

**The Quest for a Coherent School Science Curriculum: The Need for an Organizing
Principle**

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Abstract

Achievement test results from TIMSS and NAEP suggest that the performance of US students in science is not strong either in terms of international or national standards. Yet, the US is perceived as a world leader in standards-based and “hands-on” science reform. In this paper I argue that the major policy issue confronting the science community that addresses this apparent disconnect is the development of an organizing principle that would serve to limit the number of essential topics, subordinating some topics in science standards to others.

Furthermore, this organizing principle would weave the reduced set of topics into a sequence that is logical and that leads to an unfolding of a key story or stories in science that are intrinsically interesting to students and that provide the needed basis for understanding science by future literate citizens and not just the memorization of isolated facts to be forgotten as school finishes.

How can the US achieve a more coherent and rigorous school science curriculum? This I suggest is one of the most important policy questions before the science community. What more remains to be done? Careful sets of science content standards to guide standards-based reform have been developed. The National Science Foundation (NSF) has funded the development of science curricular materials based on these standards— materials available for implementation in US classrooms immediately.

Yet, ample evidence exists that the performance of US students is not strong either in terms of NAEP or in terms of international assessments such as TIMSS. On the National Assessment of Educational Progress (NAEP) only around 20 percent of US twelfth graders meet the National Governing Board's (NAGB) definition of proficiency in science. (NCES, 2001) In terms of international standards of excellence as evidenced by The Third International Mathematics and Science Study (TIMSS), the relative standing of the US declined from fourth to twelfth grade so that by the end of secondary school the US out performed only two other countries on a basic literacy test. (Schmidt, McKnight, Cogan, Jakwerth & Houang, 1999)

Standards, many argue, serve as a basis for educational reform. Science content standards have been set out by the American Association for the Advancement of Science (AAAS, 1993) and the National Research Council of the National Academy of Sciences. (NRC, 1996) They have been replicated and adapted by many individual states. They have been further replicated and adapted by many school districts within those states.

Through the multiple efforts of NSF, leading scientists and leading science educators, concrete curricular materials have been developed to provide immediately usable programs in US classrooms. These curricula exist. They can be adopted at any time by any state or district interested in their approach to science education. These efforts are innovative, state-of-the-art concrete embodiments of school science in curricular materials that are in fundamental accord with at least the national level of science content standards and with most state-level standards that largely reflect those broader standards.

Is there anything left to do to achieve more coherent, effective science education in US classrooms? Certainly there is no need to re-invent broad-based science standards. However, I believe there is a third task yet to be accomplished that lies beyond developing standards and developing curricular materials, a task the nature and importance of which only becomes clear through an examination of the science standards of other countries

What is missing is an organizing principle that would serve to limit the number of essential topics, subordinating some topics in science standards to others that play larger roles according to that organizing principle. What is missing is an organizing principle that weaves this reduced set of topics into a sequence that is logical and that leads to an unfolding of a key story or stories in science that are intrinsically interesting to students and that provide the needed basis for understanding science by future literate citizens and not just the memorization of isolated facts to be forgotten as school finishes.

Science learning opportunities are available through curriculum materials. Those opportunities have been keyed to specific topics in the content standards. What is missing is the integration of those science learning opportunities into a coherent vision of what all children

need to know about science. The coherence of that vision is more than just the thematically bundling of science topics and related learning opportunities. It is also a matter of expressing priorities, sequences, and conceptual links among topics and experiences both within disciplines and perhaps more importantly across the various science disciplines.

It is an approach that has been used by the highest achieving countries in TIMSS but not by the US. Analyses of the TIMSS curriculum data for the highest achieving countries in science makes clear what the result of such an organizing vision or principle is and the consequences for the US of not having such a vision or principle are also apparent. (Schmidt, et al, 2001; Schmidt, McKnight, Cogan, Jakwerth & Houang, 1999; Schmidt, Wang and McKnight, submitted for publication) I propose in this paper the need for the development of such an organizing principle that produces a set of internationally benchmarked science learning opportunities that establish priorities, sequences, and links among science content. This is not necessarily a matter of developing new standards or new materials but yet a third task lying beyond either of those two developmental tasks.

INTERNATIONAL BENCHMARKS

The Third International Mathematics and Science Study (TIMSS), the largest international study of science curriculum and student achievement ever undertaken, provides both a compelling impetus and an invaluable resource for reexamining, rethinking, and restructuring what we do in US science education. Against the international backdrop of TIMSS, the performance of United States students in science was much less outstanding than we might have liked, especially at eighth and twelfth grade. Correspondingly, our science curriculum seems to be less focused, less coherent, less rigorous and not as much connected around

significant disciplinary themes than what was demonstrated by the science curricula in the top achieving TIMSS countries.

Briefly, our students fell in their relative international standing in science achievement from second only to one other country at fourth grade to slightly above the international mean at eighth grade to performing better than only two countries, Cyprus and South Africa, on the end of secondary (twelfth grade) assessment of science literacy.

The TIMSS design enabled the measurement of the subtle effects of curriculum on learning. The major conclusion of a recent work that capitalized on the strength of this design, is that curriculum and the learning opportunities it structures are strongly related to learning (gain from seventh to eighth grade) at the country level and at the classroom level within the United States (Schmidt, et al. 2001). The picture of the US system that emerges from the TIMSS data is that the US does not have a coherent, focused and rigorous science curriculum that provides all students with a reasonable chance to learn to their potential (Schmidt, McKnight, Cogan, Jakwerth & Houang, 1999).

Such a result seems inescapable given the nearly 16,000 local school districts, each with its own version of science standards, and textbook manufacturers that strive to meet the standards of as many districts as possible that result in bulky, disconnected textbooks that contain few meaningful connections from one year to another. (Schmidt, McKnight & Raizen, 1997; Schmidt, McKnight, Cogan, Jakwerth & Houang, 1999; Valverde, Bianchi, Wolfe, Schmidt & Houang, in press)

Curriculum Focus

TIMSS found that the US intends the introduction in grades one through three of nearly seven times the number of science topics as are typically intended in the TIMSS countries that outperformed the US (See Display 1). This pattern is not atypical. Textbooks, content standards and teacher coverage all point to the same generalization; the US science curriculum typically covers more topics in most grades than did curricula in other TIMSS countries (Schmidt, McKnight, Cogan, Jakwerth, & Houang, 1999). Additionally, the collection of topics that are often taught in the US at a given grade level are nothing more than a large and mostly arbitrary collection of what the district, state, or even, in many cases, the teacher believes are interesting things for children to do in science.

Insert Display 1 about here

Display 2 indicates the number of topics considered in-depth at each grade. Not only does the US lag behind the countries outperforming it, it also lags behind the international average. In fact, through the first eight years of US schooling, no topics are intended for in-depth consideration.

Insert Display 2 about here

A logical inference from these two displays is that teachers never have time to do anything in depth and likely never reach the more demanding topics. In fact, this is what was observed: the nature of the US curriculum never seems to get much beyond the more descriptive aspects of geology and biology even by the end of eighth grade. There is also very little coverage of the fundamental concepts in physics and chemistry (Schmidt, McKnight, Cogan, Jakwerth, & Houang, 1999).

Biology, as an illustration, focuses on structure and classification as compared to biochemical processes which is what is more commonly found in the curriculum of other countries. For example, instead of concentrating on the parts of the eye, the emphasis in these countries is on the actual chemical processes by which the information carried by photons entering the eye are transmitted ultimately to the brain and interpreted there into what we see.

The TIMSS curriculum work has revealed that the US science curriculum lags behind that of other countries in challenge and rigor particularly during the middle school years—grades six through eight. In seventh and eighth grade in the TIMSS countries, and particularly in the top achieving countries, their curriculum stresses an in-depth consideration of more advanced topics such as chemical properties, chemical changes, as well as the fundamental topics of physics such as forces, atomic structure, light, and magnetism (Schmidt, Raizen, Britton, Bianchi & Wolfe, 1997).

Curriculum Coherence

Insert Display 3 about here

The concept of curriculum coherence as a critical policy issue is best illustrated in Display 3 which lists the science topics covered in the top achieving nations by grade level. (Schmidt, Wang, & McKnight, in preparation) The observed pattern of coverage of the topics over grade levels implies the presence of an underlying logical structure governing their assignment to specific grades. I further argue that the logical structure is inherent in the science disciplines themselves.

The following is an excerpted description of that logical structure:

Science is a combination of topics from these four different disciplines in elementary school, and even for middle school, in most countries. At the most theoretical level there are inter relational implications for knowledge across the disciplines. For example, the chemical basis (chemistry) of cellular activity (biology) includes the structural fact that living cells are comprised of quarks and electrons (physics) and that cells require certain minerals (geology) for their metabolic functioning (bio-chemistry). However, this does not imply a strict hierarchical ordering of topic coverage — especially when intended school coverage focuses more on the descriptive aspects of science.

One implication of this is that one might not expect *a priori* to have as hierarchical an ordering of science topics as for mathematics at least at the elementary and middle school levels. Another possibility is that topics might remain in the curriculum over an extended period of time as the intended coverage progressed from more elementary descriptive aspects to more theoretical and explanatory aspects; the progression of topics over grades then would reflect the more theoretical inherent logical structure.

The first of these two possibilities would imply more of an *ad hoc* structure across all of the science topics, one that might be formally structured within any one of the four disciplines but appear arbitrary when they were combined. The second possibility would likely manifest itself in an upper-triangular structure similar to mathematics, but one in which topics remained in the curriculum relatively longer reflecting not redundancy in intended coverage but a within-topic progression from more descriptive to more theoretical.

The data from the top achieving countries are consistent with this second possibility. The pattern of [Display 3] suggests that for science the key question is at what grade a topic enters the curriculum; once intended it essentially remains intended for all subsequent grades. The structure underlying [Display 3] reflects a "spiral" approach but one that is "staggered" over topics — that is, not all topics are spiraled from the same starting point.

There is, somewhat surprisingly, no agreed-upon science topic to be introduced in grades one and two among the A+ countries. Three of the four A+ countries do not have formal science as a part of their curriculum until grade 3. As a result of the spiral approach seen in [Display 3], most of the science topics introduced in the primary grades (grades three and four) continue in the curriculum through grade eight....They represent some of the most fundamental concepts of science: (1) the classification of living organisms and their systems — plants, fungi, animals, organs, tissues, and life cycles; (2) the classification of earth's physical features — rocks, soil, and bodies of water; (3) the classification of physical properties and changes of matter; and (4) different forms of energy — light, electricity and heat. These fundamental topics come from physics, biology and earth science and run through the first eight years of schooling (although for three of the A+ countries this coverage is not intended to begin until third grade).

...The lower middle grades (grades five and six) continue these same topics (with the exception of light and electricity) but introduce additional and more complex topics from each of the three sciences involved. Biology concepts presented in the primary

grades dealing with the classification of living organisms and their morphology provide a foundation for the study of (1) within-organism development and (2) the interaction of living organisms both with other organisms and with their environment. These latter topics mainly deal with what has been termed ecology and environmental science. Within-organism development focuses on the basic aspects of life cycles themselves and on reproduction.

Some earth science topics are also related to concurrent life science topics for the lower middle grades. While students are expected to learn how living organisms interact with their environment; supportive earth science topics for these grades are weather and climate and the composition of the earth. The solar system is the other major thrust of the earth science curriculum in grades five and six. In the physical sciences, building on the study of matter and energy begun in grades three and four, the top achieving countries intend their students to study magnetism, types of forces (such as gravity), and 'time, space and motion' at grades five and six. The latter two topics are conceptually related to the solar system topic included in these lower middle grades.

In the upper middle grades (seven and eight) the top achieving countries' science curriculum intends students to study chemistry and related topics for the first time. This includes atoms, ions and molecules; explanations for physical changes (including boiling, freezing and dissolving); chemical changes such as oxidation-reduction; and explanations for such chemical changes (e.g., covalent bonding and electron configurations). Physics topics also are included — sound and vibration; types and sources of energy such as potential and kinetic; and the dynamics of motion. 'Light' also returns as a topic, having been introduced in grade three but absent after that.

Earth science topics introduced in grades seven and eight build on the concomitant physics and chemistry topics introduced in those upper middle grades. These include physical cycles such as the rock and water cycles; plate tectonics; the atmosphere; and conservation topics such as pollution. In the life sciences, using newly introduced physics and chemistry topics and building on the study of organs and tissues, the A+ countries introduce biochemistry and the physiology of organisms — covering such topics as sensing and responding, cells (including cell membranes, mitochondria and vacuoles), and human nutrition.

In one sense the science curriculum...[has] an upper triangular structure with three tiers. ...Science's first tier serves as the unifying element ... since those fundamental topics introduced in grades three or four continue throughout the rest of the first eight years of schooling. The lower middle grades (five and six) serve as the second tier and focus mainly on ecology and environmental science (supported with topics from both biology and earth science), the solar system (supported by physics topics), and magnetism. The upper middle grades (seven and eight) provide the third tier ...; they are focused in the top achieving countries on chemistry, physics, biochemistry, physiology and earth science topics that build on chemistry (Schmidt, Wang & McKnight, submitted for publication).

Given that US students were second only to those in South Korea at fourth grade, one might well question the advisability or necessity of changing anything with respect to US elementary science education. In fact, of the top science achieving nations at eighth grade (Singapore, Czech Republic, Japan, and Korea), only one outperformed US students at fourth grade, two were no different from the US, and one (Singapore) performed significantly below the US. The TIMSS eighth grade assessment provides a much better indicator of the ultimate level of science literacy students have acquired as well as their fitness for future advanced study of the sciences than does the fourth grade assessment. The fact that these four top science achieving nations at eighth grade begin teaching science to their students two or three years later than the US yields yet another reason to consider how they have organized, structured and sequenced their science instruction.

In contrast to the upper triangular pattern of the top achieving countries, the NAS/NRC standards evidence the absence of such a structured pattern. Science is intended to be covered in grades one and two in the US in contrast to the top achieving countries. In grade three the NAS/NRC standards suggest covering around 30 topics while the majority of top achieving countries only intend the coverage of around 10. (Schmidt, Wang, McKnight, submitted for publication)

Display 4 presents a similarly derived composite curriculum for 21 states. Why I believe there is a need for change becomes self-evident from this and the NAS/NRC standards. The silhouette of the top achieving intended topics coverage is superimposed on the data in Display 4.

Insert Display 4 about here

The picture of the US science curriculum that emerges from these data is that it lacks focus, coherence and rigor when contrasted with the composite curriculum of the top achieving countries in TIMSS. What especially is telling and central to the point is that the science curriculum of the top achieving countries reflects a sequence of topics that is logical and reflective of the internal structure of the four disciplines undergirding the science curriculum. This apparently is not true in the US.

A PROPOSED POLICY APPROACH

Mirroring the top-achieving countries' overall structure for topic focus through the years with rigor built in incrementally, and with the sequencing of the topics emanating from the coherence of the disciplines themselves, I propose the need for the development of an alternative structure for the United States science education curriculum. The data in the previous section suggest why this is so critical; US achievement results only worsen over the years of schooling.

What is needed is the development of a focused, logical, and coherent science program based on what we have learned from other countries in TIMSS. The science education program I envision would drastically re-configure our educational content and skills standards (National Research Council, 1996; AAAS, 1993) and couple these standards with hands-on activities and technology. I do not propose the replacement or recreation of the NRC Standards but that they be used to help develop a sequence of grade-specific learning opportunities that would help realize the broad goals of the AAAS and NRC Standards while being consistent with the coherence and rigor demanded by international benchmarks.

My goal in proposing the development of a focused and coherent sequence of grade-specific standards is to insure that all children learn science in a meaningful and comprehensive

way so that they may become scientifically literate citizens and have the necessary skills to be life-long learners as science and technology continue to advance.

For curriculum to be coherent the content standards must be articulated over time as a sequence of topics and performances that reflect a logical and, where appropriate, the sequential or hierarchical nature of the disciplinary content from which the subject matter derives. This implies that a set of content standards to be coherent must evolve from particulars to deeper structures. It is the deeper structure by which the particulars are connected. This evolution should occur both over time within a particular grade level and across grades (Schmidt, Wang and McKnight, in preparation).

The logical first step in this process I suggest is to identify an organizing principle. The idea behind the principle is not to base the progression of topics over grades one to eight in a somewhat arbitrary fashion nor to base it strictly on a disciplinary focus. Rather it implies identifying an organizing principle or story line which first of all provides a basis for selecting a limited number of science topics that are fundamental for all children to learn. Further, such a principle would structure and sequence those topics so as to reflect their inter-disciplinary connections leading to grade-specific science knowledge and empirical inquiry experiences (hands-on activities) that would help in the development of sound scientific literacy by the end of eighth grade. The development of such a principle should be informed by characteristics of the science curricula of the top-achieving TIMSS countries -- such as the focused emphasis on a small number of topics and the coherent sequencing of topics across the years of schooling.

Based on what has been learned from other countries, the best policy option is the development of a single organizing principle. This would in turn lead to a common coherent curriculum for all US students (Schmidt, Mcknight & Raizen, 1997; Schmidt, Houang & Cogan,

2002). Putting that which may not be politically attainable aside, a reasonable alternative would be the development of some small number of such organizing principles which deal with the same concepts and principles. Multiple organizing principles would allow choice across states which is politically more tenable and an approach some would argue is desirable.

The detailed grade-specific topic standards developed in this fashion would be both empirically benchmarked against proven international standards and represent the best of what has been done in this country through the efforts of the AAAS, the National Academy of Sciences and NSF.

One example of a possible organizing principle focuses on theories from astrophysics about the nature of the universe and how it and life within it are interrelated. This could be done so as to be consistent with the logical structure of each of the four disciplines making up the science curriculum (physics, chemistry, geology and biology) but also provide a good mechanism for integrating them in a non-traditional manner, but yet consistent with the principle of coherence described previously.

This particular organizing principle is somewhat consistent in its implications, although at a much different level of complexity, with the basic premise of the American Renaissance in Science Education (ARISE) Project directed by the Nobel Laureate Leon Lederman (see <http://www-ed.fnal.gov/arise/>). ARISE is an example of an effort to build a program that sequentially and logically builds up high school science (physics first, chemistry second and biology third) to insure that students come to understand and not just memorize facts. As Lederman (1998) said:“The sequence of high school study in science –biology, chemistry and physics – was set out in 1894 on the basis of a prestigious national commission (The

Committee of Ten). Today's high school science courses, largely textbook-driven, are treated as independent and unrelated. This, in spite of eloquent voices in the educational literature who have, in vain, called attention to the absurdity of the sequence. The sequence is inappropriate and does not respect developments in the disciplines over the past century. ...The science of biology strives for explanations of important processes at the level of cellular events, rather than mere descriptions. That a prerequisite of high school levels of physics and chemistry could provide such explanations is the essence of students learning science like scientists learn science. This teaches the science way of thinking."

Research on US science education over the past two decades, has reported how students have lost motivation in learning science after the first few years of schooling. The traditional curriculum has failed to address the issue of engaging students, of making curriculum relevant to them. It fails to hook to students' natural curiosity, natural need to know and natural desire to make sense of the world in which they live. Carefully chosen, an organizing principle could also serve as a plot or theme by which to capture the imaginations of young children in ways that stimulate further their natural inquisitiveness. Studying in a system where the curriculum is structured as represented by Display 4 further exacerbates the problem by making science appear to be an arbitrary collection of interchangeable topics that are unrelated to each other and simply a set of things to be memorized.

The organizing principle given above as an example has the advantage of providing the big picture in which the universe and life operate. Within that big picture, the particulars not only make sense but are connected, even if only abstractly, with the world in which we live. It is also tied to the time dimension. Elementary and middle school children enjoy learning about the universe and the beginning of time. The almost universal interest of young children in dinosaurs

serves as an illustration of this point. Using the universe and its relationship to life as a possible story line could be especially motivating for children.

Some good examples of how such an organizing principle can weave the science disciplines together are provided by several popular science books written by research scientists, such as *The First Three Minutes: A Modern View of the Origin of the Universe* (Weinberg, 1988), *The Whole Shebang—A State of the Universe(s) Report* (Ferris, 1997), and *Rare earth: Why Complex Life Is Uncommon in the Universe* (Ward & Brownlee, 2000). These books represent in a very integrated fashion many of the most important and basic scientific principles that are essential to the definition of scientific literacy.

One example of how such an organizing principle can be used to integrate topics across the disciplines is as follows: the formation of many of the heavier elements in the periodic table occurs through nuclear reactions contained within stars and those elements are spread across the galaxies by supernovas and, correspondingly, those elements once spread throughout the galaxy provide the material out of which planets, such as the earth are formed and ultimately provide the important chemical basis for carbon based life as we know it. The detailed knowledge and discovery about how life is essentially composed of matter originating from the Big Bang and how all of this has developed to its present state is arguably one of the great discoveries of the 20th century. Additionally, from a motivational point of view, children's' and many adults' eyes light up when they are told they are made of matter from supernovae— and that the matter out of which they are made was present at the origin of the universe some 13 billion years ago.

Through such an organizing principle students can acquire a sense of how many of the fundamental processes by which the earth operates as well as by which life itself functions are based on elementary principals from chemistry and physics. For example, the above story line

can be used to gain an understanding of the fundamental issues of chemical bonding and atomic structure. Once the central concepts and the associated specific knowledge required to support those concepts can be identified, they can be integrated into an interesting story line associated with the principles by which the universe, earth in particular, and life on earth operate. Even the most fundamental aspects of high energy physics can be integrated into such a story since under current theories, the universe began as a thick plasma of elementary particles. This theme is arguably one of the more logical approaches by which to structure a coherent science curriculum and yet make it potentially interesting to elementary and middle school children.

ONE WAY TO PROCEED

The method I propose for carrying out this work is a variation of the discourse methodology that proved so successful in working with international scholars in creating the curriculum frameworks and instrumentation used in TIMSS (Schmidt, et al, 1996). A group of research scientists, science educators, and teachers could be brought together to identify: (1) what the most fundamental scientific concepts are for all children to learn using the AAAS and NRC standards as starting points, and (2) the specifics of an organizing principle (or principles) that can be used as an interesting and motivating way to develop these ideas over the first eight grade levels.

The task for this group would be to generate a structure that challenges students, whether they, at later points in time, take more science, or simply need a sound fundamental knowledge in order to function as a scientifically literate individual in an increasingly technologically complex society, or to acquire a job that requires basic scientific literacy.

A separate task once this was completed would include the specification of how the better of the currently available curriculum materials could be integrated in total or at least in part into

providing a sequence of specific learning opportunities based on the principle and, as a result, to provide some of the curricular materials needed to support the implementation. It would also provide a blueprint for the future development of materials indicating what is still needed and at which grades. This could be made available to curriculum developers, textbook publishers and to NSF.

FINAL THOUGHTS

One of the impressions I have when comparing science as portrayed in the popular science books mentioned previously with what constitutes science education in most US schools is how much school science is mired in details and misses the bigger, more encompassing ideas which bring together in theoretical ways those various smaller details into a more coherent whole. It is not that facts and detail should not be a part of a school science curriculum; it is just that without the broader structure such detail leads only to fragmented knowledge at best but most likely only to things long forgotten when the school year ends.

I believe that the most important aspect of early elementary and middle school science education is to develop such a broad framework within which scientific theories and principles can be embedded but which is also associated with empirical inquiry. This seems far more critical than to flesh out at the finest level of detail what is often covered in many middle school biology and physical science classes -- a level of detail that focuses more on vocabulary than on the deeper scientific principles.

Thus, one of the most salient policy issues confronting the science community concerns the development of a coherent elementary and middle school curriculum which provides all children with the opportunities to become scientifically literate by the end of eighth grade. To do this I argue it is not necessary that new standards be developed nor necessarily that all new

curricular materials be developed, but that the critical issue is one of developing an organizing principle(s) that structures a coherent sequence of learning opportunities over the first eight years of formal schooling.

The proposal is to use two elements – scientific theories and empirical inquiry - to structure an elementary science curriculum that leads to the possibility of a deeper study of important aspects of science in middle school and for greater specialization in high school depending on interest and career choice. The sequence of topics and performance expectations over the years based on this structure should make the internal logic of science transparent to the student and to the teacher, thus providing them with a manifestation of the coherence inherent in the sciences and why it is worth learning about. Based on the TIMSS curriculum data, currently what is made manifest to most teachers and students is that science is mostly an arbitrary collection of topics (much like a laundry list) that are difficult to learn and easily forgotten particularly since the goal of most lessons is only to memorize facts rather than to learn the conceptual framework in which to place these most salient facts.

Clearly there are pitfalls to what is being proposed. One is that the interface between the bigger ideas and concepts that define the organizing principle and the detail that is necessary to support them must be carefully framed. What would be equally disastrous to the current situation is the development of a “fluffy” theme-based science curriculum that is void of any serious scientific content. Another potential problem is that the success of such an effort depends heavily on the composition of the convened group to develop an organizing principle that truly meets all four criteria of coherence, being potentially interesting to children, rigorous by international standards, and driven by empirical experiences. The balance will be hard to define. Not only is

there the “fluffy” science pitfall, but also pitfalls associated with being conceptually too abstract or making the “hands-on” part trivial.

Avoiding the pitfalls requires that the science community must identify those fundamental topics that are essential for all children to learn and to ensure that they be covered in a coherent way so that learning becomes more than merely the memorization of isolated facts. Those fundamental topics must become part of an emerging conceptual structure. Once identified, the point of this paper is that these fundamental principals, facts, and empirical processes can be made more interesting to students by integrating them into a broader story line. This broad story line or organizing principle which serves to integrate the various parts, together with important science content and the pursuit of empirical inquiry into a coherent whole provides a curriculum that would be first of all, more competitive by international standards and, secondly, more interesting to students and hence more likely to engage them in active learning.

END NOTES

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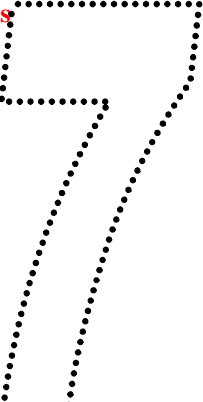
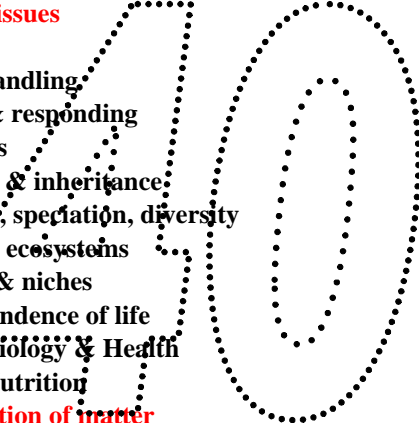
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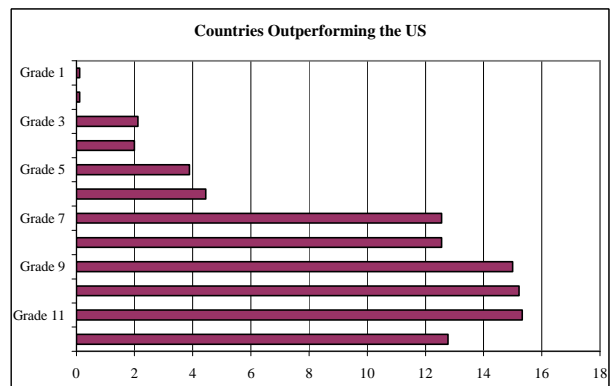
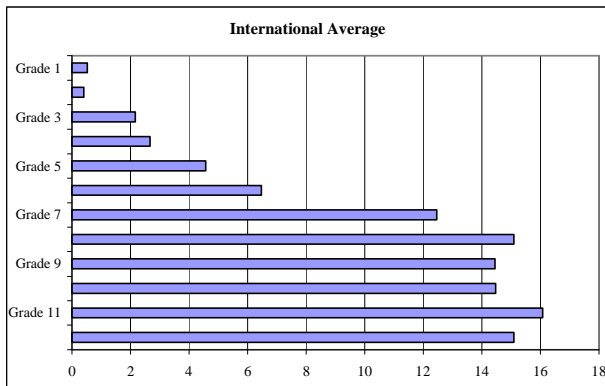
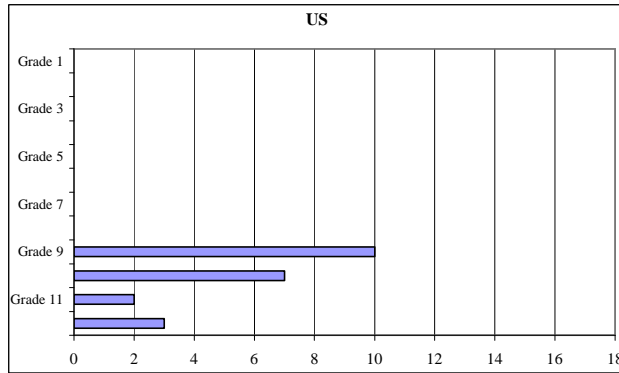
Weinberg, Steven. (1988). *The first three minutes: A modern view of the origin of the universe*. New York: Basic Books.

Display 1. Science Topics Intended for Introduction in Grades 1-3

Topics Intended for Introduction by at least 50% of the Countries Out Performing the U.S. in TIMSS	Topics Intended for Introduction by at least 50% of the Participating States
<p>Rocks, soil</p> <p>Plants, fungi Animals</p> <p>Organs, tissues</p> <p>Classification of matter Physical properties</p> <p>Light</p> 	<p>Earth's Composition Land forms Bodies of water Atmosphere Rocks, soil Weather & climate Physical cycles Earth in the solar system Planets in the solar system Plants, fungi Animals Microorganisms Organs, tissues Cells Energy handling Sensing & responding Life cycles Variation & inheritance Evolution, speciation, diversity Biomes & ecosystems Habitats & niches Interdependence of life Human Biology & Health Human Nutrition Classification of matter Physical properties Chemical properties Energy types, sources, conversions Heat & temperature Sound & vibration Light Electricity Types of forces Time, space, & motion Nature or Conceptions of Technology Interactions of Science, Technology & Society History of Science & Technology Land, Water, Sea Resource & Conservation Material & Energy Resource Conservation Nature of Scientific Knowledge</p> 

This table presents a broad picture of the science topics introduced (representing the aggregate and not individual countries) in the following countries: Singapore, Czech Republic, Japan, Korea, Bulgaria, Netherlands, Slovenia, and Hungary.

Display 2. Number of topics intended for in depth coverage at each grade level: the US (top graph), International Average across TIMSS Countries (bottom left), and TIMSS countries outperforming the US (bottom right)



Display 3. Science topics intended at each grade by the top achieving TIMSS 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 & Temperature				●	●	●	●	●
Bodies of Water				●	●	●	●	●
Interdependence of Life					●	●	●	●
Habitats & Niches					●	●	●	●
Biomes & Ecosystems					●	●	●	●
Reproduction					●			●
Time, Space, Motion					●	●	●	●
Types of Forces					●	●	●	●
Weather & 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 & Energy Resource Conservation							●	●
Explanations of Physical Changes							●	●
Pollution							●	●
Atmosphere							●	●
Sound & Vibration							●	●
Cells							●	●
Human Nutrition							●	●
Building & Breaking								●
Energy Types, Sources, Conversions								●
Dynamics of Motion								●
Organism Sensing & Responding								●

This table presents a broad picture of the typical sequence of science topics introduced (representing the aggregate and not individual countries) in the following top achieving (in 8th Grade Science) countries: Czech Republic, Japan, Korea and Singapore.

Display 4. Science topics intended at each grade by a majority of the 21 participating states.

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	●	●	●	●	●	●	●	●
Animal types	●	●	●	●	●		●	
Classification of matter						●		
Rocks, soil		●	●	●	●	●	●	●
Light								
Electricity				●	●			
Life cycles			●	●	●			
Physical changes of matter								
Heat & temperature				●	●	●		
Bodies of water				●	●			●
Interdependence of life	●	●	●	●				
Habitats & niches				●				
Biomes & ecosystems								
Reproduction								
Time, space, motion	●	●	●	●	●	●	●	●
Types of forces	●	●	●	●	●			
Weather & 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 & energy resource conservation				●		●	●	●
Explanations of physical changes								
Pollution						●		●
Atmosphere							●	●
Sound & vibration								
Cells							●	●
Human nutrition								
Building & breaking								●
Energy types, sources, conversions	●	●	●	●	●	●	●	●
Dynamics of motion								
Organism sensing & responding								