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Curriculum Coherence: A Comparative Analysis of Elementary Science Content Standards in People's Republic of China and the USA

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CURRICULUM COHERENCE: A COMPARATIVE ANALYSIS OF ELEMENTARY SCIENCE CONTENT STANDARDS IN PEOPLE'S REPUBLIC OF CHINA AND THE USA

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This study examines elementary science content standards curriculum coherence between the People's Republic of China and the United States of America. Three aspects of curriculum coherence are examined in this study: topic inclusion, topic duration, and curriculum structure. Specifically this study centers on the following research questions: 1) What science knowledge is intended for elementary students in each country? 2) How long each topic stays in the curriculum? 3) How these topics sequence and connect with each other? 4) And finally, what is the implication for elementary science curriculum development?

Four intended science curriculum frameworks were selected respectively for each country. A technique of General Topic Trace Mapping (GTTM) was applied to generate the composite science content standards out of the selected curriculum for each country.

In comparison, the composite USA and Chinese elementary science content standards form a stark contrast: a bunch of broad topics vs. a focus on a set of key topics at each grade; an average of 3.4 year topic duration vs. an average of 1.68 year topic duration; a stress on connections among related ideas vs. a discrete disposition of related ideas; laundry list topic organization vs. hierarchical organization of science topics.

In analyzing the interrelationships among these characteristics, this study reached implications for developing coherent science content standards: First, for the overall curriculum, the topic inclusion should reflect the logical and sequential nature of knowledge in science. Second, for each grade level, less, rather than more science topics should be focused. Third, however, it should be clarified that a balance should be made between curriculum breadth and depth by considering student needs, subject matter, and child development. Fourth, the topic duration should not be too long. The lengthy topic duration tends to undermine links among ideas as well as lead to superficial treatment of topics.

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Fang Huang

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INTRODUCTION

Research Background

Globalization is often defined primarily in terms of its economic dimension. However, with the increasing globalization of economies, there is also a need for globalization of the socio-cultural and ethical dimensions that shapes international exchanges and cooperation in education. As the International Commission on Education for the Twenty First Century—the Delors report to UNESCO stressed that "learning to live together" will only occur through the possession of self-knowledge and understanding and appreciation of others' (Delores, et al, 1996).

Science education, in the era of increasing international competition, proliferation of new technology, and reconstructing of industrial structure, has been increasingly identified as a way to equip young people to lead meaningful and productive lives. In task of developing and improving shared understanding of science education among countries, science curriculum standards play an important role. Curriculum standards shape subsequent teaching, assessment, tests, professional development, and accreditation. Science curriculum standards serve as a foundation policy document that provides the overall vision of science education in different systems.

At the national level, the People's Republic of China and the USA both benefit and strengthen connections through projects that compare and elaborate for clarification national science curriculum standards. There are several reasons for this need of shared understanding about the science curriculum in each country, with economics clearly playing a significant role. For the USA, to remain a global leader in a knowledge-intensive and high-tech world, it cannot afford to isolate itself educationally, an understanding of global education efforts is needed to strengthen and build connections to other parts of the world. China has made great strides in the past thirty years as its economy has shifted from a rigid and demanding central planning toward a more free market economy since the Chinese economic reform initiated in 1978. Its industrial structure has moved from an agriculture-oriented toward a more industrial and service-oriented composition.

Currently China is the third largest economy in the world after the US and Japan with a nominal GDP of US$4.4 trillion (2008) when measured in exchange-rate terms, and the second largest in the world after that of the United States with a GDP of $7.8 trillion (2008) when measured on a purchasing power parity (PPP) basis (Agency France Presse, 2009). These changes and challenges put science education in a particularly crucial position given the intense international economic competition as well as interdependence. The globalization of economies requires the adaption of science education to meet both national demand and international concerns for both the USA and China.

The development of science knowledge is international in scope. The principles of science are universal. Science differs from history or language which are more strongly influenced through local culture or shaped by to religious battles. The science taught in one country should not be markedly different from the science taught in other countries.

While there may be slight variations based on geographic, cultural or religious paradigms it is presumed that students of the same age all over the world will or should have studied similar, if not exactly the same, science material. This universality of science provides the feasibility for across-nation comparison study on science curriculum.

To strengthen the communication and connections in science education between the USA and China comparison studies of their science curriculum standards provides one perspective for exploring the globalization of science education.

Elementary School Systems in the USA and China

Both the USA and China have large elementary education systems. According to the *Digest of Education Statistics* from the USA National Center for Education Statistics, America had about 97,382 public elementary and secondary schools between 2005 to 2006 (NCES, 2009). In 2006, 34,221 million students were enrolled in public schools from prekindergarten (preK) through grade 8, and the public school enrollment in grades preK-8 is projected to set new records each year from 2007 to 2018, reaching an estimated high of 38.2 million in 2018. In China, the statistics released on the official website of Chinese Ministry of Education (MOE, 2009) indicates that there were 320,061 elementary schools and 105.64 million enrolled elementary students in 2007. According to the Press Conference on September,11, 2009 held by the Chinese State Council Information Office, the gross enrollment ratio of elementary education in China has reached 99.5% by 2008 (www. http://learning.sohu.com/s2009/xwfbh/).

Science is one of the four core academic subjects along with language arts, mathematics, social studies and science broadly offered in the USA elementary school

(Education Encyclopedia, 2002), though it is given less emphasis compared to language arts and mathematics. According to a nation-wide survey of elementary science teachers (Horizon research, 2002), grade K-5 self-contained classes spent an average of 25 minutes each day on science instruction, compared to 114 minutes on reading/language arts, 53 minutes on mathematics, and 23 minutes on social studies, as indicated in Table 1.1 Since most elementary schools meet five days each week, the time spent on science in a week is approximately two hours.

Table 1.1: Average Number Of Minutes Per Day Spent Teaching Each Subject in Self-Contained Classes In USA

	Number of Minutes		
	Grade K-5	Grade K-2	Grade 3-5
Reading/Language Arts	114	119	108
Mathematics	53	49	58
Science	25	21	30
Social Studies	23	18	28

Source: Horizon Research, 2002. The 2000 National Survey of Science and Mathematics Education: Status of Elementary School Science Teaching.

In China, Chinese, mathematics, and English are three core academic subjects in elementary education. Science as a new curriculum area replacing the previous “nature” course in elementary schools first appeared in 2001, two years later the basic science education reform in China commenced. Though attached less importance than the other three core courses, elementary science is drawing increasing attention from Chinese public due to its fundamental role in improving citizen lives, building a democratic society and shaping the labor market.

According to the Tentative Curriculum Schema for Compulsory Education released by the Chinese Ministry of Education (MOE, 2001), science course is allocated two lessons each week for students from grade three to six, with Chinese eight lessons, mathematics five lessons, and English two lessons. Given that each class is usually given 45 minutes, the total time on science course each weeks amounts about 90 minutes, about half an hour less than that of 120 minutes in the USA. The detailed teaching load for each subject in Chinese elementary school is described in Table 1.2.

Table 1.2: Number of Lessons and Minutes Assigned For Each Subject Each Week in Chinese Elementary Curriculum

	Grade 1-2	Grade 3-6
Chinese	9 (405minutes)	8 (340minutes)
Mathematics	5 (225minutes)	4 (180minutes)
Moral Education	2 (90minutes)	2 (90minutes)
Physical Education	4 (180minutes)	3 (135minutes)
Arts(Music or fine art)	4 (180minutes)	4 (180minutes)
Comprehensive practice activity	3 (135minutes)	2 (90minutes)
English	N/A	2 (90minutes)
Science	N/A	2 (90minutes)

Source: Chinese Ministry of Education, 2001. Tentative Curriculum Schema for Compulsory Education.

In summary, there is a growing focus on elementary science coursework. Though elementary science coursework is paid less emphasis than language and mathematics in both the USA and China, there is no doubt that science course is gaining increasing attention given the large elementary student population in both of the two nations who is studying science and the foundation elementary science education provides for further science learning.

Curriculum Standards

The ideal of curriculum is hardly new, but the way of understanding it has altered over the years and there remains considerable dispute as to meaning. However, there seems to be a consensus on three levels of curriculum originated from the idea of Keeves (Keeves, 1972), namely (1) the intended curriculum; (2) the implemented curriculum; and (3) the achieved curriculum.

The intended curriculum is concerned with curriculum at the theoretical level in terms of learning objectives and subject topics, and sometimes may also includes suggestions about teaching methods, activities that match the topic and materials. The implemented curriculum focuses on the practice in the classroom where knowledge is translated from teachers to students. The achieved curriculum deals with the productive stage of education indicating knowledge, skills, and understanding that individual student has internalized from learning experience.

Focus of this study falls on the intended curriculum particularly on subject content standards. As a strong influential guidance to student, content standards are crucial for the intended curriculum providing a clear description of what student should learn at appropriate age and making the structure of the discipline visible to students so that they could move from simple particulars to sophisticated ideas as the topics sequence.

Definition of Curriculum Standards

Originally from similar words in Middle English, Old English, Old French, and the Germanic, the word "standards" refers first to "a conspicuous object formerly carried at the top of a pole and used to mark a rallying point or to serve as an emblem". In this sense, a standard is "something established by authority, custom, or general consent as a model or example"(Merriam-Webster, 1993, p.1145); it is a criterion by which judgment or decision may be made. At the same time, a standard is also "something set up and established by authority as a rule for the measure of quality, weight extent, value, or quality". That is, a standard may also "be defined as a criterion, gauge, yardstick, touchstone" (Merriam-Webster, 1993, p.1145). Therefore, "a standard is both a goal (what should be done) and a gauge for determining how well it was done" (Ravitch, 1995, p.7).

In education, the term "standard" has two commonly used meaning. One refers to content standards and the other pertains to performance standards. A content standard, serving as the foundation of the curriculum standards, is a summary description regarding "what it is that students should know and/or be able to do within a particular discipline" (Mclnerney, Etten, & Dowson, 2007, p.6). Content standards sometimes are also called curriculum standards. Content standards focus on the theoretical level of curriculum that describes specific knowledge and skills that teachers are supposed to teach and students are expected to learn. Content standards primarily serve to organize an academic subject domain through a manageable number of generally stated goals for student learning. This knowledge includes the most important and enduring ideas, concepts, issues, dilemmas, and information of each discipline. These statements help to clarify the broad goals within the discipline and provide a means for readers to navigate the standards document when searching for specific content.

Content standards are defined at different levels such as national content standards, state content standard, and local content standard. Standards may "be mandatory (required by law)", or "voluntary (established by private and professional organizations and available for use by anyone else)" (Ravitch, 1995, p.9).

Performance standards "define degrees of mastery or levels of achievement" (Ravitch, 1995, p.12). They answer the question of how well the level of the standard is met. Everyone has a definition of "good". One school's "A" might be another school's "B". One teacher's "A" might be equal to another teacher's "B". Performance standards ensure that there is a common understanding of the quality of student achievement. They "indicate both the nature of the evidence (such as an essay, mathematical proof, scientific experiment, project, exam, or combination of these) required to demonstrate that content standards have been met and the quality of student performance that will be deemed acceptable (what merits a passing grade or an "A" grade)" (Ibid, p.22). The achievement levels that describe the kind of performance are usually set as advanced, proficient, basic, or below basic, or represented as a proficiency scale from A to F.

The Calling for High Quality Content Standards

"Education means to lead forth, but it is impossible to lead anyone anywhere without knowing where to go" (Ravitch, 1995, p.25). High quality content standards are necessary for educational improvement because they are the starting point and provide guidance for evaluating and improving the quality of education.

Clear and rigorous content standards establish explicit expectations about what students must learn to succeed in school. Students should understand that their teachers structure their instructional practice (content and pedagogy) around the goal of helping them meet the externally defined standards. Student learning should focus on understanding of important science ideas and connections among them, rather than knowing fragmented bits and pieces of information. A number of international studies (Lapointe, 1989; Smith & O'Day, 1991, p.254; Medrich & Griffith, 1992) that summarizes previous international studies of mathematics and science, by describing each study and its primary results, also demonstrated the trend that: "students....from countries with more demanding curriculum learned more of the kinds of items tested in the survey, and performed better..." (Smith & O'Day, 1991, p.254).

With goals of student understanding spelled out, teachers know what they should teach and prepare their lessons based on the goals of the standards. The explicit content standards provide parents the accurate information about what their children are learning and allow them to evaluate schools that meet the standards. Consensus on the primary goals of the schools should support targeted investment in teacher education, staff development, instructional materials, technology and testing and evaluation. A system of standards will force curriculum developers to focus on the standards in writing materials for schools instead of random isolated facts (Raizen, S.A., 1997; American Federation of Teachers, 1999).

High quality standards serve as a signaling device that organizes all forces within the educational system toward a common goal. Therefore, it is desirable for education systems to establish well planned, comprehensible, challenging, and coherent standards.

Coherence—Key Indicator of High Quality Content Standards

Coherence is one of the most critical, if not the single most important, defining element of high-quality curriculum (Schmidt et al, 2001). The concept of coherence is used in different ways. Prior to the Third International Mathematics and Science Study (TIMSS) in 1997, most researchers addressed curriculum coherence as the alignment between school practice and various policy instruments such as content standards, tests, and textbooks, and alignment within these instruments (Furhman, 1993; American Federal of Teachers, 2001; Hatzakis, Lycett., Serrano., 2007). The concept of coherence has been adopted in various research projects and taken on different names. For example, Newmann, Smith, Allensworth, and Bryk (2001) used "instructional program coherence" to refer "a set of interrelated programs for students and staff that are guided by a common framework for curriculum, instruction, assessment, and learning climate." Sherin & Edelson's (2004) "intra-unit coherence" or "inter-unit coherence" defines coherence as the coordination between the learning goals, practices, and classroom activities within or across units and school years.

The 1997 TIMSS study used coherence as a central criterion of high quality curriculum by defining it as "connectedness of the ideas and skills presented to students within each grade and across the grades" (NRC, 1999, p.147). Schmidt, Wang, and McKnight (2005) later clarified the definition of coherence in standards content study and refined coherence as a logical approach to the subject. For these researchers, coherence refers to the order and connectedness of subject content. Standards are coherent if they are logically articulated over time as a sequence of topics and, if appropriate, hierarchical nature of the disciplinary content from which the subject-matter derives. This does not suggest one singular sequence for topics of a subject. Rather, it implies that topics should evolve from elementary to more advanced both across grades and within grade levels.

This definition of coherence primarily concerns two dimensions of curriculum standards: Curriculum focus and rigor. Focus means "attention given to single topics" (NRC, 1997, p.147). This implies that standards should emphasize on appropriate number of topics in effort to assign enough time for teaching. Rigor refers to "how deeply into the structure of the discipline and at what grade level (or age level) one moves to that depth" (Schmidt, et al, 2005). It implies that standards should increase in terms of depth as students move across the grades. Using focus and rigor as two indicators of coherence, one could think of the lack of coherence as a disease and the lack of focus or rigor as symptoms that indicate the disease.

Coherence is an important indicator of high quality content standards. Standards are coherent if they specify topics, including the depth at which the topic is to be studied as well as the sequencing of the topics, both within each grade and across the grades, in a way that is consistent with the structure of the underlying discipline (Schmidt, et al, 2001).

Problem of Science Curriculum Coherence in the USA and China

A wide variety of research projects (Popham, 2006; Finn, C.E., & Petrilli, M. J., 2000) have criticized state science content standards in the USA for curricular aims that are “too numerous”, that “ignored certain important subject areas” and are “vague, vapid, and misleading”. In a 2000 appraisal of 46 state science standards, 20% of the states earned a grade of A; 22%, B; 13%, C; 20% D; and 26%, F. The majority states remain mediocre to miserable upon their standards (Finn, C. E., & Petrilli, M. J., 2000). The TIMSS evaluation of existing elementary curricula (NRC, 1999; Schmidt., McKnight., Raizen., 1997; Schmidt., et al., 2001) indicated that most USA curricula deal with an extremely broad range of topics, and does not focus on coherent age-appropriate learning goals. Schmidt et al. (1997) concluded that “no simple, coherent, intellectually profound and systematically powerful vision guides USA mathematics and science education” (p.89).

Science education in China also exhibits the problem of lack of curriculum coherence. As aforementioned, China initiated a nationwide basic education reform in 2001. One of the new actions is the emergence of “science” course content focus in place of the traditional “nature” course content focus at the elementary school level. The “nature” course mainly emphasized on natural science and subject matter, while the new program is defined as integrated, child-centered and life-oriented by combining science, technology and social issues together. The Chinese Ministry of Education (MOE) issued the *National Science Curriculum Standards* in 2001 followed by a large scale trial of new science textbooks in 38 pilot districts across the country. As planned, all the elementary students in China were supposed to use the new textbooks by 2005 (Cai, 2003). With the implementation and popularization of the new program, implementation problems arose regarding the issue of curriculum coherence. For example, Sun, Xu, and Li (2008) found in the evaluation of three series of science textbook these textbooks included large amount of contents which lead only to a rough learning at the cost of in-depth understanding. Zhong and Gao (2007) found that the lack of coherence among the curriculum components leads to an mismatch between the learning goal and learning process.

Given the importance of high quality content standards and current problem of elementary curriculum coherence confronting both of the USA and China, this study focused on the coherence of elementary science content standards. The excluding of secondary education in this study mainly lies in the complicated and chaotic state of current science course at the middle school level in China. The Chinese secondary education (grade 7-12) used to teach separate science subjects including biology, physics, chemistry, and geography. The 2001 nationwide basic education reform started requiring middle schools (7-9) to teach either integrative science course or stay with the traditional separate science courses. Though many middle school implemented the integrative science course in the following years, this new science course has been suffering ceaseless disputes and ends up with the metropolis of Wuhan city first canceling the new science course and resuming teaching science subjects separately in 2008 (http://www.chinanews.com.cn/edu/jygg/news/2009/01-09/1520859.shtml).

The objections to the new middle school science course mainly arise from two concerns. First, the science teacher education program in China does not make appropriate adjustment in corresponding with science education reform (Hu, 2005; Yang, 2008). Prospective teachers are still trained in separated discipline, which gives rise to a serious shortage of qualified science teachers in China. Second, the new science course creates a disconnection between the middle school and high school science education. In Chinese high school (grade 9-12), physics, chemistry, biology, and geography are required for students who plan to major in science or engineer program at university or college. These four subjects along with mathematics and Chinese constitute the nationwide college entrance examination for the science or engineer major. Given the highly competitive examination, Chinese students and their parents rigorously appealed for a restoration to separate science subject course in middle school for a more solid knowledge base.

Under these pressure and considerations, currently some Chinese middle schools are implementing the new general science course, some staying with the traditional separate science subject, and others include both while treat the separate science subject courses as required core courses and the general science course as selective (China Education Daily, 2008). Given the wide variety of middle school science courses in China, this comparison study only focuses on the science curriculum at elementary level to avoid possible confusion caused by the diverse Chinese middle school science.

Purpose of the Study

The purpose of this study is to examine the coherence of elementary science content standards between the USA and China. This central research question is defined by a subset of questions:

What science knowledge is articulated in science content standards for elementary students in each country?

How long do science topics stay in the curriculum in each country?

How science topics are organized in the standards in each country? Do topics connect with each other and manifest the inherent logic of the subject?

Based on the examination, what are the commonalities and differences of the elementary science standards between the two countries in terms of coherence?

Finally, what is the implication for elementary science curriculum development in both countries?

CHAPTER II

LITERATURE REVIEW

This literature review summarizes and draws on research in four main areas: the definition of coherence, the rationale for calling for a coherent curriculum, the current status of elementary science curriculum coherence in the U.S.A and China, and a review of existing comparison studies of science curriculum in the two nations. The examination of existing literature reveals the lack of and the need for a comparison study on coherence of elementary science content standards between the U.S.A and China.

Definition of Coherence

As described in chapter I, coherence in the perspective of curriculum content refers to expressing priorities, sequences, and conceptual links among topics that underlies logical structure inherent in the science disciplines themselves (Schmidt, 2003). As a supplement to the literal interpretation of coherence and to illustrate coherent content standards in a more visual and consistent manner, Schmidt et al. (2005) adopted a technique called General Topics Trace Mapping (GTTM) to demonstrate curriculum coherence in a pictorial view.

GTTM first appeared in the TIMSS study (Michigan State University, 1993) and was initially used by education officials of each nation to indicate content topics by grade level (Bevilacqua, Gianneto, & Matthews, ed. 2001, p.86). As shown in Figure 2.1 with the topic of earth' composition as an example, grades included in the box indicates when the topic of earth features is intended to be taught over school years. By this way, GTTM visually demonstrates the "life" of a topic in the curriculum.

Grade 1 2 3 4 $\boxed{5\ 6\ 7\ 8\ 9\ 10\ 11}$ 12 Earth's composition

Figure 2.1: Using GTTM to Indicate the Intent on Science Topics.

Later, Schmidt el al (2005) applied GTTM for the large scale mapping of content standards, and transformed the extensive science curriculum into a neat chart, as indicated in Figure 2.2. In this chart, each row represents a specific topic and indicates the "life" of the topic in the curriculum over all years of schooling. Each column represents a specific grade level and indicates the topic "profiles" at this grade level. The overall map manifests both the overall content and structure of the science curriculum highlighting the sequencing and connections between topics as they move across grades.

Topic	*Grade 1*	*Grade 2*	*Grade 3*	*Grade 4*	*Grade 5*	*Grade 6*	*Grade 7*	*Grade 8*
Organs, tissues			●	●	●	●	●	●
Physical properties of matter			●	●	●	●	●	●
Plants, fungi			●	●	●	●	●	⊙
Animals			●	●	●	●	⊙	●
Classification of matter			⊙	⊙	⊙	⊙	●	●
Rocks, soil			⊙	⊙	⊙	⊙	●	●
Light			⊙				●	●
Electricity				⊙		⊙	●	●

Figure 2.2: Using GTTM to Describe Science Curriculum.

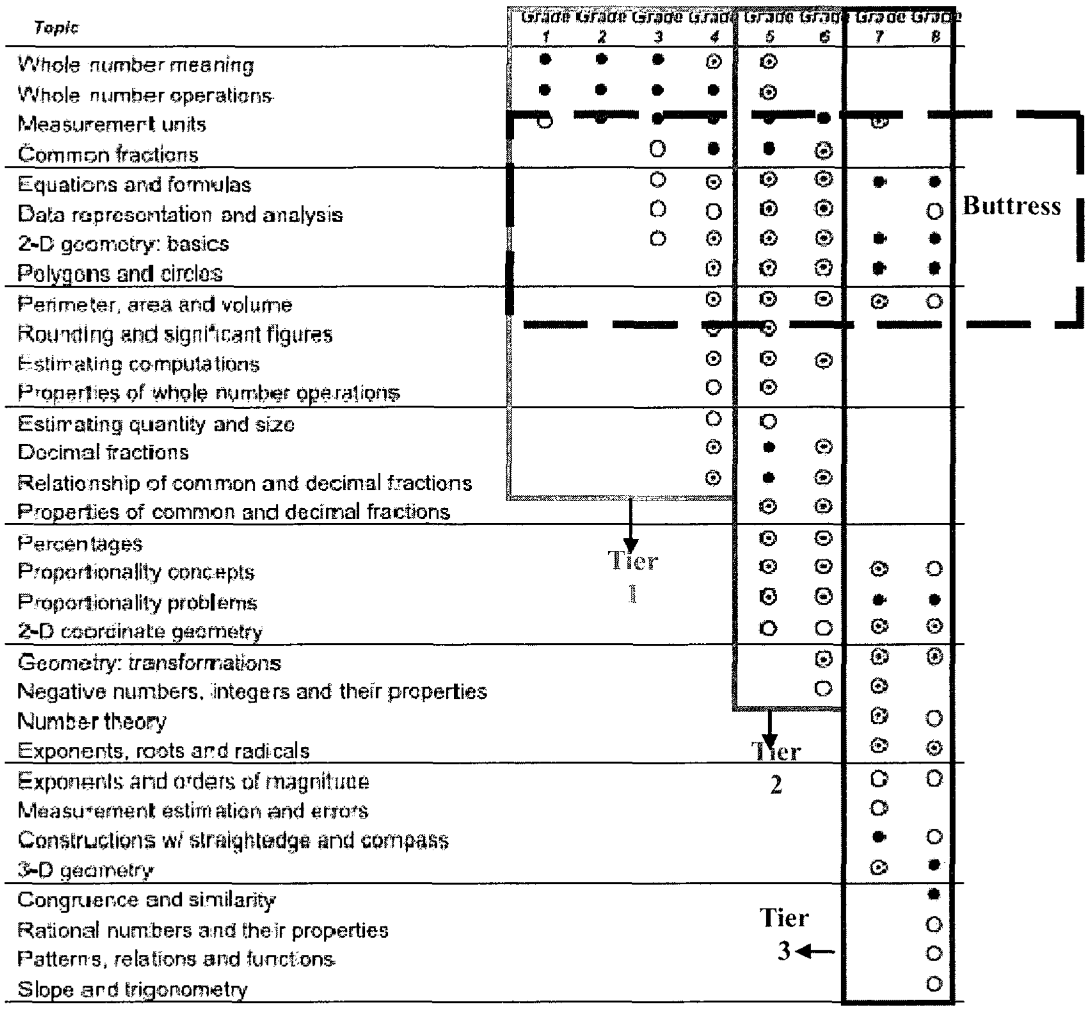
In order to generate a "model" content standard that reflects curriculum coherence for school science, Schmidt and his research colleagues (2005) applied the GTTM technique to content standards of top achieving countries in mathematics and science respectively by using TIMSS 1995 data. The top achieving countries refer to those that "had the highest mean middle-school student achievement (total score) without identifying more than five additional countries that could be statistically equivalent to them" (Schmidt et al, 2005). In mathematics, six such countries were indentified—Singapore, Korea, Japan, Hong Kong, Belgium (Flemish) and the Czech Republic; in science there were four such countries—Singapore, the Czech Republic, Japan, and Korea.

Figure 2.3 is a GTTM chart for grades 1-8 mathematics topics derived from the mathematics curricula of the six top mathematics achieving countries. Each dot in the chart represents a particular topic intended at a particular grade. The dark dot suggests topics intended by all the six countries, the circled dot indicates topics intended by five countries, and the circle indicates topics intended by four countries. The overall resulting map represents a composite science curriculum standards common to the six top mathematics achieving countries. An upper triangular structure including three tiers is readily seen in Figure 2.3. The first tier covering grades 1-4 confined by the orange text box indicates an emphasis on arithmetic concepts such as the whole number, common and decimal fractions, and estimation and rounding. Grade 5 and 6 within the green text box serve as the second tier continuing attention to primary topics, but with an introduction to the more advanced topics in the third tier. The third tier highlighted by the red text box comprises of grades 7 and 8 and consists primarily of advanced number topics, algebra, and geometry. The three tiers together reflect an increasing mathematical complexity in that the more complex topics build on those in the previous tier. This logical sequencing and connecting among topics is inherent in the mathematics and suggests a coherent curriculum.

Another feature of the composited international science framework is residing with the six topics that are covered in all the three tiers, as shown in the blue dashed text box in Figure 2.3. These six topics are fundamentals of algebra, geometry, measurement and data analysis, progressing from most elementary aspects to the more complex. The continuous attention suggests great importance attached to these topics in the international mathematics benchmarks. These topics stretch across all the three tiers and function as a "buttress", which insures the stability of the three tiers and supports the overall curriculum structure.

In the same manner, Schmidt et al (2005) produced the international science frameworks from the science standards of four top science performing countries using GTTM technique, as seen in Figure 2.4.

The GTTM chart for the four top science achieving countries also displays an upper triangular structure with three tiers. All these four countries begin teaching science course at grade three. The primary grades (grade 3 and 4) as the first tier cover fundamental concepts such as plants, fungi, and animals, as shown in the orange text box. The middle grades (grade 5 and 6) forming the second tier continues these same topics while introducing additional and more complex topics such as ecology and environmental science, as highlighted by the green text box. The higher grades (grade 7 and 8) serve as the third tier and introduce the study of chemistry and related topics such as atoms, ions and molecules, as shown in the red text box.



Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
Whole number meaning	●	●	●	⊙	⊙			
Whole number operations	●	●	●	●	⊙			
Measurement units	○	●	●	●	●	●	⊙	
Common fractions			○	●	●	⊙		
Equations and formulas			○	⊙	⊙	⊙	●	●
Data representation and analysis			○	○	⊙	⊙		○
2-D geometry: basics			○	⊙	⊙	⊙	●	●
Polygons and circles				⊙	⊙	⊙	●	●
Perimeter, area and volume				⊙	⊙	⊙	⊙	○
Rounding and significant figures				⊙	⊙			
Estimating computations				⊙	⊙	⊙		
Properties of whole number operations				○	⊙			
Estimating quantity and size				○	○			
Decimal fractions				⊙	●	⊙		
Relationship of common and decimal fractions				⊙	●	⊙		
Properties of common and decimal fractions					⊙	⊙		
Percentages					⊙	⊙		
Proportionality concepts					⊙	⊙	⊙	○
Proportionality problems					⊙	⊙	●	●
2-D coordinate geometry					○	○	⊙	⊙
Geometry: transformations						⊙	⊙	⊙
Negative numbers, integers and their properties						○	⊙	
Number theory							⊙	○
Exponents, roots and radicals							⊙	⊙
Exponents and orders of magnitude							○	○
Measurement estimation and errors							○	
Constructions w/ straightedge and compass							●	○
3-D geometry							⊙	●
Congruence and similarity								●
Rational numbers and their properties								○
Patterns, relations and functions								○
Slope and trigonometry								○

Figure 2.3: Mathematical Topics Intended at Each Grade by TIMSS Mathematics Top-achieving Countries.

Source: Schmidt, W. H., Wang, H. C., & McKnight, C. C. (2005). Curriculum Coherence: an examination of US mathematics and science content standards from an international perspective. Journal of Curriculum Studies, 37:5, 525-559.

Note: ● Intended by all six mathematics top achieving countries

⊙ Intended by five out of six mathematics top achieving countries

○ Intended by four out of six mathematics top achieving countries

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
Organs, tissues			●	●	●	●	●	●
Physical properties of matter			●	●	●	●	●	●
Plants, fungi			●	●	●	●	●	⊙
Animals			●	●	●	●	⊙	●
Classification of matter			⊙	⊙	⊙	⊙	●	●
Rocks, soil			⊙	⊙	⊙	⊙	●	●
Light			⊙				●	●
Electricity				⊙		⊙	●	●
Life cycles				●	●	●	●	●
Physical changes of matter				●	●	●	●	●
Heat and temperature				●	●	●	●	●
Bodies of water				⊙	⊙	⊙	●	●
Interdependence of life					⊙	●	⊙	⊙
Habitats and niches					⊙	⊙	⊙	⊙
Biomes and ecosystems					⊙	●	⊙	⊙
Reproduction					⊙			⊙
Time, space, motion					●	●	●	●
Types of forces					⊙	⊙	●	●
Weather and climate					⊙	⊙	●	●
Planets in the solar system					⊙	⊙	⊙	⊙
Magnetism						●	●	●
Earth's composition						⊙	●	●
Organism energy handling						⊙	⊙	●
Land, water, sea resource conservation						⊙	⊙	●
Earth in the solar system						⊙	⊙	⊙
Atoms, ions, molecules							●	●
Chemical properties of matter							●	●
Chemical changes of matter							●	●
Physical cycles							⊙	●
Land forms							⊙	●
Material and energy resource conservation							⊙	●
Explanations of physical changes							⊙	⊙
Pollution							⊙	●
Atmosphere							⊙	⊙
Sound and vibration							⊙	⊙
Cells							⊙	⊙
Human nutrition							⊙	⊙
Building and breaking								●
Energy types, sources, conversions								●
Dynamics of motion								⊙
Organism sensing and responding								⊙

Buttress

Tier 1

Tier 2

Tier 3

Figure 2.4: Science Topics Intended at Each Grade by TIMSS Science Top-achieving Countries.

Source: Schmidt, W.H., Wang, H. C., & McKnight, C.C. (2005). Curriculum Coherence: an examination of US mathematics and science content standards from an international perspective. *Journal of Curriculum Studies*, 37:5, 525-559.

Note: ● Intended by all four science top achieving countries

⊚ Intended by three out of four science top achieving countries

○ Intended by four out of six mathematics top achieving countries

The upper triangular structure of the international science framework differs from that of the international mathematics by having a larger "buttress" part. In mathematics, only six topics that were paid continued attention across all three tiers constitute the "buttress". While in science, 12 topics are intended to be taught throughout the three tiers. These topics relate to organs, tissues, physical properties of matter, plants and fungi, and animals, reflecting the fundamental knowledge base of the international science standards.

As to the reset "non-buttress" topics in the science frameworks, though they are not covered by all the three tiers, once introduced almost all of them remain in the curriculum for the subsequent grades. The long duration of both the buttress and non-buttress topics in the science frameworks implies a within-topic progression from simple to more complex. In other words, topics are staying in the curriculum for a long time and taught across the grades from more descriptive to more theoretical in nature, which sometimes is also referred as a "spiral" approach to subject. This is unlike topics in mathematics in that topics stay in the mathematics curriculum for a short time and after a point there would be no deepening of a particular topic, only repetition.

In summary, the GTTM technique illustrated two different types of curriculum frameworks that indicate a coherent curriculum organization. One pattern is an upper triangular structure with three tiers as evident in the mathematics frameworks generated from six TIMSS mathematics high performing countries. Each tier focuses on a set of key ideas with increasing sophistication by grades. In other words, the international mathematics benchmarks manifest both focus and rigor, suggesting a coherent vision of mathematics. Most topics stay in the mathematics curriculum for a short time except the six "buttress" topics that covered by all the three tiers in the mathematics frameworks. The other pattern implying a coherent curriculum is identified in the science framework produced from four TIMSS science high performing countries. The upper triangular structure with three tiers is also readily seen in the international science frameworks. However, it differs from the mathematical curriculum by having a larger buttress and more topics intended for a longer time to cover. This continuous attention on topics reflects a "spiral" approach to subject in that topics stay in the curriculum over a long period with increasing sophistication level each time revisited.

Distinguishing Coherence from Continuity and Integration

The confusion over curriculum coherence, curriculum continuity, and curriculum integration are well documented in the literature, because they are often used in a variety of ways to refer diverse practices and sometimes they are even used interchangeably. To have a well-defined conception of curriculum coherence in this study, an interpretation of curriculum continuity and integration will help clear up the confusion and misunderstanding.

Curriculum Continuity

Curriculum continuity deals with the vertical structure or repetition of the curriculum components over time. It "accounts for the reappearance in the curriculum of certain major ideas or skills about which educators feel students should have increased depth and breadth of knowledge over the length of the curriculum" (Ornstein & Hunkins, 1998, p.240). Continuity is not simply repetition of content but repetition with increasing levels of complexity and sophistication. Continuity is most evident in Bruner's (1995) notion of the "spiral curriculum" with basic ideas introduced and reintroduced in increasing depth and breadth as students advance through the school program.

Curriculum Integration

Curriculum integration has been around in one form or another for many years (Daviaon, Miller & Metheny, 1995) and grew in popularity in the 1990s (Pang & Good, 2000). It refers to the cross link of all types of knowledge and experiences contained within the curriculum plan. As Beane (1997) states: "Curriculum integration is a curriculum design that is concerned with enhancing the possibilities for personal and social integration through the organization of curriculum around significant problems and issues, collaboratively identified by educators and young people, without regard for subject area boundaries (p. 19)". Curriculum integration emphasizes horizontal relationships among various content topics and themes involving multiple domains of recognized knowledge (Oliva, 2005, p.435). Taba (1962) provided another explanation of integration from the perspective of individual that calls for the integration unifying knowledge and the learner's own experience.

Based on above statements, it is clear that continuity, integration and coherence are interrelated with each other but also have substantial differences. They each emphasize the connections between curriculum elements. However, they differ from each other by focusing on different dimensions and components of curriculum. Curriculum continuity is concerned with the vertical structure of the curriculum and addresses the repetition or reappearance of particular topics. Curriculum integrity emphasizes horizontal relationships among various content topics, themes, and activities. While curriculum coherence, under the definition by Schmidt et al (2005), emphasizes on the sequencing of topics and their connectedness. Curriculum coherence differs from continuity by including all topics in the discipline and the links between them instead of focusing on the development of particular topics. It differs from curriculum integrity by stressing on the inherent structure of the discipline rather than the combination and cooperation between diverse curriculum resources.

Rationale for Curriculum Coherence

Experts and Students

Coherent understanding distinguishes expert scientists from students. Research comparing science experts with novices reveals that experts in a discipline have a large amount of interconnected knowledge (Bransford, Brown, & Cocking, 1999; Chi, Feltovich, & Glaser, 1981; Larkin & Reif, 1979). These studies show that experts' knowledge is organized around central principles while novices often rely on formulas and memorized facts. Experts understand the central principles in their field so it makes sense to use these big ideas to organize knowledge. In contrast, students often do not understand the principles, lack extensive knowledge, and do not develop connections among ideas.

According to Bruner (1995), "to understand something is to sense the simpler structure that underlies a range of instances" (p.333), knowledge of the relationships between ideas and of the deeper structures enable learners to integrate new ideas into their existing knowledge systems. This indicates that the logic of the content and connections between ideas in a discipline is important and the goal of helping students develop an understanding of a subject matter is enhanced by making accessible the connections and co-ordination between the topics (Schmidt, et al., 2005).

Student Preconceptions

Students come to class with prior knowledge about how the world works (Bransford, et. al, 1999). Prior knowledge acts as a lens through which students view and absorb new information. They learn and remember new information best when it is linked to relevant prior knowledge. Research suggests that carefully chosen and sequenced content is necessary to scaffold students' attempts to construct meaningful ideas (Arons, 1990; Linn & Slotta, 2006). E. James Rutherford (2000) of the American Association for the Advancement of Science described the ideal curriculum as follows:

> "the topics and activities making up a science lesson or chapter ought to connect with one another to tell a (very limited) story....similarly, the lessons or chapters making up a science unit should connect one another in interesting ways to tell a complete (but still limited) story, and units should connect with one another in interesting ways to tell a more comprehensive story.... All of the parts forming a unit or course must be coherent, and all of those parts must join together to for a conceptual whole" (p. 22-23).

In this sense, the coherent curriculum standards that focus on the connection between prior knowledge and new ideas will inspire and excite students and encourage them to construct their understanding of a coherent system of concepts related to their own experience. Compared to those students who receive science knowledge as a collection of isolated information and formulas unrelated to the real world, students exposed to a coherent curriculum will be more likely to develop a deep understanding of the ideas and their interconnections.

Spontaneous Ideas

Students often construct contradictory and fragmented ideas originating from their interactions with the material and social world (diSessa, 1988; Pfundt & Duit, 1991), such ideas are called spontaneous ideas. These ideas are generated by students from observations, analogies to related events, cultural practices, or the colloquial use of language. Students usually hold multiple unstructured, fragmented pieces of knowledge one time. These intuitive ideas do not need to be replaced but rather developed and refined.

A Coherent context helps student thinking develop from alternative and disconnected ideas to a coherent view of science. Longitudinal studies show that students attempt to make sense of their disparate ideas when the instructional setting enables them to compare and contrast perspectives. Researchers view the development of expertise as a gradual process that involves grappling with many promising ideas and while making frequent regressions and digressions (diSessa, 1988; Clark & Linn, 2003). This highlights the importance of the coherent curriculum that makes the inherent logical structure of the discipline visible to students and provides links between topics.

Benefits of Coherent Instructional Materials and Activities

A coherent curriculum and instruction not only helps students better understand subject matter currently of interest, but also promotes their learning in the long run. Arzi, Ben-Avi, and Ganiel (1985) showed that long-term retention of chemistry concepts increases when students relate science content taught in one course to another. Linn and Eylon (2006) found that students possessing a coherent understanding of displaced volume continued to learn following instruction, whereas students lacking a coherent understanding did not. Students with a more coherent understanding are more able to apply their ideas in new situations and learn related information more quickly (Bransford, Brown, & Cocking, 1999; Perkins & Salomon, 1988).

Current Elementary Science Standards and Textbooks in the USA and China

Multiple studies revealed the highly repetitive, unfocused, unchallenging and unrelated topics in the American science standards and curriculum (Kirst & Anhalt, 1997; National Center for Educational Statistics, 1996, 1998). Science curricula in the USA is often characterized as “one mile wide and an inch deep”(Schmidt, McKnight, & Raizen,1997). Multiple stakeholders in the education system cite the wide use of inferior science curriculum materials. For example, the elementary science teacher Mrs Songer argued that “early-grades science tends not to challenge students to move beyond very basic facts and reasoning”, which “partly explains American students’ struggles as they move from elementary to middle school science” (Cavanagh, 2009); curriculum researchers contended that there is “a tension of far too many objectives, benchmarks, and standards at individual grade levels and grade bands”, whereas “the important unifying themes and principles of science are getting lost in favor of concept coverage”(Duschl, Shouse, & Schweingruber, 2007).

From an international perspective, the TIMSS study demonstrated serious threats to quality of coherence in American elementary science curricula. A strong impression conveyed through TIMSS textbook analysis is that the American science textbooks include far more topics when compared to textbooks in other countries. The average number of fourth grade topics in science textbooks of the TIMSS participating countries is around 25. The American science textbooks contain about 55 topics (NRC, 1999. p.38). Additionally, in the classroom, you might discover that American teachers cover more topics than in other country. This approach is often described as "more is less", implying a lower overall achievement when students are less engaged with the core concepts, while exposed to a wider range of concepts.

The second disadvantage of elementary science curricula in the USA is the use of widely scattered and loosely connected topics. Science content is more like a "long laundry list of topics" (Schmidt, et al, 1997a) without emphasis and focus. Five topics emphasized most heavily in U.S fourth grade science textbooks accounted for just over 25% of the total material covered, compared to an international median of 75% (NRC, 1999, p.39).

The third problem with American elementary science curricula is the repetition of topics. Topics remain in the American curricula for more grades than all but a few other TIMSS countries. For instance, the topics of physical properties of matter, fungi and plants, and earth in the solar system are anchored at grade one and remain all through grade eight in the American standards, contrasting to an average of 5 year coverage in four science top-achieving countries (Schmidt et al., 2005). This approach is characterized as "come early and stay late" (U.S. Department of Education, 1997). To make matters worse, very little depth is added each time the topic is addressed (Schmidt, et al, 1997a). Schmidt, McKnight and Raizen (1997b) concluded that there is "no simple, coherent, intellectually profound and systematically powerful visions guide U.S. mathematics and science education" (p.89).

Science curriculum reform is a centerpiece of current ongoing Chinese basic education reform. The new curriculum has shifted emphasis away from mere knowledge transmission to the all-round development of students, from an overemphasis on the rigidity of individual disciplines to an integration of subjects, and from the isolation from student real world to a more student life-orientation. As the widespread adoption of the new science curriculum materials and their integration into practice, issues concerning the curriculum construction have surfaced in several studies.

One growing concern over current Chinese elementary science curriculum is the broad topic coverage at the expense of in depth study of key concepts (Qiu, 2007; Sun, Xu, & Li, 2008). For example, science course is on average allocated about 30 classes at third grade level each semester in Chinese elementary schools, while the corresponding science textbook published by Hebei People Press approximately needs about 40 lessons to finish. Consequently the pressing timeline will constrain science teachers from engaging students in higher level thinking activities such as group discussion, investigation and problem solving and give rise to superficial treatment of scientific knowledge. The other growing concern over the Chinese elementary science curriculum relates to the inappropriate knowledge arrangement. Zhong and Gao (2005) identified disconnections between the elementary and middle school levels and that some topics intended in the elementary science curriculum actually are beyond the cognitive capacity of elementary students. Qiu (2007) pointed out that there is also a disconnection among different subjects, for example, several topics in science curriculum turned out difficult to teach due to student lack of mastery of prerequisite mathematical knowledge base. However, these researches overemphasis on content, yet leaving other aspects of curriculum design such as organizations and assessment yet to be properly explored.

Chinese scholars also examine the Chinese science curriculum through international lens by comparing them with science curriculum in other countries. The international attention mostly focuses on such developed countries as the USA, U.K., Canada, and France. In general, the Chinese elementary science curricula have objectives similar to with respect to biology, physics, and earth and space science (He & Ding, 2008; Tang, 2001). However, textbooks in these countries appear more colorful, having more illustrations, graphs, and pictures (Ding, 2000; Wang, 2004). They are also closely connected with new technology, student life, and social issues, making the content knowledge more practical. While most Chinese science textbooks are less colorful, text dominated, and lack of relevance to student daily life (Cai, 2001; Zeng, 1999). The research on comparative study is vigorous on the surface, but much of it seems to focus on foreign practices and is based on the translation of textbooks and journals. Little is done to study the curriculum as a whole and propose effective measures to change the actual Chinese science curriculum reality.

Comparison Study of Chinese and American Science Curriculum

Since the early 1980s, several worldwide comparative studies of science curriculum have been conducted including China and the USA. The main research institutes or researchers on these studies are the International Association for the Evaluation of Educational Achievement (IEA), a group of professors at the University of Michigan, Michigan State University and the University of California at Los Angeles (UCLA), the International Assessment of Educational Progress (IAEP), and Asia Society.

Most of these cross-national studies focus either on student achievement or education systems, and curriculum comes under study only as a factor associated by student performance or a component of education systems. Efforts specifically focusing on curriculum coherence are limited, two studies stand out as they brought curriculum coherence into public view, namely, the Second International Studies in Educational Achievement (IEA) study of Science Education (SISS) (Rosier, 1987; Rosier & Keeves, 1991) and 1995 Third International Mathematics and Science Study (TIMSS) study (U.S. Department of Education, 1997; Schmidt et al, 2001).

The Second IEA Science Study (SISS) was conducted between 1982 and 1986. SISS stressed student science achievement and its correlation in 23 participating countries. It included three student cohorts of 10-year-old, 14-year-old, and terminal secondary school students. Partly because of its large size, as well as lack of experience in large scale surveys, China restricted its participation to three cities of Beijing, Tianjin and Taiyuan. However, due to some unknown reason, no information on Chinese science curriculum was released in the publications of SISS study. The only channel to peek at Chinese science curriculum is through the studies on Hong Kong given that they all have Chinese as the majority population. According to the SISS study, Hong Kong at that time provided no science courses except biology to elementary students. Among 17 surveyed biology topics, the Hong Kong curriculum covered seven topics in contrast to the USA, where the aggregated curriculum covered 15 topics, indicating a wider range of science topics in the United States (Rosier & Keeves, 1991).

TIMSS is the largest and most ambitious international study of student achievement ever conducted and has been undertaken in a four-year cycles since 1995. The TIMSS 1995 study placed particular attention on curriculum coherence and focus, in contrast to TIMSS study in other years which exclusively emphasized student achievement. The 1995 study had 45 participating countries and regions including Hong Kong and the USA. Both the American elementary science content standards and textbooks examined in TIMSS 1995 are characterized as containing too many discrete, superficial and repetitive topics indicated by the number of topics in science textbooks, distribution of teachers' attention given to topics and organizations of topics (U.S. Department of Education, 1997). The number of TIMSS framework topics intended by each country varies greatly. The American curriculum included 79 topics in their science standards and 78 in textbooks, while in striking contrast, Hong Kong only included 22 topics in its standards and 37 in textbooks (Schmidt et al, 2001).

The review of literature highlighted two weaknesses of existing studies. First, both the 1995 and SISS studies were conducted more than a decade ago, information from which has been outdated as the participating countries continuously devoted to improving science education. This raises a need to undertake a new study which could reflect the latest condition of science curriculum in each country. Second, what makes a new comparative study between the USA and China even more urgent is the inherent distinction of science education between Hong Kong and mainland China. Hong Kong was colonized by the United Kingdom for over one hundred years. Its education system is virtually transplanted from the European system; this is very different from Mainland China which features a typical Eastern culture. In this view, science curriculum of Hong Kong manifested in SISS and TIMSS 1995 study cannot represent the case of mainland China and therefore a study of science curriculum targeting on mainland China is desirable.

In summary of the literature review, there is a need for a comparison study on science curriculum coherence between Mainland China and USA due to the importance of science curriculum coherence, the urgency to improve the current status of science curriculum, limitations of existing studies and the growing ties between Mainland China and the USA.

CHAPTER III

METHODOLOGY

Method Introduction

General Topics Trace Mapping (GTTM) is applied in this study to compare the science content standards in the USA and China in terms of curriculum coherence. Given that the study of curriculum has proceeded almost exclusively by means of qualitative studies, the GTTM provides a more complex and comprehensive path to view curriculum both qualitatively and quantitatively.

In brief, this study will first generate the aggregate elementary science content standards for each country using GTTM technique, and then compare the composited science content standards between China and the USA meanwhile taking the composited TIMSS international science framework as reference standards.

Data Collection

Science Content Standards Selection

The first step in creating a GTTM chart is to identify topics intended at each grade level in each country. However, the national science standards in both of the USA and China feature a clustering organization of science topics. The American *National Science Education Standards* (National Academy Press, 1996) articulate learning goals for elementary students by grade group of k-2 and 3-5. Similarly, science knowledge in China's *National Science Curriculum Standards* (Ministry of Education, 2001) is presented in the grade band of 3-6. This grouping of grades creates an ambiguity in ordering topics by each grade level. To avoid this ambiguity, state/provincial science standards that specify science standards by grade provide an alternative option for comparison.

To best capture the reality of elementary science content standards that are used across each country, this study selected science curricula from state/provinces with different levels of science achievement performance, that is, low, medium, and high elementary student science performance level. For the sake of convenient comparison with the international science frameworks, four state/province elementary science curriculum from each country are chose separately in consistent with number of the counties in generating the international science frameworks. Accordingly, the four states/provinces selected respectively for China and the USA turn out to be one state/province with high science achievement performance, two states/provinces in the middle, and one state/province at the bottom.

With regard to the USA, the four states were chosen according to the most recent student science achievement results of the National Assessment of Educational Progress (NAEP) investigation which took place in 2005 (http://nationsreportcard.gov/science_2005/s0106.asp). NAEP is the only continuing nationally representative assessment of what America's students know and can do in various subject areas. Based on forth graders' performance in science (total score), four states were identified with Virginia topping the list, Mississippi down at the bottom, and Texas and Indiana in between. As seen in Table 3.1, the average fourth-grade science total score for the 44 USA participating states is 149, ranging from the high of 161 to the low of 133. Virginia outperformed all its peer states by achieving the highest score of 161, Indiana rank 22nd and Texas 26th whose fourth grader's performance is around the average level, and Mississippi with the lowest score of 133 is down at the very end of the ranking list.

Table 3.1: Rank of Four Selected States by Fourth Graders' Total Science Scores in 2005 NAEP Study

	Fourth grader total science score	Rank
Virginia	161	1
Indiana	152	22
Texas	150	26
Mississippi	133	44

Source: The Nation's Report Card (Science).
http://nationsreportcard.gov/science_2005/s0101.asp?printver

In China, province corresponds to the state in the USA in light of administration level. However, currently China do not have science standards at the provincial level and the *National Science Curriculum Standards* (grade 3-6) (Ministry of Education, 2001) is the single standard for the nation. Therefore, it is infeasible to achieve the aggregate Chinese science curriculum by assembling science standards at provincial level.

A substitute for provincial science content standards to mirror the intended science curriculum at provincial level would be science textbooks developed by different provinces. In China, the <science> series (grade 3-6) published by the Chinese educational science press (2001) are the first science textbooks endorsed by the Chinese Ministry of Education as a national science curriculum. After that several provinces have designed and published their own elementary science textbooks. These textbooks are mainly circulated within their own provinces but sometime also adopted by schools in other provinces. They reflect the intention of individual provincial government for science education and more or less bear the mark of the unique local features such as culture, history, geography and topography. An examination of provincial elementary science textbooks will help generalize a science curriculum that reflects the intended elementary science knowledge in China.

At present there are eight elementary science textbook series available in China, including the national science textbook series and seven other science textbook series designed by seven different provinces respectively. In selecting four sets of representative science textbooks, the national science textbook series are identified first for two reasons. First, as described in above paragraph, this science textbook series is authorized by the Chinese Ministry of Education (MOE) and was first published in 2001 as the first trial science textbook since the 1999 basic education reform. To a great extent, it represents the intention of the central government for science education and provides a model for science textbooks at the provincial level. Second, this series has been adopted widely by schools across China compared to other science textbooks: it is used in approximately 150 districts in 24 provinces/cities (http://xxkx.cersp.com/kxjc/kjb/200601/283.html). In this view, the elementary science textbooks designed by the Chinese Educational Science Press greatly represent science knowledge current majority Chinese elementary students are learning and therefore was given the priority to be included in this study.

Due to the lack of a national assessment for elementary science performance in China, the selection of the other three science textbook series resorted to provincial elementary education condition which roughly reflects the elementary science education level of each province. Given the limited accessible information on China's provincial elementary education, the judgment on current provincial science education condition falls on two parameters: 2006 elementary student enrollment rate and 2006 provincial budgetary investment on elementary education (per student).

As shown in Table 3.2, the seven provinces sorted in descending order of elementary enrollment rate are Shandong, Jiangsu, Henan, Guangdong, Hunan, Hubei, and Hebei province. By provincial budgetary spending, provinces in descending sort are Jiangsu, Hebei, Guangdong, Shandong, Hunan, Hubei, and Henan province. Jiangsu province took the lead in both of the two arrays, and Guangdong province held a moderate position in both of the two orderings. These two provinces are thus identified as the sample provinces in this study representing excellent and moderate science education level.

The fourth province representing a poor science education condition is selected based on a slightly different consideration. Though either Hubei, Henan, or Hebei province could be an option for the fourth province given their low ranking in either one of the two orderings, Hebei province in stead of Henan or Hebei province was finally recruited in this study. This selection was made primary out of the consideration of representativeness. As seen in Table 3.2, the Hubei version is published in 2003, about 2-3 years earlier than its Henan and Hubei counterparts. Since 2003 the Hebei version science textbook has been piloted in over one hundred schools across 12 provinces

(Science Curriculum Development Team in Hebei Education Press, 2006). In this sense, the Hubei version science textbook are more widely used than the other two and could better represents science knowledge current Chinese students are expected to learn.

Table 3.2: Currently Circulated Chinese Elementary Science Textbook and the Elementary Education Condition in their Corresponding Publishing Provinces

Science Textbook	Publisher	Year Published	Provincial Elementary Enrollment Rate (%)	Provincial Budgetary Investment (RMB/Student)
Science (3-6)	Chinese Educational Science Press	2001	N/A	N/A
Science (3-6)	Jiangsu Education Press	2001	99.86	2670.33
Science (3-6)	Hebei Education Press	2003	99.41	1908.06
Science (3-6)	Henan Elephant Press	2003	99.86	1118.33
Science (3-6)	Guangdong Education Press	2003	99.72	1896.16
Science (3-6)	Qingdao Press, Shandong Province	2004	99.96	1781.66
Science (3-6)	Hunan Science and Technology Press	2005	99.53	1688.49
Science (3-6)	Hubei Education Press	2006	99.49	1395.55

Source: <2006 National Education Investment Statistics Report>, www.moe.gov.cn

Criterion for Topic Inclusion

After indentified the American states and Chinese provinces for the science curricula to be used in this study, the next step is to decide on a criterion for selecting science topics to be included in the GTTM chart. The TIMSS study (Schmidt et al, 2005) applied a criterion of three fourths to draw topics from the science curricula of the four top achieving countries. That is to say, only topics intended by at least three out of the four (75%) countries are included in the composite international frameworks.

However, this criterion creates a problem of too few topics represented at each grade level which causes an ambiguity in understanding the science curriculum. Take the USA for an example, with a three fourth (75%) criterion 25 topics were included in the composited science standards and 12 topics on average were intended for each grade level. When change the topic inclusion criterion to two out of four (50%), 30 science topics were embraced in the standards and 20 topics on average were intended for each grade level. The detail is seen in Table 3.3.

By comparison, more topics are drawn into the composite USA science content standards with a 50% criterion than that with a 75% criterion. The science curriculum formed with a 50% criterion appears more comprehensive and richer in respect to the number of topics for both the overall standards and each grade level. This is the same for the Chinese composite science standards. Accordingly, this study adopted the topic inclusion criterion of two out of four (50%) in stead of three fourths. This suggested that topics only common to at least two of the four states/provinces can be included in the composite science content standards.

Table 3.3: Number of Topics Included in the Composite USA
Science Standards by Different Topic Inclusion Criteria

	Number of Topics in the science standards by a three fourth (75%) topic inclusion criterion	Number of Topics fin the science standards by a two fourth(50%) topic inclusion criterion
Grade 1	11	23
Grade 2	12	16
Grade 3	12	18
Grade 4	15	26
Grade 5	9	19
Total number of topics	25	30
Average number of topics per grade	12	20

Reference Standards

The aggregate GTTM chart for the four science top achieving countries serves as a model against which to compare the American and Chinese GTTM charts. Using a 50% criterion for the aggregate USA and Chinese science standards also means that the international model must also apply the same topic inclusion criterion to keep consistency across the three standards.

This change, however, raises the concern that adding more topics by change the original 75% topic inclusion criterion to 50% might alter the original structure of the model GTTM chart for top science achieving countries, and thus weaken it as a reference model. Figure 3.1 shows the reproduced international science standards with the new criterion of 50%. The generated pattern is a little bit distorted. One change is that a few topics stay in the curriculum longer due to their earlier introduction. For example, the topics of atmosphere, sound and vibration are intended to be taught all six years in the new international frameworks in stead of just two years in the original model. This brought the second change that four topics including magnetism, atmosphere, sound and vibration, and sensing and responding now become part of the buttress-like topics—essentially being intended in the curriculum for all six grades. However, as displayed in Figure 3.1, the basic upper-triangular structure still holds, the logical connection is obvious, and coherence is preserved. Therefore, this study applied a two fourths topic inclusion criterion on the international science frameworks which is used as a yardstick for compare the USA and Chinese science curriculum standards.

Data Analysis

By using the GTTM technique with a 50% criterion, topics common to at least two of the four selected state/provincial science curricula are draw into the composite science content standards for the USA and China respectively. The two generated science curriculum standards are displayed in two separate GTTM charts. For better judgment, the GTTM chart for the international science curriculum frameworks as a reference is imposed separately on the USA and Chinese GTTM chart. The degree of the overlapping between the topic mapping of the international science frameworks and that of the science standards for each country serves as an indicator to evaluate the coherence of each country's science curriculum. Three aspects pertaining to curriculum coherence are paid to particular attention in this study:

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
Organs, tissues			●	●	●	●	●	●
Physical properties of matter			●	●	●	●	●	●
Plants, fungi			●	●	●	●	●	⊙
Animals			●	●	●	●	⊙	●
Classification of matter			⊙	⊙	⊙	⊙	●	●
Rocks, soil			⊙	⊙	⊙	⊙	●	●
Light			⊙	•	•	•	●	●
Electricity			•	⊙	•	⊙	●	●
Life cycles			•	●	●	●	●	●
Physical changes of matter			•	●	●	●	●	●
Heat and temperature			•	●	●	●	●	●
Bodies of water			•	⊙	⊙	⊙	●	●
Interdependence of life					⊙	●	⊙	⊙
Habitats and niches				•	⊙	⊙	⊙	⊙
Biomes and ecosystems				•	⊙	●	⊙	⊙
Reproduction					⊙	•		⊙
Time, space, motion					●	●	●	●
Types of forces					⊙	⊙	●	●
Weather and climate				•	⊙	⊙	●	●
Planets in the solar system				•	⊙	⊙	⊙	⊙
Magnetism			•	•	•	●	●	●
Earth's composition						⊙	●	●
Organism energy handling						⊙	⊙	●
Land, water, sea resource conservation				•	•	⊙	⊙	●
Earth in the solar system					•	⊙	⊙	⊙
Atoms, ions, molecules						•	●	●
Chemical properties of matter					•	•	●	●
Chemical changes of matter					•	•	●	●
Physical cycles					•	•	⊙	●
Land forms						•	⊙	●
Material and energy resource conservation						•	⊙	●
Explanations of physical changes						•	⊙	⊙
Pollution						•	⊙	●
Atmosphere			•	•	•	•	⊙	⊙
Sound and vibration			•	•	•	•	⊙	⊙
Cells					•		⊙	⊙
Human nutrition						•	⊙	⊙
Building and breaking								●
Energy types, sources, conversions						•		●
Dynamics of motion								⊙
Organism sensing and responding			•	•	•	•		⊙

Figure 3.1: Science Topics Intended by TIMSS Top-achieving Countries with the Criterion of Two Fourth.

Source: Schmidt, W.H., Wang, H. C., & McKnight, C.C. (2005). Curriculum Coherence: an examination of US mathematics and science content standards from an international perspective. *Journal of Curriculum Studies*, 37:5, 525-559.

Note : Intended by half of the four countries •
Intended by three of the four countries ⊙
Intended by all of the four countries ●

Topic Inclusion

Topic inclusion refers to topics included in the science standards. In the GTTM chart, each row represents a specific topic intended in the curriculum, and each column indicates a specific grade level. Each dot in the chart indicates a specific topic intended at a particular grade. This study inspected the topic inclusion in two perspectives: 1) by looking at the overall rows, how many topics and what topics are intended in the elementary science standards of each country? 2) by looking at each column, how many topics and what topics are expected for each grade level in each country?

Topic Duration

Topics duration indicates the time for a topic staying in the science curriculum. In the GTTM chart, the "life" of a particular topic is represented by the total number of dots scattered in the row where the topic is labeled. The examination of topic duration addressed three aspects: 1) generally, by calculating the dots for each topic in the GTTM chart, what is the statistical frequency distribution of topic duration in the elementary science standards for each country? 2) Subsequently, what is the average topic duration for topics in the elementary science standards of each country? 3) How many and what topics are intended for all the years across the elementary level? In other words, what are fundamental topics that receive continuous attention in the elementary standards of each country?

Standards Structure

The dots distributed in the GTTM all together shaped a tracing map that illustrates the sequencing and connections among topics in the science standards. The examination of curriculum standards structure thus falls on the following questions: 1) what is the overall pattern of the elementary science standards of each country as displayed by the GTTM? Do they manifest an upper triangular structure similar to the international science benchmarks or a different one? 2) Do topics proceed from simple to complex level that is inherent in the discipline or in a different way? 3) Does the topic progression manifest any connections between the previous concepts and the following ones?

Limitation of Methodology

The research design of this study has several limitations. The first limitation concerns the alignment between the Chinese textbooks and standards. Given the lack of provincial science standards in China, this study selects science textbooks published by various provinces to reflect intention of provinces for science education. This alternative, however, creates the unexpected consequence regarding the representativeness of science textbooks for science standards. Standards define general learning goals while textbooks describe learning objectives at a more detailed and specific level. Contents included in science textbooks are not always aligned with those intended in standards. In other words, there might be a gap between the standard expectations and the actual content presented in textbooks. Therefore, representing Chinese science standards by selected science textbooks might affect the accuracy of research results.

The second limitation of this research design rests with the criteria for coherent science standards. Data analysis in this study is mainly based on the international science benchmarks against which science standards of the USA and China are examined. The international science benchmarks as a model example define the coherent science curriculum in this study. That is to say, the judgment on curriculum coherence of the USA and Chinese science curriculum is determined by the degree of consistency between the curriculum in study and the international benchmarks, the higher the consistency, the more coherent the science standards. However, one has to admit that there is far more than one coherent curriculum model beyond the international science benchmarks and accordingly the criteria for coherent science standards should not be confined to those only featured by the international science benchmarks. Therefore, the judgment on science standards coherence in this study does not take into account all kinds of factors concerning curriculum coherence and merely involves factors inherent in the international science benchmarks.

The third limitation of this study concerns the possible bias in data analysis. The purpose of this study is to place the USA and Chinese elementary science standards side by side to diagnose the strength and weakness of each science standards in terms of curriculum coherence. However, as a Chinese researcher, objectivity concerning the strengths and limitations of the Chinese science curriculum is difficult, and may lead to interpretations and conclusions that other researchers would find biased and prejudiced.

For example, it is widely accepted in China that Chinese basic education builds a much more solid knowledge foundation than its US counterpart. On the other hand, Chinese people think highly of the USA science curriculum as it demonstrates more flexibility and practicability. These perceptions may implicitly affect the objectiveness of this study on judging the strengths and weakness of the USA and Chinese standards.

CHAPTER IV

FINDINGS

The GTTM results of the international, USA, and Chinese science content standards indicate the following trends: the international science frameworks for elementary level have the largest number of science topics, followed by the Chinese elementary science content standards, and then USA elementary science content standards; As to topic duration, the USA standards intend a notable long time for topics to stay in the curriculum, the international frameworks intend a moderate topic duration, and the Chinese science content standards intend a striking shorter topic duration than the other two counterparts; The topic duration also suggests a within-topic progression in the international and USA standards in that topic stay in the curriculum for a long period with increasing sophistication level every time revisited, which is also referred as a spiral approach to subject; The upper triangular patter with three tiers in the GTTM chart for the Chinese science content standards suggested a logical progression among topics from simple to complex, while the laundry list pattern displayed in the GTTM chart of the USA science standards indicates loose connections among topics and lack of organization.

Figure 4.1, Figure 4.4, and Figure 4.7 separately lay out the topic mapping of the international elementary science frameworks, the aggregated American elementary science content standards, and the Chinese elementary science content standards. More details of the three aspects pertaining to curriculum coherence are discussed in the following sections.

International Elementary Science Benchmarks

Figure 4.1 represents the international elementary science benchmarks generated from the four science top achieving countries by the GTTM technique. In this GTTM chart, each dot represents a particular topic intended at a particular grade. The large dark dot indicates topics intended by all the four science high performance countries, the circled dot indicates topics intended by three of them, and the small dark dot indicates topics intended by two of the four countries. This is to say that only topics intended by at least half of the four countries are included into the international science frameworks. The dark line delineates the start grade of topics in the international science frameworks, which as a whole helps highlight the overall pattern of topic mapping in the GTTM chart.

Topic Inclusion

The international elementary science benchmarks (grades 3-6) contain 39 topics. The topics come from physics, biology, chemistry and earth science. The main themes in these 39 topics are matter, force and motion, energy type and resources conservation, life process, living system, earth systems, and earth patterns and change.

As seen in Figure 4.1, the primary level (grades 3 and 4) emphasize fundamental topics including characteristics of life process involving organs, tissues, plants, and animals, physical properties and changes of matter, light and electricity, magnetism, sound and vibration, heat and temperature, rocks and soil, and bodies of water.

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
Organs, tissues			●	●	●	●	●	●
Physical properties of matter			●	●	●	●	●	●
Plants, fungi			●	●	●	●	●	⊙
Animals			●	●	●	●	⊙	●
Classification of matter			⊙	⊙	⊙	⊙	●	●
Rocks, soil			⊙	⊙	⊙	⊙	●	●
Light			⊙	•	•	•	●	●
Electricity			•	⊙	•	⊙	●	●
Life cycles			•	●	●	●	●	●
Physical changes of matter			•	●	●	●	●	●
Heat and temperature			•	●	●	●	●	●
Bodies of water			•	⊙	⊙	⊙	●	●
Interdependence of life					⊙	●	⊙	⊙
Habitats and niches				•	⊙	⊙	⊙	⊙
Biomes and ecosystems				•	⊙	●	⊙	⊙
Reproduction					⊙	•		⊙
Time, space, motion					●	●	●	●
Types of forces					⊙	⊙	●	●
Weather and climate				•	⊙	⊙	●	●
Planets in the solar system				•	⊙	⊙	⊙	⊙
Magnetism			•	•	•	●	●	●
Earth's composition						⊙	●	●
Organism energy handling						⊙	⊙	●
Land, water, sea resource conservation				•	•	⊙	⊙	●
Earth in the solar system					•	⊙	⊙	⊙
Atoms, ions, molecules						•	●	●
Chemical properties of matter					•	•	●	●
Chemical changes of matter					•	•	●	●
Physical cycles					•	•	⊙	●
Land forms						•	⊙	●
Material and energy resource conservation						•	⊙	●
Explanations of physical changes						•	⊙	⊙
Pollution						•	⊙	●
Atmosphere			•	•	•	•	⊙	⊙
Sound and vibration			•	•	•	•	⊙	⊙
Cells					•		⊙	⊙
Human nutrition						•	⊙	⊙
Building and breaking								●
Energy types, sources, conversions						•		●
Dynamics of motion								⊙
Organism sensing and responding			•	•	•	•		⊙

Figure 4.1: Science Topics Intended by TIMSS Top-achieving Countries with the Criterion of Two Fourth.

Source: Schmidt, W.H., Wang, H. C., & McKnight, C.C. (2005). Curriculum Coherence: an examination of US mathematics and science content standards from an international perspective. *Journal of Curriculum Studies*, 37:5, 525-559.

Note : Intended by half of the four countries •

Intended by three of the four countries ⊙

Intended by all of the four countries ●

The middle grade levels (4 and 5) continue these topics while introducing new topics including interdependence of life, habitats and niches, reproduction, cells, force and motion, chemical properties and changes of matter, weather and climate, physical cycles, earth in the solar system. The third level (grades 5 and 6) is characterized by advanced topics with a continuing attention to the previous topics. These advanced topics include organism energy handling, human nutrition, explanation of physical change, atoms, ions, molecules, land forms, atmosphere, land forms, material and energy resource conservation, pollution, and energy types, sources and conversions. In conclusion, the international science benchmarks have different focus of science topics at different grade interval. As grade level increases, the difficulty level of the focal science knowledge and the scope of science knowledge increase as well.

Along with the increasing width and depth of knowledge at each grade level, the number of topics at each grade also demonstrates an increasing tendency. From grade three to six, the international science benchmarks intend 16, 21, 30, and 39 topics respectively, with an average of 26.5 topics, as indicated by the blue line in Figure 4.2.

In summary, the international science benchmarks involve four science disciplines (life science, earth science, physical science, and chemistry science). Each grade level emphasizes a particular set of science topics, and the width and depth of knowledge manifests an increasing trend by grades. These characteristics are also reflected in the following two aspects of topic duration and topic organization structure.

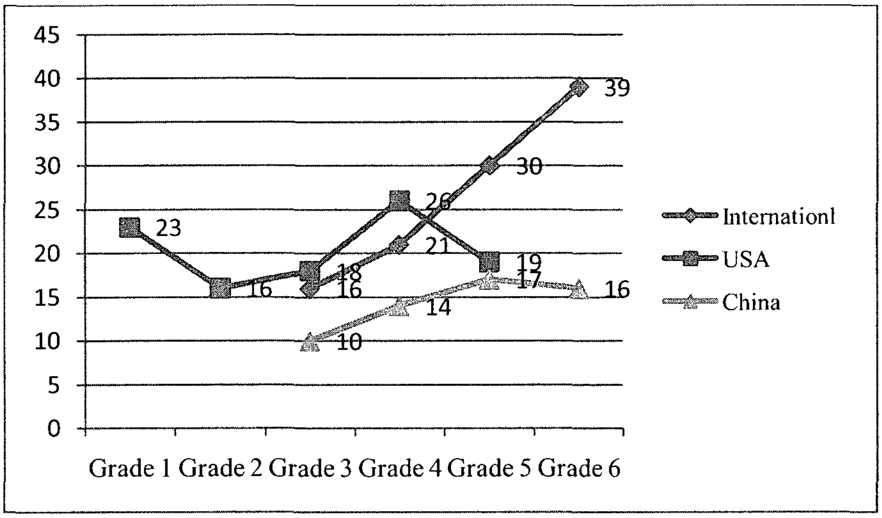


Figure 4.2: Number of Topics Intended at Each Grade Level.

Topic Duration

Topic duration refers to how many school years a topic is targeted to be taught in the science curriculum. In the international science benchmarks, topic duration varies from one year to all four years from grade three through six, with an average of 2.62 years. In detail as indicated in Figure 4.3, out of the 39 topics, 15 topics (38.5%) are intended to be taught four years, 5 topics (12.8%) three years, 8 topics (20.5%) two years, and 11 topics (28.2%) topics only one year. To add the first two figures up, 51.3% of the 39 topics is aimed for studying three or four years. Given that science course are set for four years from grade three to six in the elementary curriculum of the four science high performing countries, the large portion of topics receiving at lest three-year attention implies a within topic progression. In other words, the topic stays in the curriculum for a relatively long time and deepens from year to year, which is also referred as a spiral approach where the same topic is revisited at increasing levels of sophistication over a period of years (Harden, 1999).

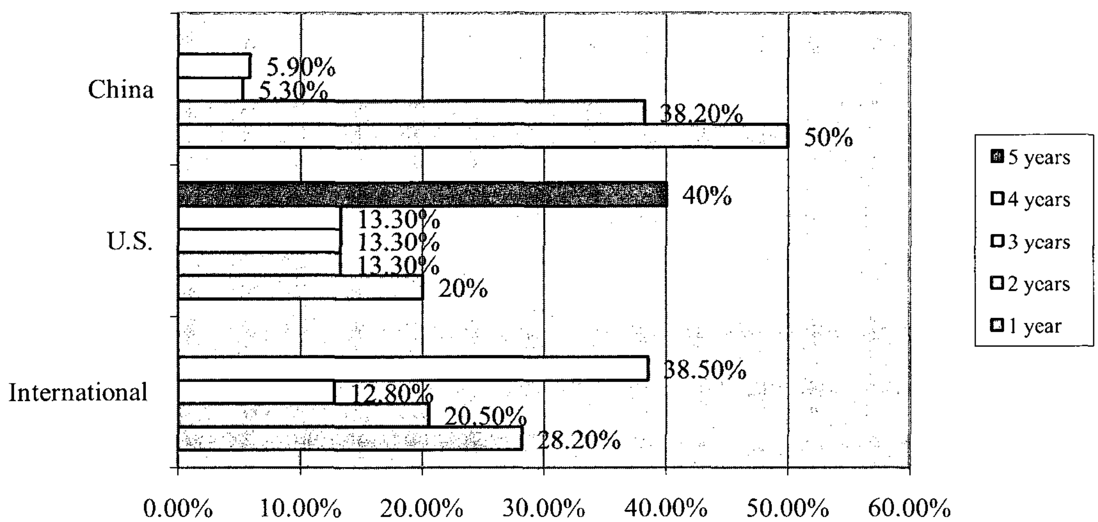


Figure 4.3: Percentage of Topics by Topic Durations in Each Science Standards.

This spiral approach also corresponds to the topic inclusion pattern of the international benchmarks. As described in above section, new topics are introduced into the international benchmarks with continuing attention to the prior knowledge. The previous topics coexist with the new ones in the science curriculum and are repeated with each successive encounter at a higher level of development of the topics.

The long duration of topics also implies great importance placed on topics that receive continuous attention. Topics receiving four-year continuous attention in the international science standards primarily focus on the study of plants, fungi, animals, organs and tissues, life cycles, physical properties and classification of matter, light, electricity, magnetism, rocks and soil, bodies of water, heat and temperature, and atmosphere. These topics form the knowledge base of the international benchmarks underlying the subjects.

Topic Organization Structure

As illustrated in Figure 4.1, generally the international benchmarks manifest an upper triangular appearance. This upper triangular structure consists of three tiers: the first tier resides in primary grades (grades 3 and 4) covering basic concepts such as plants, fungi, and animals; Grades 4 and 5 constitute the second tier which continues these same topics while introduced additional and more complex topics such as the ecology and environmental science; the higher grades (grades 5 and 6) form the third tier intending students to study chemistry and related topics such as atoms, ions and molecules for the first time. The topic sequencing and organization thus is clearly laid out in this chart. Topics proceed from simple to complex and the new topics build on prior ones, which virtually mirror the internal structure of the disciplines.

In summary, the description of topic inclusion, topic duration, and the topic organization of the international science benchmarks all together picture an intended science curriculum that focuses on certain science topics at each grade level, employs a spiral approach within each individual topic, and articulates topics from basic to complex level.

The American Elementary Science Content Standards

The GTTM chart generated for the USA elementary science content standards is displayed in Figure 4.4. Same as the international science benchmarks, the large dark dot indicates topics intended by all the four selected USA states, the circled dot indicates topics intended by three states, and the small dark dot indicates topics intended by half of the states. The shading area in Figure 4.4 represents the international science frameworks same as displayed in Figure 4.1. The international science frameworks are imposed on the USA science standards to serve as a reference. The dark line highlights the start grade of topics in the international science frameworks. The green shading indicates topics covered in the international science benchmarks but not intended by the USA science standards. Findings revealed from the USA GTTM charts are stated below.

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Organs, tissues					
Physical properties of matter	●	●	◎	◎	●
Plant, fungi	●	●	●	◎	◎
Animal	●	●	●	●	◎
Classification of matter	◎	◎			◎
Rocks, soil	●	◎	◎	◎	◎
Light	●	●	●	◎	◎
Electricity				◎	
Life cycle	◎	◎	◎	●	
Physical changes of matter	●	●	●	●	●
Heat and temperature	◎			●	●
Bodies of water	●				
Interdependence of life	●	◎	●	●	●
Habitats and niches	●	◎	◎	◎	●
Biomes and ecosystem					
Reproduction				●	
Time, space, motion	●				●
Types of forces	◎		◎	◎	●
Weather and climate	◎	●	◎	●	●

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Planets in the solar system	●	●	●	●	●
Magnetism	●	●		●	
Earth's composition					
Organism energy handling				◎	
Land, water, sea resource conservation	●		◎	◎	
Earth in the solar system				◎	◎
Atoms, irons, molecules					
Chemical properties of matter					
Chemical changes of matter					
Physical cycles	●	●	●	◎	●
Land forms					
Material and energy resource conservation	◎	●	●	◎	
Explanations of physical changes					
Pollution	●		●		
Atmosphere					
Sound and vibration	●		◎	●	●
Cells				●	
Human nutrition					
Building and breaking				◎	
Energy types, sources, conversions	●	●	●	●	●
Dynamics of motion				◎	●
Organism sensing and responding					

Figure 4.4: Science Topics Intended at Each Grade Level in the Composite American Science Content Standards.

Note : Intended by two out of four states ●

Intended by three out of four states ◎

Intended by all the four states ●

Topic Inclusion

The American elementary science content standards for grade one through five is comprised of 30 topics. These topics come from physics, biology, and earth and space but not chemistry topics. It is undeniable that a few states in the USA intend chemistry knowledge for elementary science education such as California and Michigan states. However, as far as the four sampled states are concerned in this study, only the state of Mississippi intends chemistry knowledge at the elementary level, and this minority looses representativeness in the GTTM chart.

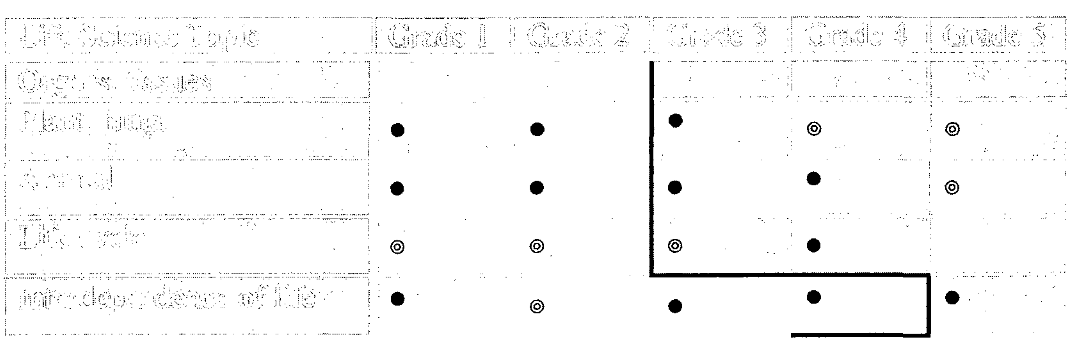
Among the 30 topics, 28 topics are common to the international benchmarks, and the other two American topics are building and breaking tied to earth science and dynamics of motion which surprisingly enters the international benchmarks in grade eight. Eleven topics are missing from the USA science standards compared to the international science benchmarks, as highlighted by green shadings in Figure 4.4.

The 28 commonly shared topics between the USA and international science benchmarks mainly concentrate on the descriptive aspects of the three science disciplines including physical properties and classification of matter, physical changes of matter, physical cycles, plant and fungi, animals, independence of life, habitats and niches rocks and soil, light, life cycle, weather and climate, and planets in the solar system. The 11 topics that only appear in the international elementary science benchmarks are mostly advanced topics introduced at higher grade levels (grades 5 and 6). These topics deal with organs and tissues, biomes and ecosystem, earth's composition, chemical properties of matter, chemical changes of matter, atoms, irons, and molecules, land forms, explanations of physical changes, atmosphere, human nutrition, and organism sensing and responding. In conclusion, the nature of the USA science standards seems to get little beyond the descriptive aspects of biology and geology, and there is also very little involvement of theoretical level in physics. For example, biology in the USA science standards emphasizes on structure and classification of animals and planet as compared to biomes and ecosystem in the international standards introduced from grade three. It is an effective way for learning to start with broad general knowledge which in Hirsch's (2001) view is "the best entrée to deep knowledge". A vivid description or an introduction of broad context of a topic helps students develop a sense of the whole concepts. Students cannot gain deeper understanding without having broad factual knowledge. However, piling up too many facts do not really add much to student understanding. To gain real insight into the concepts students also need to explore in depth a moderate number of specific ideas beyond the broad general knowledge. In this view, the American science standards are strong in providing a broad and intelligible knowledge base that is easy and interesting for students to learn, but on the other side fall short of details and in-depth study of the subjects.

For topics intended at each grade level, the American science standards contains 23, 16, 18, 26, and 19 topics from grade one through five respectively as indicated by red line in Figure 4.2, with an average of 20.4 topics which is about six topics less than the international benchmarks for each grade. An increasing trend in topic number is evident from grade two to four in the USA science standards suggesting growing scope of knowledge by grades, which is similar to the pattern in the international benchmarks. But in a different way grade one in the USA science standards contains obviously more topics than most of its subsequent grades and counts a high of 76.7% (23 out of 30) of all the topics in the standards. Besides, number of topics drops sharply from 26 in grade four to 19 in grade five, which is at odds with the routine that the higher grade level, the broader the knowledge covered. One possible account for the small number of topics at grade five is that students are exposed to more demanding science topics, which requires more time on each topic and therefore limits the total number of topics covered. However, a comparison of topics at grade four and five in the USA science standards does not show more advanced topics added at grade five, as can be seen in Figure 4.4. The other possible explanation for the unusual small number of topic at grade five is within-topic deepening of knowledge that the same topic continues over grades with more sophisticated aspect addressed, which requires more time for in-depth learning and accordingly the overall knowledge scope narrowed. However, an inspection of the American science standards does not indicate much increase of knowledge difficulty level at grade five compared to grade four. More often, the cases are just different aspects of the topics are addressed at grade five but without apparent increasing of sophistication level. Take the topic of heat and temperature as an illustration, the Indiana 's *Academic Standards for Science* articulates that fourth graders are expected to investigate, observe and explain that heat is produced when one object rubs against another, and describe things that give off hear such as people, animas, and the sun. At grade five students are supposed to investigate, observe, and describe that when warmer things are put with cooler ones, the warm ones lose heat and the cool ones gain it until they are all at the same temperature. The knowledge addressed in the two grades all falls on the descriptive aspects of the topic of heat and temperature. There is neither visible connection built between the two ideas nor any deepening of knowledge over grades. Therefore the conclusion can be achieved that the drop of number of topics at fifth grade has little to do with the enhancement of critical thinking or deep learning of topics.

A further look at topics at each grade level in the American standards reveals a lack of focus. As shown in Figure 4.4, the primary grades (grades 1 and 2) include not only fundamental concepts but also sophisticated ones that are not introduced in the international benchmarks until the advanced grades (grades 5 and 6) such as pollution, material and energy resource conservation, and energy types, source and conversions. In addition, grade five in the USA standards mainly deals with basic concepts, while gives little attention to advanced topics such as sound and vibration, energy types, sources, and conservation, and dynamics and motion.

The reorganization of topics in the USA science standards into three separate disciplines (biology, physics, and earth science) provides a more visual and explicit account for the lack of focus in the USA science standards. As seen in Figure 4.5, topics in each discipline are listed out in separate chart and the shading area indicates topics intended by the international science frameworks. The dark line indicates the start grade of the topic in the international science benchmarks. The green shadings represent topics intended by the international science benchmarks but not the USA science standards.



Life Science Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Habitats and niches	●	◎	◎	◎	●
Biomes and ecosystem					
Reproduction				●	
Organism energy handling				◎	
Human nutrition					
Organism sensing and responding					

Earth Science Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Rocks, soil	●	◎	◎	◎	◎
Bodies of water	●				
Weather and climate	◎	●	◎	●	●
Planets in the solar system	●	●	●	●	●
Earth's composition					
Earth in the solar system				◎	◎
Physical cycles	●	●	●	◎	○
Land forms					
Atmosphere					
Building and breaking				◎	

Physical Science Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Physical properties of matter	●	●	◎	◎	●
Classification of matter	◎	◎			◎
Light	●	●	●	◎	◎
Electricity				◎	
Physical changes of matter	●	●	●	●	●
Heat and temperature	◎			●	●
Time, space, motion	●				●
Types of forces	◎		◎	◎	●
Magnetism	●	●		●	
Atoms, ions, molecules					

Physical Science Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Chemical properties of matter					
Chemical changes of matter					
Explanations of physical changes					
Sound and vibration	●		◎	●	●
Energy types, sources, conversions	●	●	●	●	●
Dynamics of motion				◎	●

Figure 4.5: Science Topics Intended at Each Grade Level by Disciplines in the Composite American Science Content Standards.

Note : Intended by two out of four states ●

Intended by three out of four states ◎

Intended by all the four states ●

It is apparent from the above three charts that the USA science standards present similar topics at each grade level. Most of these topics are introduced into the curriculum from early years and students are exposed to a blending of both simple and complex science topics. In the international science benchmarks, a pattern of increasing topic sophistication level is readily recognized as new topics build on the old ones. However, such pattern is hard to identify in the USA science standards. Topics in the USA standards are more like a pile of jigsaw puzzles pieced together without inherent logic.

Based on the above observations, three characters pertaining to topic inclusion of the American elementary science standards can be generated. First, the USA standards lack of appropriate focus. Each grade level addresses similar science topics and the focal science topics for each grade are not clear. Second, the USA standards present less rigor and challenge in comparison with the international science benchmarks. The USA standards consist of less advanced topics than the international benchmarks and weighs more on descriptive than on theoretical and explanatory aspects of science. Third, the topic sequencing in the USA standards lacks of proper order either in light of topic number or the difficulty level of science content at each grade level. In the international science benchmarks, the higher the grade level, the more science topics covered, and more advanced topics intended. However, these trends are not evident in the USA science standards.

Topic Duration

The USA science standards intend longer duration of topics than the international science benchmarks. On average, topics in the USA standards receive a continuous attention of 3.4 years, varying from one year to all five years through elementary level. Out of the 30 topics, 12 topics (40%) are intended to be covered full length of elementary education, 4 topics (13.3%) four years, 4 topics (13.3%) three years, 4 topics (13.3%) two years, and 6 topics (20%) only one year, as illustrated in Figure 4.3. By adding together the first three figures, about 66.7% topics are intended for at least three years which is obviously higher than that (50.3%) in the international benchmarks. This long duration of topic coverage implies a spiral approach within individual topic, that is, topics appear in the curriculum over several years with different level or aspect addressed each time revisited.

An investigation of the sampled state science standards in this study confirms this spiral approach. Take the topic of physical properties of matter in the *2010 Mississippi Science Frameworks* for an example. Grade one starts engaging students in observing the concrete and real life phenomena---water evaporation into air and freezing to ice; Grade two successively introduces the fundamental concepts of gas, liquid and solid as three states of matter; Grade three further leads students to explore and identify physical changes that transform matter between the three different states, including melting, freezing, boiling, evaporation, and condensation. A brief concept flowchart is seen in Figure 4.6.

One feature of the spiral approach in the USA science standards is its slow ascending in the difficulty level of topics. In other words, little depth is added at higher levels each time the topic is encountered. It is desirable to teach a spiral curriculum given its nature of interlocking ideas and skills together. Besides, the gradual progression of topics breaks topics into small pieces so as to facilitate students to develop profound understanding of concepts.

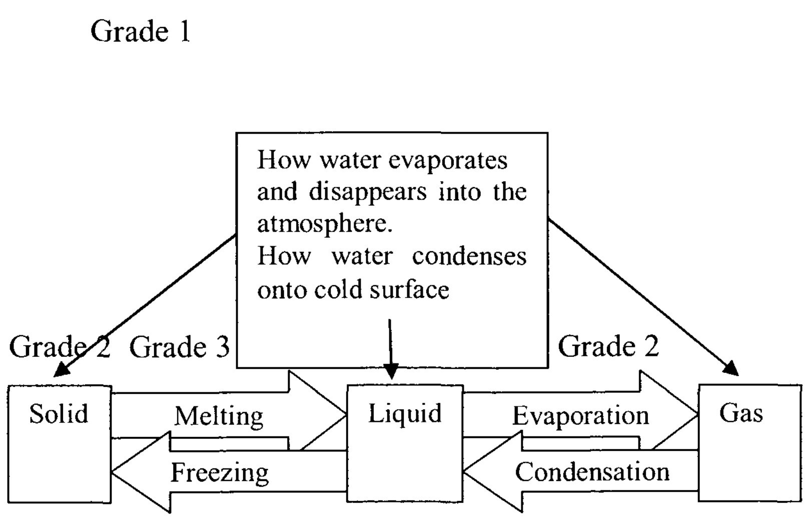


Figure 4.6: Concept Flowchart of Physical Properties of Matter as An Example of Spiral Approach to Subject.

Source: Mississippi State Board of Education, 2008. 2010 Mississippi Science Frameworks.

On the other hand, the slow progression of topics also risks superficial treatment of topics which consequently might lead to a shallow and loose curriculum. As demonstrated from Figure 4.6, the learning of the topic on physical properties of matter does not see much growth in topic sophistication level over three years. What is more, addressing a topic over pretty long time makes the topic appear jumping all over the curriculum without ever coming to a comprehensive picture. This at worst even destroys the inherent structure and cohesiveness of the discipline that makes both teaching and learning difficult.

With regard to the 12 topics that receive ongoing attention through five years in the USA standards, six of them (50%) are also paid continuous attention in the international benchmarks. These six topics are physical properties of matter, plant and fungi, animal, rocks and soil, light, physical changes of matter. The other six topics in the USA standards are interdependence of life, habitats and niches, weather and climate, planets in the solar system, physical cycles, and energy types, sources and conversions. Though these six topics do not stay all the time in the international benchmarks, most of them receive continuous attention for two or three years. This indicates that the USA standards and the international benchmarks share similar knowledge foundation.

In conclusion, the USA science standards intend a longer duration for topics than the international benchmarks. This long topic duration reveals a spiral approach to science subjects. However, this spiral approach differs from that in the international science benchmarks by spending significantly longer time on topics. Topics receive continuing attention through the USA science standards constitute knowledge foundation for the elementary science course. These fundamental science topics are also attached great importance in the international science benchmarks, suggesting that the USA science standards share similar knowledge base with the international science benchmarks.

Topic Organization Structure

The overall structure of the tracing map for the USA science standards is shown in Figure 4.4. Topics are scattered across grades which substantially differs the international benchmarks where an upper triangular structure is clearly laid out. The upper triangular structure essentially reflects a sequence of topics that is logical and reflective of the internal structure of the science disciplines undergirding the science curriculum. This apparently is not true in the USA standards. In the USA science standards, it is hard to identify a clear topic sequence that mirrors the inherent structure of the subject matter. For example, the knowledge of types of forces is the basis for understanding magnetism and further the knowledge of earth in the solar system, however, in the USA standards these three topics are introduced the same time at grade one.

Another angle to examine the USA science standards structure refers to the overlapping degree of the topic tracing maps between the USA science standards and the international science benchmarks. As the international benchmarks serve as a model example, the matching degree actually indicates the extent to which the topic placement in the USA science standards is identical to that in the international benchmarks. The total 102 dots in Figure 4.4 represent topics intended in the USA elementary science standards. Each dot indicates a particular topic at a particular grade level. Among these dots, only 40 (39.2%) hits within the silhouette of the international benchmarks, indicating that 39.2%

of the topics in the USA standards are intended to be taught about the same time as the international benchmarks do. The rest dots (60.8%) all hit before the outline of the international benchmarks, suggesting an earlier introduction of these topics. The 60.8% also highlights a great difference between the USA science standard and the international benchmarks in terms of topic placement.

Disagreement might arise here that science course in the USA usually starts from grade one through five, compared to grade three to six when science is set up in the four science top achieving countries. The different timeframes of science course inevitably creates the mismatch of topic placement between the USA and international science standards. Given this dispute, this study closely examined topics intended at grade 3-5 where the two standards overlap. In this overlapping stage of grade 3-5, there are 63 topics included in the USA science standards as indicated by dots between the column of grade three and grade five in Figure 4.4. Among the 63 dots, 40 are superimposed by the topic tracing map of the international benchmarks, suggesting that 63.5% (40/63) of topics in the USA standards are intended to be taught at the same grade as those in the international benchmarks. The remaining 36.5% (23/63) topics all fall in front of the outline of the international benchmarks, implying an earlier introduction of these topics in the USA standards than in the international benchmarks. Compared to the previous figure of 60.8% that indicates the discrepancy of topic placement between the overall USA and international standards, 36.5% clearly suggests less divergence between the two standards. However, the 36.5% still indicates a noticeable mismatch between the two standards and therefore previous claim still holds that USA science standards considerably differs from the international benchmarks in terms of topic structure.

In summary, the examination of topic structure of the USA science standards reveals a significant difference from the international science benchmarks. Topics of the USA science standards are in a more scattered sequence. Later topics appear disconnected with the previous ones. The overall structure of the USA science standards is like building a wall with a brick here and a brick there with the expectation that a complete wall will result. However, the lack of inherent logic and cohesiveness does not ensure this will happen.

The Chinese Elementary Science Content Standards

The GTTM tracing map of the composited Chinese elementary science standards generated from four selected provinces are displayed in Figure 4.7. As with the international and USA science benchmarks, the large dark dot in the figure indicates topics intended by all the four selected Chinese provinces, the circled dot indicates topics intended by three provinces, and the small dark dot indicates topics intended by half of the provinces. The shading area in Figure 4.7 represents the international science frameworks. The dark line highlights the start grade of topics in the international science frameworks. The international science frameworks are imposed on the Chinese science standards to serve as a reference. The red shading indicated topics intended in the international science benchmarks but not the Chinese science standards. Following are findings revealed from the Chinese GTTM charts.

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Organs, tissues				◎		
Physical properties of matter			●	◎		
Plant, fungi			●	◎	●	◎
Animal			●	◎	●	◎
Classification of matter			◎			
Rocks, soil			◎	●		
Light					●	
Electricity					●	
Life cycle			●	◎		
Physical changes of matter			●	◎		●
Heat and temperature				●	●	
Bodies of water			●			
Interdependence of life					◎	◎
Habitats and cycles					◎	◎
Biomes and ecosystem						●
Reproduction					●	
Time, space, motion				◎		
Types of forces				◎	●	
Weather and climate			●	◎		
Planets in the solar system					●	●
Magnetism			●		●	
Earth's composition						
Organism energy handling						
Land, water, sea resource conservation						◎
Earth in the solar system					◎	●
Atoms, ions, molecules						
Chemical properties of matter						◎
Chemical changes of matter						◎
Physical cycles					◎	
Land forms					◎	

Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Material and energy resource conservation						◎
Explanations of physical changes						
Pollution						
Atmosphere						
Sound and vibration				◎		
Cells						◎
Human nutrition				◎		●
Building and breaking					●	
Energy types, sources, conversions					●	◎
Dynamics of motion				●	●	●
Organism sensing and responding						

Figure 4.7: Science Topics Intended at Each Grade Level in the Composite Chinese Standards.

Note : Intended by two out of four provinces ●

Intended by three out of four provinces ◎

Intended by all the four provinces ●

Topic Inclusion

The Chinese science curriculum as shown in Figure 4.7 includes a total of 34 science topics for elementary students from grade three through six, involving four disciplines of physics, biology, earth science and chemistry. Among the 34 topics, 32 topics are in common with those in the international benchmarks, and the other two topics are building and breaking in earth science, and dynamics of motion. There are seven topics missing from the Chinese science standards in comparison to the international benchmarks. These seven topics are earth's composition, organism energy handling, atoms, irons, and molecules, explanations of physical changes, pollution, atmosphere, and organism sensing and responding, as highlighted by red shadings in Figure 4.7. Most of these seven topics demand higher level thinking and set forth at higher grade level in the standards. In this view, the Chinese standards include fewer advanced topics than the international benchmarks. However, in comparison with the American standards, the Chinese standards encompass more complex topics such as biomes and ecosystem, dynamics of motion, chemical properties and changes of matter, which suggests a deeper exploration of science than the American standards.

A closer inspection of the grade-specific science topics in the USA and Chinese also confirmed that the Chinese science curriculum demonstrates more in-depth learning than its USA counterpart. Grade four, as an illustration, intends introduction of electricity in both the USA 2010 Mississippi State Science Framework and the Chinese <Science> textbook published by Chinese Educational Science press (1999). In the Mississippi science framework, students at grade four are expected to understand parts of an electric circuit and resulting actions when circuits are opened or closed. In comparison, the topic of electric circuit in the Chinese <science> textbook for fourth grade involves a whole array of related ideas that take one unit to finish. The first lesson in the unit starts engaging students in observing the light bulb in an electric circuit, the second lesson introduces the basic components of an electric circuit. Next in the third lesson students are divided into groups to diagnose an electric circuit with problems and fix it, and in the last lesson students are exposed to the more demanding concept of series circuit and parallel circuit through discussing the difference and similarities of the two types of circuits in group activities.

The comparison of topic presentation pattern between the USA and Chinese science standards reveals a stress on academic knowledge as well connections among ideas in the Chinese science standards. Chinese students are exposed to more information about a topic than their American peers of the same grade. The way knowledge unfolds in the Chinese science standards helps group the subordinate ideas under a general topic together and delineate a systematic picture which promises a better grasp of knowledge for students. However, throwing out a bunch of ideas all at once also raises the concern of academic overload on students. Students might not be able to take in all these information within just several lessons. The intensive learning on subject matter also likely divorces the curriculum from reality and suppresses student interests and creativity.

With regards to number of topics at each grade level the Chinese curriculum covers 10, 14, 17, and 16 topics respectively for grade three to six, on an average of 14.25 topics, as indicated by the green line in Figure 4.2. It is apparent that the Chinese science standards contain much fewer topics for each grade than both the international and USA science standards. The number of the topics at each grade level in Chinese science standards only counts for 50%~70% of that in the international and American standards. This is partly due to the elaboration on topics once the topic is introduced in the Chinese science standards. Since each topic takes a relatively long time, the overall number of topics covered at each grade is therefore limited given the confined school time. The small number of topics for each grade level benefits a focused curriculum that helps learners easily recognize core concepts and conduct deep study. However, an unexpected consequence of such a curriculum is a narrow knowledge foundation which confines learners' horizon. Being aimed to provide students a general perception upon physical setting, society, and technology, a narrow science curriculum merely concerning science subjects apparently is insufficient to fulfill such vision.

The number of topics for each grade level in the Chinese science standards also manifests an increasing trend which is similar to the international standards. This implies a growing scope of knowledge as each subsequent grade level adds new topics into the curriculum.

On closer inspection, one finds that the lower level grades (grades 3 and 4) in Chinese science standards primarily focus on characteristics and classification of living organism and matter, and force and motion. The middle level grades (grades 4 and 5) continue most of these topics while introducing more complex concepts including interdependence of life, habitats and niches, earth/space system, and energy types and conservation. The higher level grades (grades 5 and 6) shift in focus from more descriptive to more theoretical and explanatory aspects of sciences. Topics at this stage include some of the previous fundamental concepts and a large portion of advanced concepts such as chemical properties and changes of matter, material and energy resource conversation, and cells. These observations reveal a topic progression pattern from simple to complex as well as different focus of science content by grades in the Chinese science standards.

A reorganization of topics in the Chinese science standards into three separate science discipline also confirms the above assertion that each grade level in Chinese science standards focuses a particular set of topics and introduces topics from basic to advanced level. Figure 4.8 presents topics expected for Chinese elementary students in each discipline, with corresponding part of the international benchmarks imposed on each chart as defined by the shading areas. The red shadings represent topics intended in the international science benchmarks but missing from the Chinese science standards.

Life Science Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Organs, tissues				◎		
Plant, fungi			●	◎	●	◎
Animal			●	◎	●	◎
Life cycle			●	◎		
Interdependence of life					◎	◎
Habitats and niches					◎	◎
Biomes and ecosystem						●
Reproduction					●	
Organism energy handling						
Cells						◎
Human nutrition				◎		●
Organism sensing and responding						

Earth Science Topics	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Rocks, soil			◎	●		
Bodies of water			●			
Weather and climate			●	◎		
Planets in the solar system					●	●
Earth's composition						
Earth in the solar system					◎	●
Physical cycles					◎	
Land forms					◎	
Atmosphere						
Building and breaking					●	

Physical Science Topics	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Physical properties of matter			●	◎		
Classification of matter			◎			
Light					●	
Electricity					●	
Physical changes of matter			●	◎		●
Time, space, motion				◎		
Types of forces				◎	●	
Magnetism			●		●	
Atoms, irons, molecules						
Chemical properties of matter						◎
Chemical changes of matter						◎
Explanations of physical changes						
Sound and vibration				◎		
Energy types, sources, conversions					○	◎
Dynamics of motion				●	●	●

Figure 4.8: Science Topics Intended at Each Grade Level by Disciplines in the Composite Chinese Science Content Standards.

Note : Intended by two out of four states ●

Intended by three out of four states ◎

Intended by all the four states ●

The topic progression pattern reflected from each chart in Figure 4.8 is consistent with what is found in the overall Chinese science standards. Focal topics at different grade level vary. The primary levels primarily target on basic topics, and the higher levels include more advanced topics. A trend of increasing difficulty level of content knowledge by grades is recognized in these charts.

In summary, the Chinese elementary science standards bear the following characteristics: first, it involves biological, physical, chemical, and earth and space science which is same as the international benchmarks; The Chinese elementary science standards share most its topics with the international benchmarks, but intend fewer advanced topics. However, in comparison with its USA counterpart, Chinese science standards include more demanding topics. Second, the Chinese science standards intend intensive study of topics by presenting the subordinate ideas all at once in contrast to its USA counterpart that completes a topic over several grades. Third, the Chinese elementary science standards include significantly fewer topics at each grade level than both the international and American standards, which mainly attributes to the long time duration allocated on each topic. Last but not the least, each grade level in the Chinese science standards emphasizes a particular group of topics that can be readily identified by readers which contrasts to the USA science standards where focal knowledge for each grade level is hard to recognize from the blend of basic and sophisticated topics.

Topic Duration

The Chinese science standards intend remarkable shorter topics coverage duration than both of the international and USA standards. The average time spent on completing a topic in the Chinese standards is 1.68 years, varying from one year to all four years. As shown in Figure 4.3, out of the 34 topics only two topics (5.9%) are intended for all four years from grade three through six, two topics (5.9%) three years, 13 (38.2%) topics two years, and 17 topics (50%) only one year,. In total, only 11.8% of the topics receive continuous attention of at least three years, which forms a striking contrast to both of the international benchmarks and USA standards. As a result, the spiral approach disappears in the Chinese science standards, instead, the way topics unfolded more resembles that in the international mathematics standards where topics are seldom revisited once introduced. Consequently, knowledge foundation is hard to identify by topic duration in the Chinese standards due to short stay of topics.

The short topic duration essentially mirrors the way topics are delivered in the Chinese science standards. As discussed above, Chinese science standards chunk a set of related ideas together and present them all at one time, which reduces the whole time span on the topic. A closer inspection of the sampled Chinese science textbooks also confirms this inference. Take the same topic of physical properties of matter for an instance, in the USA Mississippi state science frameworks as aforementioned this topic is expected to be taught in three consecutive years from grade one through grade three, while in the science textbook series published by the Chinese Educational Science Press (2001), the same content is supposed to be taught in only one unit at grade three. As indicated in the Chinese science textbook, this unit is divided into five successive lessons: the first lesson addresses the concept of freezing by engaging students observing the phenomena of water freezing into ice; the second lesson highlights the concept of melting by having students observing ice melting into water; the following lesson engages students in the phenomena of emergence of water drop on the glass filled with ice so as to reach the concept of condensation; the fourth lesson then focus students on the transformation between water and water vapor where the concept of evaporation is obtained; and the fifth lesson serving as a review wraps up the three states of matter and natural phenomena involving the transformation between the three states. The lesson flow of this unit is displayed in Figure 4.9 below.

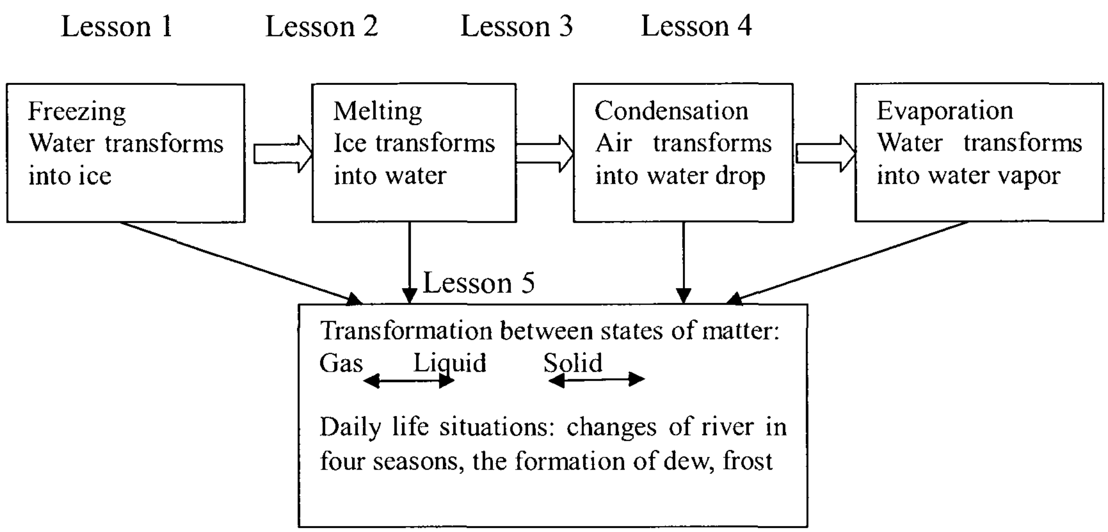


Figure 4.9: Lesson Flow of the Unit of Physical Properties of Matter in Chinese Science Textbooks.

Source: Chinese Educational Science Press, 2001.

Topic Organization Structure

In contrast to the USA standards, the GTTM display of the Chinese science standards is highly consistent with the international benchmarks. The basic upper triangular structure with three tiers is visible in Figure 4.7. The first tier, covered in grades 3-4, includes an emphasis primarily on description of matter, plants, animals, and the earth, including topics such as physical properties of matter, plant, fungi, animal, classification of matter, rocks, soil, life change, and physical change of matter. The third tier, covered in grades 5-6, consists primarily of advanced concepts that require certain theoretical foundations and critical thinking skills. Topics intended at this stage include planets in the solar system, earth in the solar system, chemical properties of matter, chemical change of matter, material and energy resource conservation, cells, energy types, sources, conversions. Grades four and five serve as an overlapping transition with continuing attention to the primary topics in the first tier as well as an introduction to the more complex and abstract concepts in the third tier. Topics intended in this middle tier include heat and temperature, time, space and motion, types of force, sound and vibration, dynamics of motion. Therefore, the upper triangular structure essentially is a reflection of topic sequencing from simple to complex that is in line with the inherent logic of the disciplines.

Another way to examine the structure of the Chinese science standards is inspecting the overlap degree between the Chinese and international science benchmarks which actually indicates the consistence in topic placement between the two standards. Out of the 57 dots that define the Chinese standards in Figure 4.7, 47 (82.5%) fall inside the outline of the international benchmarks, which means 82.5% of topics in the Chinese science standards are expected to be taught about the same time as those in the international benchmarks, suggesting a high consistence of topic arrangement between the two standards. The rest 10 topics (17.5%) are all set before the contour of the international benchmarks which indicates an earlier introduction of these topics in Chinese science standards.

However, the Chinese science standards distinguish from international benchmarks in missing out the "buttress" part which is defined by topics that continue through all the grade level. This is primarily due to the short topic duration in the Chinese standards. As aforementioned, only two topics in the Chinese standards are taught through the elementary stage, and most topics are only targeted for one or two years.

In conclusion, the Chinese standards display an upper triangular structure with three tiers similar to the international standards. This structure implies a logical organization of science topics with increasing sophistication level by grades. However, the Chinese science standards do not have the "buttress" part due to short topic duration.

Summary

The above examination on curriculum coherence in three perspectives of topic inclusion, topic duration, and topic organization structure reveals both the commonalities and differences between the international elementary science benchmarks, the USA elementary science content standards and the Chinese elementary science content standards, as listed out, in Table 4.1.

In brief, the USA and Chinese elementary science standards form a stark contrast: a long list of topics vs. a small number of topics at each grade; an average of 3.4 years long topic duration vs. an average of 1.68 years remarkably shorter topic duration; address a topic over a several years vs. chunk together related ideas under a topic and expose to students once a time; a lack of logical sequencing of topics vs. a building of topics upon the inherent logic of the discipline; a scattering display of topic mapping vs. a hierarchical structure for topic tracing. To sum it up, the USA science standards are characterized of broad, shallow, flat, and scattered, while its Chinese counterpart in comparison is narrow, deep, vertical, and hierarchical.

Table 4.1: Characteristics of International, USA, and Chinese Elementary Science Benchmarks/Standards

	International science benchmarks	USA Elementary Science standards	Chinese Elementary Science Standards
Disciplines involved	Biology, physics, earth and space science, and chemistry	Biology, physics, and earth and space science	Biology, physics, earth and space science, and chemistry
Total number of topics	39	30	34
Average number of topics for each grade	26.5	20.4	14.25
Average topic duration (year)	2.62	3.40	1.68
Topic delivery pattern	Spiral approach	Spiral approach	Cover a set of related ideas once a time
Overall structure	Upper triangular with three tiers	Scattered across grades	Upper triangular with three tiers

However, this does not mean the Chinese science standards are superior than the USA science standards or vice versa. As previously discussed, each standards bear with both strength and weakness. One-size-fits-all standards definitely are not really applicable. The following chapter further discussed the advantages and disadvantages of the USA and Chinese science standards and accordingly put forward suggestions for a coherent curriculum development.

CHAPTER V

DISCUSSIONS AND IMPLICATIONS

Discussions

Findings from the USA and Chinese science standards indicated that different aspects pertaining to curriculum coherence are actually interrelated. Achieving a coherent curriculum requires consideration on the balance between topic inclusion, topic duration and topic structure. Several relationships concerning these aspects are revealed from the standards analysis in chapter four and this chapter further elaborated these relationships.

The first relationship refers to curriculum width and depth. Take the USA science standards as an illustration, the standards place emphasis on a wide range of descriptive aspects of science, but lack a moderate number of challenging topics that require higher level thinking. Such topic inclusion favors a broad knowledge foundation that helps expand student horizon but on the down side falls short in providing students meaningful understanding of scientific concepts. However, depth in only a narrow field without breadth gives a parochial view of science and may also result in student aversion to science. Both of the two extremes should be avoided for a coherent curriculum that aims on both an abroad context of science as well as a few insights into science.

The second relationship involves topic width and topic focus. The interaction of the two factors is well presented by the USA and Chinese science standards. The USA standards encompass a broad range of topics for each grade level. For one thing this helps student develop common sense about science on a general level, while for another thing changing topics from day to day often leads students feel lost. They see lot bits of science in the book but do not perceive the "big" ideas or core concepts that they should pay most attention. In contrast, the Chinese science standards focus a moderate number of topics at each grade level which easily draws learners' attention and promotes lasting understanding.

The first two relationships also imply links between curriculum focus and depth. Only when the core topics are given priorities do they likely receive in depth treatment. Otherwise, students will only become overwhelmed with science facts by scratching the surface of topics in study but not have much appreciation on the topics.

The third relationship exists between topic duration and topic depth. The spiral approach as employed in both the international and USA science standards has gained great popularity in recent years for curriculum design. The basic idea behind the spiral approach is that children are not always ready to learn something. In stead of focusing for relatively long period of time on certain topic, a spiral curriculum revisits the concept periodically with different contexts and increasing sophistication throughout the curriculum. Addressing a topic over an extended period of time could facilitate student understanding by gradually expose students to different aspects of the concept. However, the other end of the spiral approach is taking lengthy time span over a topic which usually results a flat curriculum in that only little depth added each time the topic reappears, as is the case of the USA science standards. What is more, with extremely long periods spent over a topic, the inherent connection between these different aspects of the topic are undermined. The course can become a collection of bits and the relationships between these bits are not necessarily explored which rather hinders student understanding.

On the other hand, the Chinese science standards tend to exhaust a topic at once by drawing all its related ideas into a unit and then move to next new thing. Apparently the topic duration is great shortened, and the curriculum appears much vertical in that more in-depth information is delivered to students. Besides, clustering all the related ideas within several consecutive lessons facilitates building up connections among these ideas. While beyond these advantages arises the question that are students ready? When the course is packed with all these information, can student digest them all at once? Stuffed by academic knowledge do student interests and creativities get taken cared of?

Therefore, whether the curriculum employees a spiral approach or a much linear approach, the key issue is that appropriate time should be allocated on topic study. Excessive long time span leads to a shallow and superficial curriculum, while throwing out a bunch of ideas once a time on the other end might bring about an abstract and dry curriculum. Accordingly, topics should be given moderate time for study.

In summary, the curriculum topic inclusion, topic duration, and topic progression pattern intimately affect the curriculum depth, breadth, focus, rigor and structure. To create coherence in curriculum needs consideration of these influential factors involving topic inclusion, topic duration and topic sequencing pattern.

Implications

In retrospection, a coherent curriculum refers to the one that holds ideas together and presents students a whole story. It is not simply a collection of disparate parts or pieces of knowledge. A coherent curriculum has a sense of the forest as well as the trees, a sense of unity and connectedness, of relevance and pertinence. Based on the above discussion on factors affecting curriculum coherence, several implications can be generated from this study for future development of coherent science content standards:

First, for the overall curriculum, the topic inclusion should reflect the logical and sequential nature of knowledge in science. According to Tyler (Tyler, 1949), curriculum design generally build on three sources: the learners, cotemporary life outside the school, and the subject matter, as illustrated in the Tyler's model for selecting educational objectives in Figure 5.1. The student needs and interests, and the needs of society are important in formulating the curriculum, however, the subject matter itself is center to the curriculum. The subject matter is the carrier through which the potential student and social needs are embedded and conveyed. Therefore, regardless of the many potential curriculum development models such as learner-centered curriculum and problem-centered curriculum, the curriculum should be grounded in the understanding of the subject matter.

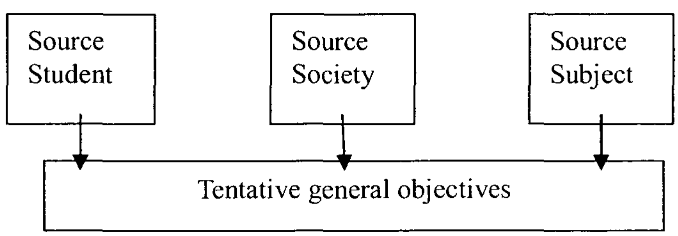


Figure 5.1: Curriculum Source for Selecting Educational Objectives.

Source: Tyler, R. W. (1949). Basic Principles of Curriculum and Instruction. Chicago: University of Chicago Press. P. 3-85.

An organization of science topics into a sequence that is logical and that leads to an unfolding of stories from which the subject matter derives will help make the logic of science transparent to student in order to develop a deeper understanding of science. An arbitrary collection of topics are difficult to learn and easy to forget, while a systematically conceptual mental schema is conductive for student to think beyond facts. This is to say, the curriculum flows from the most simple to the most sophisticated level, or in other words, the science curriculum should start from the most general an descriptive aspects to the most specific and theoretical aspects of these subject matter.

The identifying of topic organization first of all also provides the basis for selecting a limited number of science topics underlying the science subjects. Based on this broad story line, related ideas and other important parts are easily identified and integrated into the curriculum. In this view, such an organization principal is conductive to an explicit curriculum focus as well as connectivity. These big ideas play as "glue" in the curriculum that helps thread bits of information together. That is, elevating the curriculum from the accumulation of disconnected pieces to a level where it offers a unified sense of meaning.

Second, for each grade level, less, rather than more science topics should be focused. This principle actually bears on the depth versus breadth issue in curriculum development. A curriculum with many topics devotes less time on average to each and leads to insufficient development of topics. In other words, curriculum focus and rigor are mutually interacted. Focus of a fewer number of topics can be more meaning than a cursory glance at numerous topics. The sufficient specification of topics allow student to engage in more challenging tasks and develop in depth study which ensures the rigor of the curriculum. The emphasis on depth of understanding over breath of coverage shifts the pattern of "less is more" to "less is more".

Third, however, it is should be clarified that a balance should be made between curriculum breadth and depth. The curriculum can be so broad as to be superficial but also could conversely so profound as to limit learning. In either extreme learning is restricted. This issue is actually concerned with "when" and "where" the curriculum "focus" will be placed. There are a variety ways in deciding curriculum emphases at each grade level. Orlosky and Smith (1978) discussed three concerns in accomplishing the topic placement: student needs, subject matter, and child development. Student needs refers to interests of the learners. Students select what they want to know to study as the need arises. Concern on subject matter rests with the ordering of subject matter according to the prerequisite knowledge. The principle of child development emphasizes that the organization of knowledge should coincide with the different stages of the individual's development. These three aspects all together provide a basis for selecting appropriate topics for each grade level and balancing the width and depth of the curriculum. This does not conflict with the previous assertion that topics should be organized in light of the inherent structure of the discipline. The key point here is that for a curriculum with sufficient rigor as well as suitable breath, the learner's needs and interests and their mental development level should also be taken into account in standards development.

Fourth, the topic duration should be moderate. Lengthy topic duration tends to undermine the links among ideas. It also possibly leads to the superficial treatment of topics as each time only a little depth is added. However, the assumption that the time has come for students to learn something, they are going to grasp certain knowledge now and then move on to the next new concept ignores student diversity and personality. This is not to say that a spiral approach or a vertical approach to subject is inadvisable. The key point here is to have curriculum demonstrate appropriate rigor and open many doors to accommodate the array of student readiness and needs.

For Future Study

The comparison study between Chinese and US science curriculum has received considerable attention in recent years and this research left plenty room for future study. First, this study only set three criteria in evaluating curriculum coherence including topic inclusion, topic duration, and topic organization. These criteria are drawn out according to characteristics of the international science benchmarks and mainly concerned about the logic and sequence of subject matter. For future study, more factors could be considered so as to achieve a more comprehensive understanding of science curriculum coherence.

Second, a further look into factors that shape the current status of science curriculum in each country could be taken for future study. Findings of this study center on weakness and strengths of science standards regarding coherence in each country. Underneath these descriptive results, one could further dig into factors influencing the formation of science curriculum such as culture, politics, and history. Within a concrete and rich context, the understanding of science curriculum could be much deeper and more accurate.

Third, a team approach, composed of researchers from China and the United States, examining curriculum from additional regions of each country, and the evolution of curriculum standards in each country would provide greater insight into the student access to science content knowledge in each country. This team approach could lead to studies that minimize researcher bias and provide a more complete picture of elementary science education in each country.

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