology & Engineering (STE)	5	8	13(H)	R	9	11	15	35(H)	R	4	17	21(H)	R
Focus: Number of topics/grade division	15	14	-	-	17	30	30	-	-	31	32	-	-
Relative Emphasis of topics (L; M; or H)	-	-	39xL, 1xM, 1xH	-	-	-	-	38xL, 2xM, 1xH	-	-	-	26xL, Mx11, 4xH	-
Overall pattern of trends of LO across each topic (0; F; R; or D)	24 x 0; 8 x F; 5 x R; 4 x D				2 x 0; 0 x F; 21 x R; 3 x D; 15 x H					4 x 0; 3 x F; 19 x R; 15 x D			

Table 6. Duration or span of science topics across grades and regions.

	Duration or span of science topics across			
	Absent topics	1 grade division (topics located in which division)	2 grade divisions (topics located in which division)	3 grade divisions
Hong Kong (2 grade divisions)	24	5 (3 in lower, 2 in upper)	12	—
Mainland China (3 grade divisions)	2	14 (1 in 1st, 5 in 2nd, 8 in 3rd)	12 (3 in 1st & 2nd, 9 in 2nd & 3rd)	13
Taiwan (2 grade divisions)	4	11 (5 in lower, 6 in upper)	26	—

iii. Sequencing. Table 6 shows the duration or span of topics across the different grade divisions in the three regions. In mainland China and Taiwan, 13 (31% of topics there) and 26 (63%) of their topics respectively spanned across all their grade divisions although recall that mainland China has three grade divisions for primary science. In mainland China, the span of topics are quite equally divided with topics that appear once (14 topics), twice (12), and across all three grade divisions (13).

In Taiwan and Hong Kong, there are more than double the number of topics in their own regions that span all two grade divisions compared to those that appear in only once. And based on where topics appear in Table 6, most of them are more concentrated at the higher or middle grades in mainland China (e.g., 9 topics spanning 2nd & 3rd grade divisions) though this was not as obvious for Taiwan. These data therefore suggest that there is some degree of meaningful sequencing in terms of duration or span of topics; more science topics cut across all grade divisions in Hong Kong and Taiwan just as there are also more topics that span either two or all three grade divisions from mainland China.

Based on our sequencing notation scheme, Hong Kong with the fewest number of LO had 24 topics without LO ("0") in Table 5. The trend in mainland China also indicated more LO being introduced for each topic across grades with 21 ("Rise") topics followed closely by a hill pattern for 15 of its topics. With learning progressions built-in for this curriculum, this might have accounted for the "rise" patterns that was observed (Yao & Guo, 2018). Taiwan too had slightly more rising than dropping configurations though not as distinct as mainland China's with only three topics falling in LO numbers ("Drop") across grades. Some of these patterns are possibly due to the number of LO found in the grades (see Tables 3 & 4) because Grades 3-4 contained the most number of LO in mainland China.

iv. Emphasis. Again from Table 5, it can be seen that STE topics are highly emphasised ("H") in all three regions. The topics of physical properties of matter, animals, and explanations of physical changes were highly emphasised in Taiwan too. In mainland China, plants, fungi, and animals topics were those that had medium relative emphasis ("M"), but in Hong Kong it was only the interdependence of life topic that had the same coding. The Taiwanese curriculum had the largest number of high- (total of 4) and medium-emphasis topics (11) in all three regions. Of these, three and seven of these high- and medium-emphasis topics had a "R" (Rise) pattern respectively that might indicate a strong deepening of knowledge over grade divisions. The bulk of the other topics in the three regions were, however, coded as "L" that implied a low relative emphasis especially with Hong Kong with many absent topics.

An interesting overall picture of which science topics are covered among all three regions can be found if we rearranged the 41 science topics by Life Science, Physical Science, and Earth and Environmental Science categories. We then could ascertain if there were any patterns of topics that were emphasized in their intended curriculum (see Table 7).

Table 7. Topics arranged by science disciplines and the extent of coverage/emphasis of science topics in the intended curriculum from all three regions.

Topics	Lower & middle grades	Upper grades
Life Science Topics		
1. Interdependence of life	●	●
2. Plants, fungi	●	◎
3. Animals	●	◎
4. Life cycles	●	.
5. Organs, tissues	◎	●
6. Habits and niches	◎	◎
7. Organism sensing and responding	◎	.
8. Biomes and ecosystems	◎	.
9. Reproduction	.	◎
10. Organism energy handling	.	◎
11. Human nutrition	.	●
12. Cells		◎
Earth Science & Environmental Science Topics		
1. Weather and climate	●	●
2. Planets in the solar system	●	●
3. Material and energy resource conservation	●	●
4. Land, water, sea resource conservation	◎	●
5. Land forms	◎	◎
6. Rocks, soil	◎	◎
7. Earth's composition	.	◎
8. Physical cycles		◎
9. Pollution	.	.
10. Earth in the solar system	.	.
11. Bodies of water	.	
12. Atmosphere		.
13. Building and breaking		
Physical Science Topics		

1. Physical changes of matter	●	●
2. Physical properties of matter	●	●
3. Energy types, sources, conversions	●	●
4. STE	●	●
5. Classification of matter	●	◎
6. Heat and temperature	●	.
7. Light	◎	◎
8. Dynamics of motion	◎	◎
9. Magnetism	◎	.
10. Types of forces	◎	.
11. Electricity	◎	.
12. Explanations of physical changes	◎	.
13. Sounds and vibration	◎	.
14. Time, space, motion	◎	
15. Chemical changes of matter	.	●
16. Atoms, ions, molecules		.

Key: Intended by only one of the three regions .
Intended by two regions ◎
Intended by all of three regions ●
[NB. Topics from Grades 1-4 from mainland China, Grades 1-3 from Hong Kong, and Grades 3-4 from Taiwan were reorganized as lower & middle grades. All other grades were reorganized as upper grades.]

The pattern of emphasis of science topics in Table 7 is obtained by checking whether a topic is intended in the three regions by grade levels; if it is intended by all three then it is represented with a (●) and so on. Thus, we can best observe a desired upper triangular appearance among Earth and Environmental Science topics (#1-8) where topics 1-3 (weather; planets; material & energy conservation) were intended by all three regions across all grades (i.e. high emphasis). For topic 4, it was intended in all regions only for the upper grades whereas topics 5-6 were equally covered at both grade levels in two regions. Earth Science topics 7 and 8 were also intended by two regions in the upper grades, but at the lower and middle grades topic 7 was intended in a single region and topic 8 was completely absent. It thus appears from Table 7 that topics 1 to 3, and possibly 4 were the buttress topics that allowed knowledge to be deepened over grades, and topics 7 and 8 were more challenging ones in the curriculum that were left for studying in upper grades.

Among Physical Science topics, Table 7 also shows that there are four to five buttress topics (#1-5) that anchor learning sequences across grades, and in a weaker way Topics 7-8 function in a similar manner. Topics 9-14 here were intended in the lower and middle grades in two regions, but had reduced coverage in the upper grades in our sample. No clear upper triangular appearance, however, was discernible among Life Science topics across the three regions. Nonetheless, topics 9 to 12 in Life Science (e.g., reproduction; energy; cells) are generally regarded as more difficult to learn and thus often appear at upper grades as what we see here. Because a year-by-year breakdown for teaching of specific topics was not available, more in-depth analysis was not possible to detect stronger patterns of emphasis that build up scientific knowledge over the years.

Conclusion and Discussion

What schools teach and how they develop young people forms the fundamental object of all curriculum theorizing and research. This study advances this endeavour by comparing two important features—the intellectual demands and coherency—of reformed primary science curricula across three East-Asian regions. Findings here not only add to the few evidence-based comparisons of primary science curricula in the literature, but it can practically assist policy- and curriculum-making in these regions too. When these two curricular features are not organized in a satisfactory manner, it is therefore not surprising to hear of reports stating that "United States [science] teachers did not typically use the various activities to support the development of content ideas in ways that were coherent and challenging for students" (Roth & Garnier, 2007, p. 20).

What are the key results from this study? Regarding their intellectual demands of the reformed curricula that was the first research question, LO from these three East-Asian regions favoured learning conceptual knowledge with far less emphasis on metacognitive knowledge (Table 2) and most did not extend beyond the Apply cognitive level. On the whole, the intellectual demands were therefore modest though with many nuances between these regions, which was similar to what Wei and Ou (2019) had found with respect to their junior high curriculum. Like these authors, we too recommend that curriculum makers from these regions should consider increasing the intellectual demands of their primary science curriculum in order to better cultivate higher-order thinking. This must, however, be done in an age-appropriate manner.

Compared with the other two regions, reformed LO from mainland China were coded mainly as lower-order factual knowledge and in Remember categories, which can perhaps be explained by the extension of science instruction to Grades 1-2 and its intentional catering for early science instruction (MOE China, 2017). The higher proportion of LO coded as Remember in Hong Kong may also be due to this reason. However, Taiwanese LO had a predominance of Apply, which was the highest number in percentage terms for any region. This was likely a reflection of a deliberate policy to increase the opportunities for learning scientific inquiry in an integrative manner in their new reformed curriculum (MOE Taiwan, 2018). And compared to mainland China and Hong Kong, Taiwanese educators have had more interactions with international counterparts thus the development of its science curriculum was possibly influenced by US science curriculum reforms that encouraged more opportunities to inquire or learn conceptual knowledge by hands-on activities (NGSS Lead States, 2013). Comparing across grades, there were no major observable changes in cognitive process save for mainland China in the middle grade divisions (Table 3) while Factual shifted towards Conceptual typically in all upper grades with the difference most obvious in the case of Taiwan (Table 4).

The second question in our research examined the coherence of topics and it was found that coverage of topics in mainland China and Taiwan were higher than Hong Kong as science in the latter was part of General Studies (Table 5). Of course, the specific choice of topics within each region is always a prerogative decided by its own authorities. Teachers from mainland China and Taiwan had nearly the same number of topics to teach (i.e. similar focus) from Grades 4-6 although Taiwanese teachers had more LO to cover, up to 89% more in the final two years of primary schooling. In terms of sequencing, many science topics cut across all grade divisions in Hong Kong and Taiwan while a number of topics spanned either two or all three grade divisions from mainland China (see Table 6). Also, there was evidence of rising trend patterns (i.e. more LO in later grades coded as "R") in the topics from Taiwan and especially in mainland China (Table 5). These data indicate that there are indeed evidence of sequencing here that can meaningfully build up knowledge across the years in their intended curricula.

Of interest was the large number of LO that strongly supported STE-related topics in the three East-Asian regions, which was an explicit policy decision to modernise the science curriculum in Taiwan and mainland China in the latest rounds of reforms. Indeed, learning about STE in mainland China is one of the four major domains of its curriculum along with Physical Science, Life Science, and Earth and Space Science (MOE China, 2017). Moreover, Taiwan had the highest number of high- and medium-emphasis topics amongst the three regions, which provides beneficial opportunities for deepening knowledge over grade divisions as most of these were coded as a “R” (Rise) trend pattern too.

Another finding regarding curricular emphasis as well as being a mark of a quality curriculum came from checking the rearrangement of topics that enabled science learning to progress over grades (Table 7). A desirable upper triangular appearance was more evident among their Earth and Environmental Science topics while four or five buttress topics for building knowledge were observed among Physical Science topics as well. However, no clear upper triangular structure was visible for the Life Science topics. Compared to mathematics, primary science has less of a hierarchical progression structure, hence it is actually equally defensible to start developing conceptual expertise from a variety of starting points (c.f. the three versions of Biological Sciences Curriculum Study textbooks in 1963). By including more regions or levels (e.g., middle-school curricula) for comparison, detecting clearer patterns of emphasis might be easier in future research.

Recommendations arising from the coherency of topics are less straightforward compared to its intellectual demands; increases in one aspect of coherency can sometimes undermine the effects of others in a negative manner. For example, higher levels of *sequencing* across grades definitely help learners deepen core ideas, but it could equally result in unhelpful repetition or *emphasis* if the meaningful *coverage* of scientific concepts is ignored. Given these complexities, we recommend that the coherency of topics should always be considered in a holistic manner (together with curriculum rigor) for balancing these aspects within a region. Without detailed information about which topics are covered in a specific grade in these three regions, it is difficult for us to describe the development of scientific knowledge and skills (i.e. scientific literacy) over grade levels here. Other limitations in our study can be raised such as the suitability of using a coding scheme derived from general psychology (i.e. RBT) for working with science LO or the fact that classroom implementation of curricula often better predicts the final opportunities to learn that a student experiences. In other words, most of the problems of learning science in school lie with the implemented rather than the intended curriculum.

In closing, we reiterate that we are not comparing whether one region is better than the other in this study. We merely wish to empirically examine two key features in the organization of their national curricula that are amenable to evidence-based improvements by their governments. Once we are better able to understand and create quality science curricula, these certainly go a long way in raising science achievement and scientific literacy among young people.

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