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The Conceptual Speed-Bump: Losing Potential STEM Students in the Transition from Elementary School to Middle School

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Abstract

Many educators in the science, technology, engineering and math (STEM) disciplines hope to improve the number of students interested in and prepared for these more difficult disciplines through innovative teaching, demonstrations and hosted camps. Research has shown that motivation is a much smaller part of the issue; student learning outcomes are much more sensitive to fundamental academic ability. Current curriculum design fails most students miserably in helping them bridge the gap from concrete learning to abstract thought and understanding in the middle school years. Thus, they are ill-prepared to engage in the more advanced learning required to pursue the STEM disciplines, a result that no amount of innovative teaching can correct. This paper will review the performance data from industrial nations at the 4th Grade and 8th Grade levels and illustrate curriculum differences between industrial countries producing higher percentages of STEM graduates. Examination of the performance effects of many variables, including number and sequencing of topics studied, time spent on homework, teacher credentials, access to technology, class size and dollars allocated per student, yields some surprising results. The problem is not as sensitive to many of these variables as one might expect. However, the variables that seem to provide promise for significant improvement from the current state of STEM education are related to topic coverage and manner of presentation. Final recommendations include reduction in the number of topics introduced in any given year with a corresponding reorganization of the curricula, to allow STEM teachers in the middle school to focus on the transitional learning that must occur to prepare for more advanced studies.

Introduction

Much of the recent focus and attention on engineering outreach to the K-12 demographic has centered on creating intellectual excitement for the science, technology, engineering and math (STEM) disciplines through innovative teaching, demonstrations and hosted camps. While motivating young students to consider a future in the math, sciences or engineering arena is a key requirement to increase the end population of graduates with a STEM background, it is only half of the problem. In his seminal work on teaching techniques, Joseph Lowman points out that although there are many variables that affect student performance outcomes, teachers only affect a portion of the equation. Research has shown that while great teachers may maximize the variables they do control, such as interpersonal rapport and stimulation of intellectual excitement, the student learning outcome is much more sensitive to a student's fundamental academic ability [1]. Thus, regardless of how much buzz a teacher brings to the classroom, a student's understanding of prerequisite material is the dominant factor in whether or not a student achieves the given learning objective.

The authors contend that the majority of potential American engineering students are "lost" in the transition from elementary school to middle school. This is an era of key development often overlooked by engineering educational specialists. It is at this point in a student's career that he or she transitions from learning concrete facts and notions about math, literature and science to a curriculum that introduces abstract concepts. In math, symbols are introduced to represent numbers and ideas. Science requires that students begin to accept ideas that can't be easily seen or directly measured when it introduces them to the universe and its immense scale or the world of micro-scaled objects in and around them. Literature and the arts seek to expand the mind through exposure to words and figures that are meant to convey alternate or hidden meaning. While this should be an exciting time of intellectual stimulation and preparation of the key abilities required for STEM disciplines, current American curriculum design fails most students miserably. Data from years of standardized tests continues to show that American students have fallen behind students in other industrialized nations considerably by the time the tests are administered at the 8th Grade level, a decline in performance that is clear when scores from students at the 4th Grade level are evaluated. By the time a student is beginning to

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enter high school, it is all but too late to make up for the damage that has been done.

This paper will review the performance data from industrial nations at the 4th Grade and 8th Grade levels, illustrate curriculum differences between industrial countries producing higher percentages of STEM graduates, and recommend a reduction in the number topics presented, especially in the STEM arena, to allow teachers in the middle school to focus on the transitional learning that must occur. This should be a focus of effort for outreach, because once a student fails to make the conceptual transition, no amount of intellectual excitement later can make-up for the deficit in ability or desire. Conversely, once a student can imagine and describe abstract concepts in math, science and literature, the efforts to seed young minds by creating the intellectual excitement for STEM education will find fertile ground.

Falling Behind in the World: The Statistics and What They Reveal

International educational assessments conducted since the early 1990s have shown consistently that the population of students in the United States is falling further behind peer populations in industrialized countries or remaining stagnant in an ever competitive international environment. The two main assessment vehicles used for cross-national comparative analysis of student performance on STEM topics are the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). The PISA has been conducted every three years since 2000 and includes participants from 57 jurisdictions. Thirty of these jurisdictions are members of the Organization of Economic Cooperation and Development (OECD). Members of the assessment population are fifteen years old and included over 5,600 U.S. students during the 2006 assessment. This assessment is aimed at mathematics, reading and science literacy with an emphasis on measuring how well students are able to apply knowledge within a real-life context. The TIMSS has been conducted every four years since 1995. This assessment evaluates students at the fourth and eighth grade levels on mathematics and science knowledge. It also contains a study of cross-national curricula to assist in placing some of the results into appropriate context. The latest study included 58 jurisdictions with far fewer OECD nations than were represented in the PISA. Approximately 10,000 U.S. students participated in each of the evaluated grades during the 2007 study [2].

Although U.S. Department of Education summaries of the 2007 TIMSS results attempt to highlight the statistics in as positive a fashion as possible, it is clear that the state of K-12 public education in the United States is not currently, and has not been for some time, preparing students well to compete for high-tech jobs in the 21st century. Tables 1-2 highlight math and science trends from the TIMSS assessment 1995-2007; Table 3 highlights math trends from the PISA assessments 2000-2006. There is little to laud in the data.

Table 1. Trends from TIMSS (Mathematics) 1995-2007 by country (sorted by 2007 scores) [3].

Grade four				Grade eight			
Country	Average score 1995	Average score 2007	Difference 2007-1995	Country	Average score 1995	Average score 2007	Difference 2007-1995
Hong Kong SAR	557	607	50	South Korea	581	597	17
Singapore	590	599	9	Singapore	609	593	-16
Japan	567	568	1	Hong Kong SAR	569	572	4
England	484	541	57	Japan	581	570	-11
Latvia	499	537	38	Hungary	527	517	-10
Netherlands	549	535	-14	England	498	513	16
United States	**518**	**529**	**11**	Russian Federation	524	512	-12
Australia	495	516	22	**United States**	**492**	**508**	**16**
Hungary	521	510	-12	Lithuania	472	506	34
Austria	531	505	-25	Czech Republic	546	504	-42
Slovenia	462	502	40	Slovenia	494	501	7
Scotland	493	494	1	Australia	509	496	-13
New Zealand	469	492	23	Sweden	540	491	-48
Czech Republic	541	486	-54	Scotland	493	487	-6
Norway	476	473	-3	Norway	498	469	-29
Iran	387	402	15	Cyprus	468	465	-2
				Bulgaria	527	464	-63
				Romania	474	461	-12
				Iran	418	403	-15
				Colombia	332	380	48

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Table 2. Trends from TIMSS (Science) 1995-2007 by country (sorted by 2007 scores) [4].

Grade four				Grade eight			
Country	Average score 1995	Average score 2007	Difference 2007-1995	Country	Average score 1995	Average Score 2007	Difference 2007-1995
Singapore	523	587	63	Singapore	580	567	-13
Hong Kong SAR	508	554	46	Japan	554	554	-1
Japan	553	548	-5	South Korea	546	553	7
Latvia	486	542	56	England	533	542	8
England	528	542	14	Hungary	537	539	2
United States	**542**	**539**	**-3**	Czech Republic	555	539	-16
Hungary	508	536	28	Slovenia	514	538	24
Australia	521	527	6	Hong Kong SAR	510	530	20
Austria	538	526	-12	Russian Federation	523	530	7
Netherlands	530	523	-7	**United States**	**513**	**520**	**7**
Slovenia	464	518	54	Lithuania	464	519	55
Czech Republic	532	515	-17	Australia	514	515	1
New Zealand	505	504	-1	Sweden	553	511	-42
Scotland	514	500	-14	Scotland	501	496	-5
Norway	504	477	-27	Norway	514	487	-28
Iran	380	436	55	Romania	471	462	-9
				Iran	463	459	-4
				Cyprus	452	452	0
				Colombia	365	417	52

The TIMSS data shows a slight downward trend from fourth grade to eighth grade when the United States is compared against others in the data. The United States students rank significantly lower than their Asian counterparts for both the math and science samples and fall between the Russian Federation and Lithuania in the cases based upon the 2007 scores. The data from the PISA assessment is more revealing as the United States is compared against many more OECD and non-OECD countries. The United States is in the bottom quarter of OECD countries for math and in the bottom third of OECD countries for science. There are numerous students from Asian industrialized nations represented in this sample, almost all of whom fare far better in the aggregate than their counterparts in America.

Topic Coverage – Breadth versus Depth

As international assessments have matured and the United States has slipped from its perch of technical dominance, many educational researchers have been looking at the coverage of content in the classroom pointing out that in American schools "…learning goals are diffuse, coverage is king…textbooks get fatter by the year, and everything has to be taught and re-taught…." [6] This observation was possible because one of the advantages of the TIMSS assessment is the fact that it incorporates a detailed survey of curricula from participating countries to assist educational researchers in applying some context to the outcomes from the tests. A ground-breaking survey of cross-national curricula and classroom environments was conducted from 1991-1995 to support the Third International Mathematics and Science Study, the baseline study for current trends analysis in TIMSS assessment. The Survey of Mathematical and Science Opportunities (SMSO) provided insights into the international differences for pedagogical approaches to STEM education by evaluating groups of nine and thirteen year olds in the classroom. This study was an effort to determine what approaches were utilized and to see if outcomes as reflected on international assessments correlated with certain approaches. In addition to numerous survey data from students and teachers on the curricula and classroom environment, 120 classroom observations were conducted in the elementary and middle schools of six participating countries: France, Spain, Norway, Switzerland, United States and Japan. All of the data and definitions presented and discussed below and in Figure 1 were developed and gathered during the course of the SMSO [7]. Though fifteen years have passed since the original study, the window into our educational system that it provided may still produce insight into the problems the American educational system faces today.

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Table 3. Trends in PISA (Combined Mathematics Literacy) for 15 year old students from 2000-2006 by country (sorted by 2006 scores) [5].

	Year				Year		
OECD Jurisdication	**2000**	**2003**	**2006**	*Non-OECD Jurisdiction*	**2000**	**2003**	**2006**
Finland	538	548	563	Albania	376	—	—
Canada	529	519	534	Macedonia, FYR	401	—	—
Japan	550	548	531	Peru	333	—	—
Norway	528	521	530	Hong Kong SAR	541	539	542
Australia	528	525	527	Chinese Taipei	—	—	532
New Zealand	—	524	525	Estonia	—	—	531
Luxembourg	552	538	522	Liechtenstein	476	525	522
Germany	487	502	516	Slovenia	—	—	519
United Kingdom	532	—	515	Macao-China	—	525	511
Czech Republic	511	523	513	Croatia	—	—	493
Switzerland	496	513	512	Latvia	460	489	490
Austria	519	491	511	Lithuania	—	—	488
Belgium	496	509	510	Russian Federation	460	489	479
Ireland	513	505	508	Israel	434	—	454
Hungary	496	503	504	Chile	415	—	438
Sweden	512	506	503	Serbia, Republic of	—	436	436
Portugal	483	498	498	Bulgaria	448	—	434
Denmark	481	475	496	Uruguay	—	438	428
France	500	511	495	Jordan	—	—	422
Iceland	496	495	491	Thailand	436	429	421
United States	**499**	**491**	**489**	Romania	441	—	418
South Korea	—	495	488	Montenegro, Republic of	—	436	412
Spain	491	487	488	Indonesia	393	395	393
Poland	500	484	487	Argentina	396	—	391
Mexico	443	483	486	Brazil	375	390	390
Italy	478	486	475	Colombia	—	—	388
Slovak Republic	459	468	474	Tunisia	—	385	386
Greece	461	481	473	Azerbaijan	—	—	382
Turkey	—	434	424	Qatar	—	—	349
Netherlands	422	405	410	Kyrgyz Republic	—	—	322
OECD average	**500**	**500**	**500**	**Non-OED average**	**426**	**456**	**443**

During the evaluation of curricula, those conducting the study included review of each participant's intended curriculum, content of textbooks, classroom teaching techniques and student behavior in the class. The intended curriculum is generally defined as that curriculum that a school administrative authority directs for implementation in each of its classrooms. This curriculum is generally defined by some authority above the teacher. This authority often resides at a school board, school district board, state educational board or national educational council. Sometimes it is a consequence of input from multiple levels of authority.

During the study it became clear that major areas of difference included the number and complexity of topics covered in the classroom. Figure 1 is a side-by-side comparison of the number of mathematics topics covered in each grade by country. The United States and Norway present the largest number of topics in almost every grade. Japan and Spain generally present the least amount of topics. Further review of curriculum begins to shed a little more light on some of these differences. In addition to number of topics presented, the coverage of these topics was examined for each country. It became clear that most of the countries touched upon the topics that were examined, but did not explore the content in depth. Japanese teachers, however, rarely introduced a topic if there was not sufficient time to present much more detailed coverage of that topic. This relationship held especially true for mathematics. Even in the Japanese science curriculum, the vast majority of the topics that were introduced to students were explored in depth.

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Examination of the textbooks utilized by each of the SMSO study countries provides additional insight into stark differences in pedagogical approach. At the 4th grade level it is very clear that most of the textbooks used by countries in the study emphasize simple information. France is an exception in that the amount of complex and thematic information presented in the text is almost equivalent to the amount of simple information. Japanese texts emphasize almost no complex material at this grade level. The low-level of complex material in the majority of the texts is not unexpected for this stage of development. The more interesting points of comparison are seen at the eighth grade level. The Japanese texts are the only ones with a preponderance of complex material. The U.S. ratio of material (about 8% complex and thematic) remains almost unchanged from 4th grade to 8th grade, and most of the other countries' texts actually increase the amount of simple material presented. This would seem to be counterintuitive. When these individual variables and scores from the TIMSS or the PISA are viewed in isolation, there is no strong correlation between a single curricula variable and performance outcomes. The general constant is that Japanese performance far exceeds all of its counterparts in these studies, except in one case where Norwegian eighth graders had a statistically identical score in the 2006 PISA combined science literacy aspect.

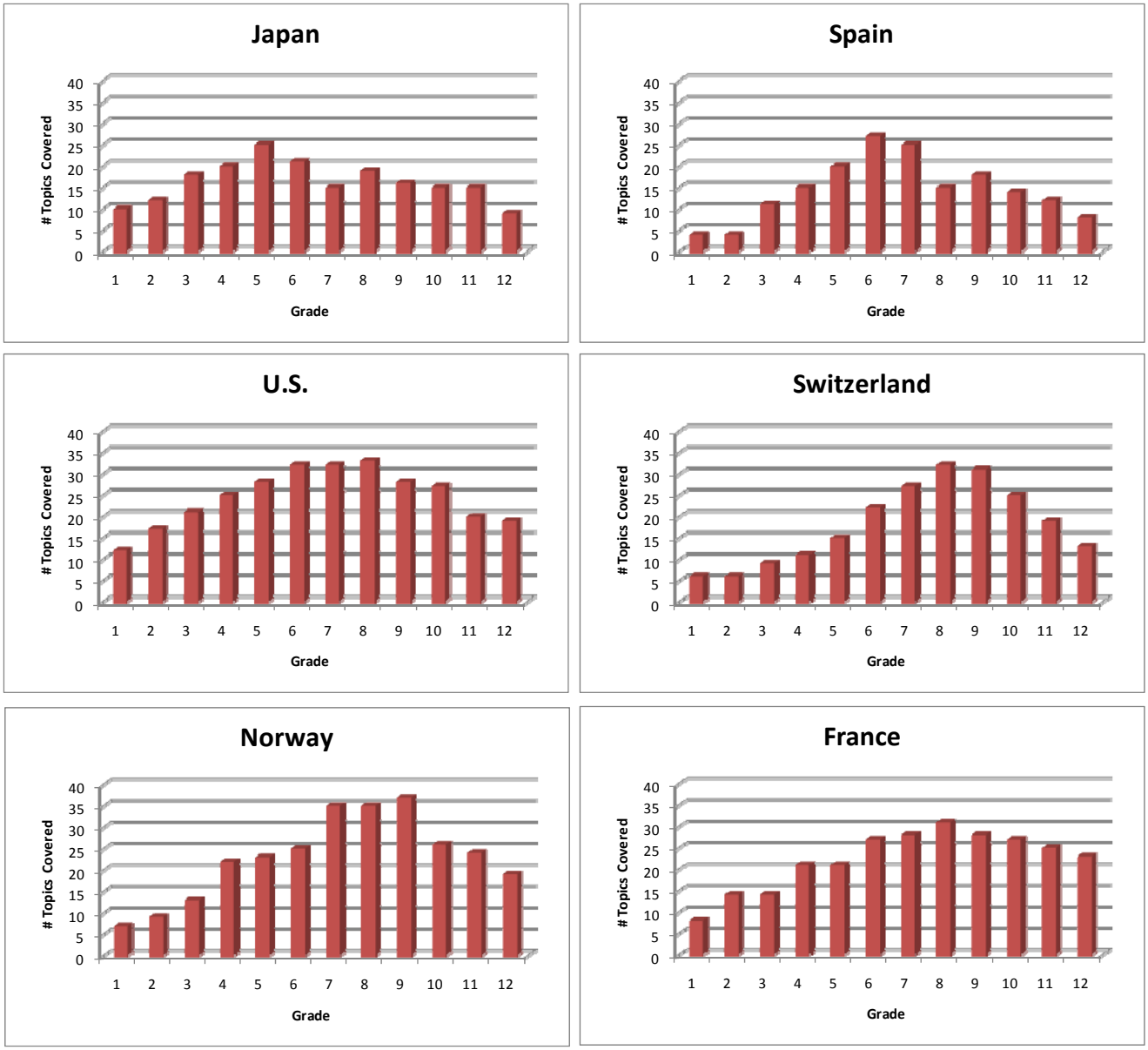

Figure 1. Mathematics topics covered at each grade level by country.

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Clearly there are lower and upper limits for the number of topics that might yield high levels of retained knowledge, but it would appear that there is more of an interaction between the variables helping to yield measurable success as defined in the international assessment program. Japan, as the best performing nation of the SMSO study, provides a benchmark for analyzing the interdependence of these variables. Unlike its SMSO counterparts, Japan has fewer topics at each grade, but it covers each topic more in depth. Japanese students also use texts that emphasize less complex material at the 4th grade level and reverse that scheme by eighth grade, unlike western peers. Additionally, Japanese texts are half the size or less of U.S. counterparts. The typical text in Japan touches on 70-90% of the five most emphasized topics. Thus, in a one hundred page Japanese text book, 70-90 of those pages would cover only five topics. U.S. science texts typically present 7-20% of the five most emphasized topics; U.S. math texts fare slightly better in a like comparison. The case for reducing breadth of content is further reinforced by Australian scholar Paul Ramsden, who argues vehemently to provide sufficient depth to key topics in order to develop satisfied students who are better suited for success in higher education. If not provided sufficient depth of material, he argues, students can still succeed on an exam by retaining material long enough to provide the correct answers, but may never develop a true understanding and appreciation of the content itself [8]. However, recommending that we should simply reduce the number of topics in the curriculum is too simplistic an argument, as countries have been successful with a wide range in the breadth of material covered.

Additional Factors and the Impact on Performance

Before isolating performance relationships to the breadth and depth of topics covered, it is important to validate that these are the dominant factors affecting success. So, what about factors other than material content that affect student achievement? Some have reviewed international assessment data and decided that the results must be from American kids watching too much television, playing too many games, interacting in social networks, and not doing enough homework. Others claim the extended Asian school years possibly improve students' development. And there are those who believe our teachers aren't as well-educated and have to deal with larger class sizes due to decreased budgets. Funding and technology has also been cited as an important role. Evaluation of these variables shows that many of the common arguments for American mediocrity are simply not factors to which the real problem is sensitive.

The results from TIMSS indicate that Japanese students watch about the same amount of T.V. as their American peers. Asian students also arguably have the same, if not greater, access to social networking sites and video games as American students. Even with a multitude of technological distracters, American 4th and 8th grade students report spending more time each week on homework than their Asian counterparts. U.S. eighth grade students actually report a significant increase in time spent on math homework. In fact, the latest TIMSS report from 2007 indicates that many low performing countries have students that report doing a lot of homework each week. Japanese and Korean students, however, report doing much less homework each week. While homework is clearly an important aspect of learning, time spent on task outside of the classroom is not a reliable predictor for success.

When teachers' credentials are examined, some researchers will point to the fact that over 50% of American math teachers and 25% of science teachers do not hold a major or minor in their subject area, and thus, cannot fully grasp the elementary and secondary school concepts [9]. While this is a higher percentage than is found in top-performing Asian nations, it is not at all uncommon to have a significant percentage of Asian teachers present material at the 4th or 8th grade levels that was not linked to a post-secondary education specialty. Over half of the teachers in the U.S. survey hold a Master's or Doctorate versus 90% of Japanese teachers who have only an undergraduate degree [10].

Japanese class sizes at the 4th and 8th grade levels, typical of the top performing Asian curricula, are well above the international average at 32-34 students per classroom, while U.S. class sizes are considerably smaller at 23-24 students [10]. And, despite reports that Asian students spend more days in class per year and time in class per day, the actual time spent in instruction (i.e. not including recess, lunch, and after-school activities) is comparable to students in a typical U.S. school district [11]. In terms of educational funding, the United States maintains the second highest per student cost for education behind Switzerland, averaging $10,390 per secondary student, and almost doubling the per capita education costs in Asian countries [12]. In addition, the education technological infrastructure in U.S. schools far exceeds the capabilities of the outdated (1950's era) and poorly maintained Asian schools. No, it seems that theoretically, the United States students' are better postured for academic excellence.

Then why are other countries' students continually outperforming U.S. students in science and mathematics, particularly in light of the 2007 TIMSS findings that high performing Asian jurisdictions like Taiwan, Singapore, Japan and Hong Kong devote significantly less curriculum time to mathematics than the U.S. average? When the average United States fourth grade school students receives 32 hours of math instruction compared to 20 hours for an average Asian fourth grader, and stills falls behind, the reason must exist within the material and manner of presentation itself. The answer is that top achieving countries are more effective in developing math and science competencies because they appear to have a more efficient secondary school curriculum. The timing, sequence, and integration of topics presented in their curricula enable them to present a greater depth and breadth of topics over the

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entire secondary schooling period with fewer topics covered each year by fewer education personnel at a significantly reduced cost per student.

The Problem of Abstraction

United States students seem to struggle the most in the transition from learning what is simple to understanding that which is abstract. Whether extending from counting objects and colors to defining letters and symbols in algebraic expression, or connecting observations of different materials to understanding celestial or microscopic entities, Asian and other top achieving countries are much more effective in bridging the gap between concrete and abstract concepts during the secondary school years. The consequences of the disparity in approaches are evident by 8th grade. At that grade level, the United States spends less than half the time that Japan devotes to Algebra, focusing more on Numbers and Geometry primarily because students are still heavily reliant on concrete measures of quantity. In fact, the United States devotes 16% of its math curriculum to Algebra versus an international average of 27% at this time in a student's career. Further evidence of this deficiency exists in the 2008 National Mathematics Advisory Panel findings that emphasized the importance of incorporating more algebra into the U.S. secondary school curriculum [13]. Similar differences in science curriculum also exist at the eighth grade level. Whereas U.S. 8th grade Biology students focus on structure and classification, their counterparts in the top six achieving countries are beginning in-depth analysis of biochemical processes. Top achieving countries' science curricula also stress more in-depth consideration of advanced topics like chemical properties, chemical change, physics, forces, atomic structure, light, and magnetism [14].

Effecting the transition from understanding concrete, simple models to intangible, complex representations of models requires a deliberate integration of key STEM themes. Unfortunately, U.S. curricula are less focused and not as well constructed around significant disciplinary themes, in contrast with many Asian schools. Textbooks are a direct reflection of this lack of coherency. As opposed to Asian texts, which are generally slim with very few diagrams or pictures, U.S. books tend to have a number of pictures, diagrams and "fun facts" in order to maintain students' attention. However, the additional material often serves to distract the students from the central theme of the lesson [11]. Without an understanding of the central theme of the lesson, students are less likely to possess the required prerequisite knowledge for future lessons, ultimately limiting their fundamental academic ability. As stated previously, a student's fundamental academic ability, what he or she brings to the table of any new learning environment is the dominant factor in determining achievement of a particular learning outcome. Without the solid under-pinning of previous foundational material, the student will likely never achieve the desired results in the future.

The inability of American textbooks to effectively capture a lesson's central theme is not simply the fault of the educational publishing industry. It is more directly a consequence of amount of material and lack of organization about those central themes within the secondary curriculum. American textbooks and teachers alike are forced to overly rely on "exciting" distractions, as they are easier to grasp for students with some familiarity of concrete concepts. The result then is that American students perpetually only have some familiarity of key STEM concepts. Few are in a position to continue deeper into the more difficult terrain of advanced study in the math and sciences programs.

Figures 2 and 3 highlight the deficiencies in existing American secondary school curricula. Figure 2 depicts a representative U.S. curriculum over the 1st Grade to 8th Grade period. Topics listed in the first column progress in increasing abstraction and generality from top to bottom. The last four topics are the four central STEM themes: Building and Breaking; Energy Types, Resources, and Conversions; Dynamics of Motion; and Organism Sensing and Responding. Ideally, all topics should nest under the development of these themes. The dots identify the years in which a specific topic has been introduced and is covered in a manner requiring more time and effort by the teacher. The asterisks represent supporting topics that are reviewed and further developed while introducing the newer topics. Figure 3 represents similar curricular structure for a representative Asian country. A few important issues should be readily apparent when contrasting the two figures on the following pages.

First, there is a significant difference in the way in which topics are timed and sequenced. The seemingly arbitrary timing of topics in the U.S. curriculum does not deliberately integrate material when compared to the organized Asian curriculum. The Asian curriculum orders the material based on the concept of progressing the student from specific, concrete models to general, abstract thought. Though the Chinese curriculum differs slightly with a linear approach, where a given topic is covered thoroughly before proceeding to the next topic, its effect is similar in developing a great depth of understanding on a few key topics [15]. The result is that Asian curricula integrate higher taxonomies of less complex topics to facilitate learning of more abstract concepts within the same instruction block. For instance, after comprehending physical properties of matter, organs, tissues and plant/animal classification in 3rd Grade, students are able to apply these principles in order to comprehend life cycles, physical changes in matter, etc. in 4th Grade. In 5th Grade, Asian students are capable of higher level application and some analysis of topics studied before. This trend in topic integration occurs throughout the Asian curricula, and is best visually represented as the triangular shape formed by the dots in Figure 3. On the other hand, U.S. representative curricula introduce several general concepts early, without strong linkage to exploration and analysis of the fundamental

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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 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 & Energy Resource Conservation				•		•	•	*
Explanation of Physical Changes								
Pollution						•		•
Atmosphere							•	•
Sound and Vibration								
Cells							•	•
Human Nutrition								
Building and Breaking								•
Energy Types, Resources, Conversions	•	•	•	•	•	•	•	•
Dynamics of Motion								
Organism Sensing and Responding								

Increasing Abstraction

•Denotes Topic Covered * Denotes Supporting Topic Used to Introduce/Develop Topics Covered

Figure 2. Content distribution, by grade, for representative U.S. curriculum [16].

supporting topics. For example, the general topic of energy types, resources, and conversions is introduced well before students learn about specific components and measures of energy like light, electricity, heat, temperature, and chemical changes. Unfortunately, American students are thus not effectively taught how to apply and analyze simpler topics in order to comprehend more abstract material. As a result, their fundamental academic ability is limited.

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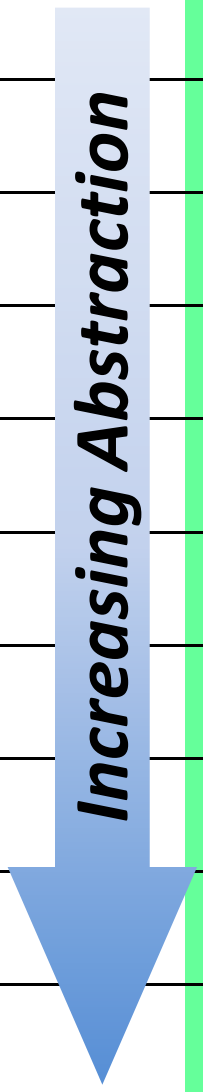
Topic	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
Organs, Tissues			•	*	*	*	*	*
Physical Properties of Matter			•	*	*	*	*	*
Plants, Fungi			•	*	*	*	*	*
Animal Types			•	*	*	*	*	*
Classification of Matter			•	*	*	*	*	*
Rocks, Soil			•	*	*	*	*	*
Light			•		*	*	*	*
Electricity				•	*	*	*	*
Life Cycles				•	*	*	*	*
Physical Changes of Matter				•	*	*	*	*
Heat 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 & Energy Resource Conservation							•	*
Explanation of Physical Changes							•	*
Pollution							•	*
Atmosphere							•	*
Sound and Vibration							•	*
Cells							•	*
Human Nutrition							•	*
Building and Breaking								•
Energy Types, Resources, Conversions								•
Dynamics of Motion								•
Organism Sensing and Responding								•



•Denotes Topic Covered * Denotes Supporting Topic Used to Introduce/Develop Topics Covered

Figure 3. Content distribution, by grade, for representative top achieving Asain curriculum [16].

Second, there is a significant difference in how long topics remain in the curriculum once introduced. The reduced topic content gives Asian teachers greater flexibility to integrate their curricula. Whereas U.S. teachers contemplate where to fit in a brief discussion of several of the seemingly arbitrarily chosen topics, the key question for Asian educators is at what point to introduce a topic, because once introduced, it is expected to remain in the curriculum as a supporting topic.

The primary basis for the timing of topics is based on how they integrate/facilitate learning in other fields [16]. In the representative U.S. curricula, once material is introduced it is not well reinforced in an integrated fashion later. For instance, electricity, heat and temperature are covered for only a few years early in the students' schooling. Unfortunately, the brief introduction and discontinuous coverage of the topics not only limits the depth in which they are covered, but increases the probability that the information will be lost when the material is not revisited or further developed in the higher grades of secondary schooling. If the topic is reintroduced, it requires significant coverage of lost information, which further constrains the available resources. Thus, not only are

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students constrained in the level of taxonomy they achieve, but are also not likely to even maintain that limited level as schooling progresses.

Third, though the breadth of topics covered within a year is significantly greater for U.S. curricula than Asian curricula; the amount of material covered over the entire secondary schooling period is less. Note in Figures 2 and 3 that 13 of the 41 topics included in Asian secondary studies are generally not covered in U.S. schooling as so many topics have to be re-visited to all the same degree as when they were first introduced. This again relates to the organization of central themes and continuity of topics covered in Asian schools. A benefit of the reduced content load in Asia curricula is that it provides the teachers with a better opportunity for logically and longitudinally integrating their students' math and science foundation. Due to the reduced content requirements and larger classes, teachers from top achieving Asian countries have a significantly lighter load in secondary education, with an average of 12 periods per week, which allows sufficient time for detailed preparation of class material [10]. This additional preparation affords Asian educators the opportunity to fully integrate their lessons. As a result, Asian schools are more efficient in covering material because they teach several topics as applied extensions of previously learned subjects. Thus, not only are Asian countries able to achieve higher levels of taxonomy, their integration of material affords their students better retention of a larger breadth of subjects.

Integration of topics in such a manner further allows Asian educators to teach based on desired competencies instead of specific topics. Thus, instead of teaching Algebra, Geometry, Trigonometry, etc., Asian educators are able to emphasize coordination of multiple representations, by integrating concrete, pictorial, symbolic and verbal representations. The program is thus built from the top-down based upon desired program outcomes instead of cobbling a program together from the bottom-up. For example, Japanese students, who practice and develop proficiency in solving problems through simultaneous solutions involving computation, geometry, algebra, etc., are better able to connect the concrete, representational, and abstract concepts of the three solution methods [17]. Similarly, Chinese pedagogy is based upon interconnected topics and concurrent instruction of multiple solution approaches to a single problem. In contrast, U.S. instruction is still overly reliant on visual representation of problems and tends to demonstrate a step-by-step, unique approach to a given problem. Students taught in this manner tend to become competent at pattern-matching but not competent at more general problem-solving. Not only does this procedural approach constrain the types of problems American students can solve, but it undermines the importance of the STEM discipline. Without the fundamental academic ability to achieve taxonomy levels beyond retention and comprehension of specific types of problems, students cannot be expected to find apparent utility and satisfaction in their STEM education. Without this, the benefits of innovative teaching techniques are very limited.

Summary and Conclusion

The reduction and reorganization of topics introduced in secondary schooling is imperative for transitional learning from concrete to abstract concepts. PISA and TIMSS assessments continue to generally reflect a correlation between the number and complexity of concepts introduced and mathematical and scientific competence of evaluated students. American schools continue to introduce the greatest number of topics in a given year of secondary school curriculum, and despite having among the best funding, facilities, education, and work habits, continue to develop students who are cognitively inferior to Asian peers in mathematics and science. Curricula materials are aimed at illustrating step-by-step recipes with the expectation that those procedures are memorized and regurgitated for exams. Students are not presented with approaches that encourage critical thinking and problem-solving approaches. The focus is on bringing the concepts *down* to what is considered a learnable and teachable level instead of working to elevate the students *up* to the higher levels of critical thought and understanding of abstract concepts necessary to set them on a path for success at higher levels of learning. It is imperative that American educators take advantage of the educational efficiencies generated by fully integrating topics in the secondary school curriculum. These efficiencies could be realized once U.S. educators determine and integrate curriculum based on a few key STEM themes.

Why is this so important now? Not only are American students performing poorly, but the United States has announced a new initiative to address the problem under the auspices of the "Educate to Innovate" campaign, announced by President Obama on 23 November 2009. This campaign to help the United States regain leadership in the fields of math, science and technology promises to expend billions of dollars in the effort. We must be extremely judicious in our excitement to execute the funds and mandate of this well-intentioned program! No amount of money will fix a problem if that money is not spent wisely. Recall that we are already spending more per student than almost every nation on the planet. Developers of new curricula must take great care in effectively streamlining content to produce the desired cognitive abilities. Ultimately, the critical curricular difference that exists between the top achieving countries and others is an ability to prioritize educational topics, giving educators the ability to limit the number of essential topics and tie them into a logical, longitudinal development sequence. This allows students to create conceptual links among topics and experiences not only within disciplines, but more importantly, among disciplines. Thus, a stage is set for further development, rekindled interest and improved STEM capabilities to better serve our students and American interests in the 21st Century.

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