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[Review]

The Trends in the U.S. and Korean Science Curriculum Reforms

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Abstract: This article describes the major themes to change in historical and philosophical perspectives of science education that lead the US and Korean science curriculum reform movements since 1957. Inquiry teaching and criticism of teaching science as inquiry in the late 1950s and the 1960s, Science-Technology-Society (STS) Curricula, and Science Literacy and the 1980s science literacy crisis are discussed. In the US, three major curricular projects as responses to the scientific literacy crisis are exemplary such as the Project 2061 sponsored by the American Association for the Advancement of Science, the Project on Scope, Sequence, and Coordination (SS&C) initiated by the National Science Teachers Association (NSTA), and the National Science Education Standards (NSES) published by the National Research Council. To identify how each set of national content standards differ, we compared specific content standards related to the theory of plate tectonics in Earth and Space science in grades 9-12 over the three national standards: Benchmarks of AAAS, NSES of the NRC, and SS&C of the NSTA. Against this historical background of the US science education reform movements, the curriculum reform movements in Korea is briefly discussed. In general, Korean science curriculum reform movements have reflected and resembled the recommendations of the US reform movements. In addition, it is important to note that throughout the history of curriculum revision in Korea, there have been continuing pendulum swings between a theoretical, discipline-centered curriculum and a liberal, humanistic, and student-centered curriculum, which pays more attention to students in terms of their interest and psychological preparedness. In conclusion, the sixth and seventh national science curriculum revisions reflect rather a student-centered movement by reducing technical and sophisticated topics, taking constructivism learning theory into consideration, and adding more STS related topics.

Key words: curriculum reform, inquiry, STS, science literacy, Project 2061, national science education standards, discipline-centered curriculum, student-centered curriculum

INTRODUCTION

It is necessary to be aware of the history of science education reform along with the major debates surrounding school science curricula in order to appraise the major paths to change that have occurred in efforts to improve science teaching in the US. Examining the historical context in which past reform efforts emerged, enables us to identify what brought the subsequent reform efforts including the contemporary reform movement toward science for all Americans. Against the historical background of the US science curriculum reform, three contemporary national reform documents (AAAS's Project 2061, NSTA's Scope, Sequence, and Coordination (SS&C), and NRC's National Science Education Standards (NSES) are reviewed. In the final section, the (potential) effects of contemporary scientific literacy reform efforts in the US as well as in Korea, along with potential barriers to change are discussed.

Throughout the history, there have been two competing traditions in US science education. One is a theoretical (a specialist, disciplinary emphasis) orientation of school science that aims at elitism, stressing the structure of the discipline and technical education. The other is a liberal (humanistic emphasis) orientation of school science that aims at populism or universal education for all citizens, stressing the science and workings of everyday things (Matthews, 1994). These two traditions are interconnected and interdependent. In the following section, we first examine the US science education reform movements.

U.S. SCIENCE EDUCATION UP TO THE 1950S

A significant trend in the development of science up to the 1950s was the increasing recognition of

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the practical, vocational, social and humanitarian aspects of science, and the inclusion of these aspects in the curriculum with the emphasis on applied and functional studies in the name of progressive education. The progressive education featured child-centered education (to move the child to the center of the educative process), the importance of real-world applications, the social importance of knowledge, and the need to make school learning enjoyable and meaningful to the student (DeBoer, 1991). According to principles of the progressive education, the job of the teacher was to start where the children were and lead them through their explorations and project work into the several fields of knowledge (Raizen, 1991). Consequently, the texts tended to be less theoretical and more encyclopedic in nature over this period, along with real-life experiences as the driving force of the curriculum. However, without considerable subject matter knowledge and clear aims of teaching on the part of the teacher, as Dewey well recognized, the child-centered and project centered curriculum could well result in a chaotic set of activities that served little educative function.

Another dominant theme of the US pedagogy during the first half of the century, the years from approximately 1917 to 1957, was the life adjustment function of education that was to prepare students for life in society by developing programs oriented toward the everyday activities of student (DeBoer, 1991). That is, the role of education was to develop the individual for effectiveness in a social world. Thus, the main objectives of an educational program could be determined by an analysis of the activities of individuals in society.

However, upon meeting such criticisms as (1) the shortages of technical personnel (professional manpower such as engineers and scientists) brought on by the war, (2) the perceived threats to national security stimulated by Cold War competition with the Soviets, which culminated in their launching of the earth-orbiting satellite Sputnik, and (3) the persistent claims by critics that progressive education had turned its back on traditional intellectual values American education moved away from the theme of social relevance and toward the theoretical, disciplinary structure of science.

1950S NATIONAL SCIENCE FOUNDATION CURRICULA

In response to the apparent technological superiority of the USSR, the main concerns of education changed to building the nation's scientific manpower as a defense-related cold war strategy (Raizen, 1991), and federal involvement in precollege education was begun. By the mid-1950s, with the support of the National Science Foundation (NSF), groups of scientists became involved in the creation of courses for the high school students. The NSF-funded science curricula were focused on the logical structure of the disciplines and on the processes of science, whereby precollege students were to engage in real science with opportunities to think like scientists. Examples of the NSF supported alphabet curricula in the late 1950s and early 1960s include the MIT's physical Sciences Study Committee (PSSC), Biological Sciences Curriculum Study (BSCS), Chemical Education Materials (CHEMS), CHEM study, Earth Science Curriculum Project (ESCP), Introductory Physical Science (IPS), Project Physics, and those developed for the elementary school such as Elementary Science Study (ESS), Science Curriculum Improvement Study (SCIS), and ScienceA Process Approach (SAPA).

The primary objective of these course materials was to present the scientist's current knowledge about the subject (the structure of various scientific disciplines) and the ways of obtaining scientific knowledge (quantitative inquiry), while little or no attention was given to technological applications (Klopfer & Champagne, 1990, p. 138). The operating principle of the new science curricula such as PSSC, for example, was to allow students to learn by doing experiments, by making their own observations, and by generalizing on these first-hand experiences as scientists in the classroom (Raizen, 1991). Along this line, they presented the science disciplines as logically structured areas of human investigation, and they encouraged students to think and act like scientists within the structure that was established as they engage in scientific discovery (Matthews, 1994). In sum, the curricular reformers of the 1960s wanted students to become scientific, not just learn science and, for this purpose, they advocated teaching science as inquiry (Matthews, 1994).

Inquiry Teaching

The inquiry or discovery learning, initiated and advocated by Joseph Schwab and Jerome S. Bruner, was to provide students with facility in the scientific way of thinking along with an accurate picture of the way scientific knowledge is generated (scientific methods), and to develop in students basic scientific attitudes. Under this approach, the teacher acts as a guide and a facilitator of learning rather than as an authoritative dispenser of information. Instructional practices associated with the inquiry method of teaching include discovery learning, teaching by the problem-solving method, and heuristic teaching which aimed to promote thinking and reasoning skills and independent research (DeBoer, 1991). According to inquiry perspective, students are viewed as little scientists who explore phenomena through hands-on activities and who use and develop scientific thinking skills to build up knowledge and conceptual understandings in the same ways that scientists use experimental work to construct new knowledge, concepts, and theories (Roth, 1992). This inquiry approach firmly established the role of the laboratory in teaching scientific processes. That is, just as science educators have generally concluded that hands-on activity is needed for a full understanding of science concepts, they have also concluded that the best way to learn science processes is by practicing them in the laboratory.

Even though teachers agreed that inquiry teaching was valuable to portray science as a process of investigation and to teach students how to use the method of science, they questioned the effectiveness of inquiry teaching as a pedagogical method in terms of difficulty to manage, time consuming, and effectiveness for most students (DeBoer, 1991; Matthews, 1994). As a compromise, a guided discovery was advocated. The guided discovery is a form of discovery teaching in which the teacher takes an active part in organizing instructional activities so that students can be led to make discoveries.

Criticism of Teaching Science as Inquiry

The curriculum reform movement in the late 1950s and the 1960s was led by college science professors, research oriented scientists from disciplines, with the help of school teachers and education faculty (science educators) played a secondary role if they were involved at all (Klopfer and Champagne, 1990). Therefore, the NSF curriculum projects featured the career or professional approach to science teaching (science for scientists), which did not appeal to most students (Hurd, 1991). The courses were too difficult for the typical high school student because of their theoretical sophistication and abstract nature, which led to decline of implementation and usage of these career oriented NSF courses by schools from the 1960s to the 1990s (Klopfer and Champagne, 1990). In addition, they did not take into account the importance of student interest or the pedagogical need to relate science knowledge not only to broad unifying themes of the discipline itself but also to the experiential world of the student, nor did they sufficiently consider the importance of readiness for learning and the need to postpone abstract learning until the student was capable of dealing successfully with such intellectual complexity.

By the end of the 1960s, from a recognition of the inquiry-oriented curriculum project's failure to achieve some of the more important social goals of science teaching, a new theme, scientific literacy, emerged. Scientific literacy came to represent the movement from the intellectual study of the structure of the disciplines for its own sake (i.e., an educational elite) toward a renewed emphasis on the study of science in its relationships to human life and action (i.e., an enlightened citizenry who can link scientific knowledge to daily life). In other words, the reform in the sciences called for modification of its commitment to the traditional discipline-bound science curriculum with the principal goal of preparing students for the practice of science (i.e., science career education for all students) and place more emphasis on the understanding of science and technology by those who are not, and do not expect to be, professional scientists and technologists (Hurd, 1991). Within scientific literacy goals, the importance of the interrelationship between science, technology, and society is reified through the science-technology-society theme--the teaching of science and technology in the context of society and social needs.

SCIENCE-TECHNOLOGY-SOCIETY CURRICULA

According to the NSTA position statement (1982), the goal of science education during the 1980s is to develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision-making--the STS interpretation of scientific literacy. Bybee (1991) contends, the NSTA policy statement provided a rationale and general guidelines for incorporating the STS theme into science curriculum and support the implementation of STS in school programs. Along this STS thrust, science education in the 1970s and 1980s was to be human and society focused, value-oriented, problem centered, and responsive to local issues (DeBoer, 1991).

Problems to be investigated are selected for their relevance to a wide range of personal, societal, and environmental concerns (DeBoer, 1991; Roth, 1992). That is, in an STS perspective, curriculum content is selected for its potential to serve the primary goals of developing students' decision-making and problem-solving process skills and of helping students learn to integrate values and moral thinking in this decision-making process (Roth, 1992). The proponents of an STS orientation, like Yager and Hofstein, suggest six essential goals of a quality K-12 science curriculum.

1) The human being, human potential, human advances, and human adaptations will serve as the organizer of the curriculum(instead of the structure of the disciplines or the scientific processes).

2) Current problems and societal issues will serve as the backbone of the curriculum.

3) Science and technological processes that students can use in everyday life will be emphasized over processes that scientists use.

4) Practice with decision-making skills using science and technology knowledge in a relevant, social context will be emphasized over skills needed to uncover correct answers to discipline-bound problems.

5) Awareness should be an integral part of science learning.

6) In dealing with problems and issues, ethical, moral, and value dimensions will be considered (in contrast with traditional science instruction, which is taught as value free and discipline bound) (Roth, 1992).

With regard to how to teach social issues in science, there were two competing views: add on and integral approaches to STS education. Recognizing the benefit and necessity of making science more socially responsive, the mainstream group advocated adding social issues to the existing science syllabus, whereas the other group advocated teaching science through social issues, claiming such advantages as increasing interest and motivation, breaking boundaries between subjects by the development of interdisciplinary STS topics, and enabling individual and pupil choices of topics (Matthews, 1994). In other words, advocators of the integral approaches to STS education, like Hofstein and Yager, argued that science curriculum should be organized around social issues rather than the logic of the organized disciplines (DeBoer, 1991). There has been strong controversy about socially relevant issues as organizing themes in the STS movement in the 1970s and 1980s.

On the other hand, research results revealed science teachers' common concerns with the integration (implementation) of STS into school science, such as concerns over the content (i.e., is there enough science?), discomfort with student grouping, uncertainties about evaluation, frustrations about the student population (i.e., what about college-bound students?), and confusion about the teacher's role (i.e., how does a science teacher teach about social issues?) (Bybee, 1991).

SCIENCE LITERACY AND THE 1980S CRISIS

By the early 1980s US met a second-generation crisis, called the science literacy crisis--the majority of American high school graduates and citizens had little scientific understanding in spite of all the money and effort that had been expended since Sputnik (Matthews, 1994). Most of the education reports of the 1980s have been motivated by two different growing public concerns. One concern is the realization that the US was not competing well in the international economic arena. The other concern consists of certain trends in US public education: low test scores (in a recent science test taken by high school students in 14 countries, American students ranked the 14th), students avoidance of science and mathematics (huge numbers of American students avoid science at both secondary and higher education levels), a demoralized and weakening teaching staff in many schools, low learning expectations compared to other technologically advanced nations, and being ranked near the bottom in international studies of students' knowledge of science and mathematics (AAAS, 1989). In particular, the publication of 'A Nation at Risk' (National Commission on Excellence in Education, 1983) spurred the government to action and influenced dozens of education reports in the next five years, in which science for all has been adopted as a goal for science education not just in the US but in most other countries.

With the concerns on providing an equitable and humane educational environment for all American youth rather than just for those planning careers in science, more attention was given to the differences in ability and interest of each individual student along with the renewed focus on the social relevance of the curriculum. Along this line, the official science curriculum in the 1990s contains neoprogressive assumptions in that it shares a similar purpose of creating a science for living (i.e., scientifically literate) with progressive educators in the 1930s (Cuban, 1995).

It is important to note that there was a significant difference between the 1960s and 1980s reform movement. In the 1980s, triggered by the highly visible national reports, the baleful test scores, and the perception of nation's losing its competitive edge in the global economy the educational reform need and concern were shared by every part of the nation including policy makers and business community, whereas in the 1960s, no one in the schools or even among the public was much concerned about the quality of education except the scientific and university communities (Raizen, 1991).

Definition of Scientific Literacy

Regardless of the multifaceted view of the nature of scientific literacy, Champagne and Newell (1992) summarized an essential component of scientific literacy as (1) an information base organized in a way that makes the information applicable to situations encountered in the workplace, and to civic responsibilities as well as to academic problems; and (2) reasoning processes necessary to apply scientific information in all contexts are necessary components of scientific literacy. Furthermore, Shymansky and Kyle (1992) contend that regardless of the ultimate theme and agenda, an understanding of the practical, social, and political dimensions of science will enable the scientifically literate citizen to participate in the framing of a new social order. Along this line, Matthews (1994) maintains that, among other things, a scientifically literate person is expected to:

1) Understand fundamental concepts, laws, principles and facts in the basic sciences.

2) Appreciate the variety of scientific methodologies, attitudes and dispositions, and appropriately utilize

them.

3) Connect scientific theory to everyday life and recognize chemical, physical and biological processes in the world around them.

4) Recognize the manifold ways that science and its related technology interact with the economics, culture and politics of society.

5) Understand parts of the history of science, and the ways in which it has shaped, and in turn has been shaped by, cultural, moral and religious forces.

Two major curricular projects as responses to this scientific literacy crisis are exemplary. One is the Project 2061, sponsored by the American Association for the Advancement of Science and the other is the Project on Scope, Sequence, and Coordination (SS&C), initiated by the National Science Teachers Association (NSTA). Project 2061's work on Science for All Americans and Benchmarks for Science Literacy served as a foundation for the subsequent National Science Education Standards (NSES) published by the National Research Council in 1996.

Based on the perceived barriers to all students' learning science, these three national standards and benchmarks agree on several important issues: First, scientific endeavor ought to be presented as a social enterprise, thus emphasis should be placed on human thought, action, depth of understanding, and the application of science to personal and societal issues (Shymansky and Kyle, 1992). The new standards in national reform documents are to teach students to see connections between concepts and the real world. Second, learning strategies ought to be based upon a constructivist epistemology. Based on the criticism of traditional instructional practices such as a commitment to the central role of the textbook, teachers as dispensers of knowledge, students as passive receivers, and teacher-prescribed activities, the reform efforts advocate constructivist principles of learning, such as learning being contextual, based on prior conceptions, socially negotiated and dependent upon individuals' personal construction of their own understanding. Third, reform must ensure the scientific literacy of virtually all students, not just those who are college-bound or who are headed for a science-related career. This is a commitment to equality of educational opportunity and achievement regardless of gender, ethnicity, or career path as well as the elimination of tracking of students and ability grouping (Anderson, 1996).

In this context, a broad range of reformers agree that improving science instruction involves identifying appropriate scientific principles, those that are accessible to a broad range of students, and helping students apply scientific principles to their everyday lives. Also, curriculum reformers of the 1990s seem united on the necessity of reducing basic coverage in textbooks and curriculum guides. The focus is on fundamental content concepts and interdisciplinary themes rather than discrete items of isolated information, namely, the less is more theme, coupled with integrated content embedded in contexts familiar to students. Against this common background, in subsequent sections the features of each document are reviewed.

Project 2061

Project 2061 is a three-phase plan of purposive and sustained action focused upon the reform of education in science, mathematics, and technology. It outlines specific K-12 learning goals in its publications: Science for All Americans (AAAS, 1989) and Benchmarks for Science Literacy (1993).

Project 2061 proposes using major themes or key ideas. That is, the main influence of Project 2061 is the addition of interdisciplinary themes to the information base and the addition of practical reasoning to the performance capabilities (technology-related capabilities) that align the outcomes of school science more closely with the demands of the workplace (Champagne and Newell, 1992). At the secondary level, the trend in Project 2061 is for students in science, technology, and math classes to work in groups instead of as competitors and to use technology. The style of instruction is heavily on hands-on with 60% of students' time devoted to lab work and the remainder to discussion, thereby students make their own discoveries rather than read about them in a book (Wirth, 1991).

Science for All Americans

This document defined science literacy and laid the groundwork for the subsequent science standards movement. To set out recommendations for what all students should know and be able to do in science, mathematics, and technology by the time they graduate from high school, five expert panels (members from the biological and health sciences; social and behavioral sciences; physical and information sciences and engineering; mathematics; and technology) determined the concepts and skills most crucial to science literacy. The main driving forces of the Science for All Americans are to teach less so that it can be taught better (less is more) and to crumble the rigid boundaries between the disciplines so that students can experience the connections among disciplines.

National Science Education Standards (NSES) by the National Research Council

The National Research Council drew heavily on Science for All Americans and Benchmarks for Science Literacy when writing the content standards in its National Science Education Standards (NSES), released in 1996. The NRC has stated that the two documents (the NSES and Benchmarks) share about 90% of the same content recommendations (AAAS, 1997). According to the NRC definition, content standards refer to the content knowledge and skills all students will know and be able to do upon completing particular grades or courses in K-12 education.

The NSTAs Scope, Sequence, and Coordination (SS&C) of Secondary School Science

The SS&C project calls for the restructuring of science at the secondary level and recommends that all students study science every year for the six or seven secondary years(i.e., scope). Moreover, it advocates carefully sequenced coordination of the four traditional disciplines, and the revisiting of fundamental science concepts over years in different contexts (spaced learning: the study of each of the sciences spread out over several years), while adhering to the separation of the traditional subjects. Since the four science disciplines share topics and processes, coordination among these four disciplines and appropriate sequencing of instruction by revisiting successively higher levels of abstraction over several years are required. Aldridge, the project founder, also recommends that students first encounter science content on a descriptive and phenomenological level and then progress through the empirical and semi-quantitative to the theoretical and abstract levels (SS&C, 1992).

Based on current research and trends in science teaching and learning, learning principles undergirding the SS&C project are: (1) spacing and sequencing of science content, (2) cooperative learning as an alternative to traditional grouping plans and instructional systems, (3) encouraging equitable classrooms for underrepresented groups such as low-come, minority, and women students, (4) learning to think in terms of cognitive skills and the intimate relationship of subject matter knowledge and reasoning processes, and (5) constructivist perspectives such as learning as students active construction of knowledge, learning by connecting new information to prior knowledge, teaching science for understanding, and the perspective of conceptual change.

In addition, according to SS&C program, the focus of learning science shifts to students and away from the textbook, tests, and even the teacher (NSTA, 1993). In other words, as students take responsibility for their own learning, the teaching process becomes a guiding process whereby the role of teacher is to provide the context for learning through managing the learning environment rather than being a holder of knowledge.

To identify how each set of national content standards differ, we compared specific content standards related to the theory of plate tectonics in Earth and Space science in grades 9-12 over three national standards: Benchmarks of AAAS, NSES of the NRC, and SS&C of the NSTA.

Although the standards share a commitment to reducing the number of topics students are taught and a common core of ideas and understandings about science that all students should know, differences among the documents still exist.

Benchmarks for Science Literacy

As a companion tool to be used with Science for All Americans, this book translates the science literacy goals in Science for All Americans (SFAA) into learning goals or benchmarks (fundamental concepts or abilities in the NSES standards) for grades K-2, 3-5, 6-8, and 9-12. That is, Benchmarks breaks down the goals by grade ranges, whereas the SFAA presents science literacy goals for high school graduates in a coherent narrative form. However, the organization of content in Benchmarks is the same as in SFAA (AAAS, 1997). Benchmarks contain content for social science, mathematics, and technology as well as for natural science. Within content sections, it also contains brief essays on teaching. Benchmarks are organized by content area, which facilitates looking for the development of ideas over time. In addition to reducing the sheer amount of material being covered, Benchmarks features emphasis on connections between traditional subject matter categories, whereby goals can be learned in many different contexts so that they can be used together in life outside of school. In contrast to the SS&C content organization, Benchmarks chapters center on science literacy, not on an understanding of each of the separate disciplines. Along this line, the content standards of the Benchmarks present a

Table 1. Content standard comparison among three national standards

Standards	Learning Goals or Benchmarks (the NSES fundamental concepts or abilities)
Benchmarks (AAAS, 1993)	4. The Physical Setting 4C. Processes that shape the earth • The solid crust of the earth-including both the continents and the ocean basins-consists of separate plates that ride on a denser, hot, gradually deformable layer of the earth. ... The surface layers of these plates may fold, forming mountain ranges. • Earthquakes often occur along the boundaries between colliding plates ... under the ocean basins, molten rock may well up between separating plates to create new ocean floor (p. 74). 10. Historical Perspectives 10E. Moving the Continents • The idea of continental drift was suggested by the matching shapes ... but rejected for lack of other evidence. Early in the 20th century, Alfred Wegener ... reintroduced the idea of moving continents ... • The theory of plate tectonics was finally accepted ... and there was a scientifically sound physical explanation of how such movement could occur (p. 248).
NSES (NRC, 1996) Content Standards	[Earth and Space Science Content Standard D (grades 9-12): Energy in the earth system] Guide to the content standard: Fundamental concepts and principles that underlie this standard include: • The outward transfer of earths internal heat drives convection circulation in the mantle that propels the plates comprising earths surface across the face of the globe (189). [History and Nature of Science Content Standard G (grades 9-12): Historical Perspectives] Guide to the content standard: Fundamental concepts and principles that underlie this standard include: • Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. Examples of such advances include ... Plate tectonics ...(p. 204).
SS&C (NSTA, 1993)	[Earth/Space Sequence Grades 6-12: The Physical Planet] Sub Topic: Solid Earth Processes: Crust and Interior Grades 9-10 Volcanism; Earthquakes; • Mountain building: Students should observe mountains directly or indirectly ... Students should consider whether earthquakes or volcanoes provide clues about forces in the Earths crust and speculate where those forces might be concentrated. ... (p. 80). Grades 11-12 Convection currents: Formation of ocean basins: • Continental drift and plate tectonics: Students ... should study the historical evolution of plate tectonics theory ...The teacher then might discuss Wegeners hypothesis ...The umbrella concept of plate tectonics evolved from the compilation ... students should appreciate how a major scientific paradigm shift can occur through advances in science and technology ... (p. 93).

common core of learning in science so that essentially all students will be able to reach all of the recommended learning goals (AAAS, 1989). In sum, the main theme of Benchmarks is to concentrate on fewer topics so that teachers can introduce ideas gradually, in a variety of contexts, reinforcing and extending them as students mature. The twelve Benchmarks chapters cover four major categories that include the nature of scientific endeavor (chapters 1 through 3), basic knowledge about the world (chapters 4 through 9), historical perspectives along with some crosscutting themes (chapters 10 and 11), and the habits of mind that are essential for scientific literacy.

As shown in Table 1, in terms of organization, the SFAA/Benchmarks takes a more integrated view of physical science, without drawing boundaries between traditional disciplines such as physics, biology, or Earth/Space science. The conventional Earth/Space science content standards can be found in The Physical Setting (chapter 4) and Historical Perspectives (chapter 10) in which the Benchmarks holds the major topics constant and varies the substance of each topic at the benchmark level. For example, subtopics of chapter 4 include the universe, the earth, processes that shape the earth, structure of matter, energy transformations, motion, and forces of nature. In the case of the plate tectonics theory, the Benchmarks presents the theory under the subtopic 4C (processes that shape the earth) in grades 9-12 level based on the descriptive study of geological phenomena in the previous grades. Benchmarks also presents the history of the rise of the theory of plate tectonics in the subtopic 10E (Historical perspectives: moving the continents) to show the acceptance of theory depends on its explanatory power as well as on the evidence that supports it.

Both documents (Benchmarks and NSES) are very similar in philosophies, language, difficulty and grade placement of their learning goals, etc (AAAS, 1997). For example, both documents share a commitment to reducing the sheer number of topics students must know to allow time for them to learn the most important ideas; excluding from basic literacy a host of topics that clutter the traditional science curriculum; emphasizing understanding ideas over memorizing technical terms; and describing most ideas and topics at the same levels of difficulty and detail. Despite the high level of agreement between Benchmarks and NSES, the features of NSES are as follows.

NSES Content Standards (Correspond to Benchmarks Chapters).

NSES includes standards not only for natural-science content, but also smaller sections of teaching strategies, professional development, guidelines for assessment, program, and systems. Moreover, even within content sections, there are essays on appropriate teaching vignettes, and example assessments. NSES divides K-12 into three bands: K-4, 5-8, and 9-12. NSES is organized by grade level, which might facilitate looking for connections across content areas within the same grade-range (AAAS, 1997). The eight categories of NSES content standards are unifying concepts and processes, presented for all grade levels: science as inquiry, physical science, life science, Earth and Space science, science and technology, science in personal and social perspective, and history and nature of science.

According to the AAAS comparison (1997), the greatest difference between NSES and Benchmarks can be found in their treatment of inquiry. Separating Scientific Inquiry from the Nature of Science, NSES emphasize inquiry, whereas Benchmarks treats it as part of the Nature of Science. NSES contends that students should understand some important things about scientific investigation and there are some skills related to inquiry that all students should retain beyond school as part of science literacy. Furthermore, students should retain the ability to think critically about reports of research. To acquire such understandings and skills, and eventually to become independent inquirers about the natural world, students are to carry out some scientific investigations themselves through hands-on work. Therefore, all scientifically literate adults should be able to actually carry out, as well as critique, scientific investigations, whereas Benchmarks considers the retained ability to conduct scientific research to be highly desirable for students who will specialize in science-related careers (AAAS, 1997). In sum, NSES puts more emphasis on learning subject matter disciplines in the context of inquiry, integrating all aspects of science content, studying a few fundamental science concepts, and implementing inquiry as instructional strategies, abilities, and ideas to be learned (NSES, 1996).

In terms of organization, as shown in Table 1, the NRC content standards vary topically by grade band, while it uses three widely accepted divisions of the domain of science (physical science, life science, and Earth and space science). For example, in studying the earth system within Earth and Space science standards, students in grades 5-8 should develop an understanding of the structure of the earth system along with Earth's history, and in grades 9-12, students focus on such topics as energy, crustal dynamics, as well as origin and evolution of the earth system. In the case of the plate tectonics theory, the NSES presents the theory under the content standard D (Earth and Space science: energy in the earth system) in grades 9-12, as a continuation of studying the earth system introduced in grades 5-8. NSES also presents the theory of plate tectonics as an historical episode in content standards G (History and Nature of Science: Historical perspectives) to show various aspects of scientific inquiry, the nature of science, and how scientific knowledge changes.

SS&C: The Content Core.

The proposed SS&C science content organizes content for each discipline (biology, chemistry, Earth/Space science, and physics) into three grade level groups: 6-8, 9-10, and 11-12. The content core also reflects the 2061 theme that less is more whereby students learn a few concepts in depth and they can apply them to new situations or problems to develop a deeper understanding of science.

One of the features of SS&C content core includes revisiting a concept repeatedly over students' school years through an upward spiraling treatment of topics. That is, in the case of plate tectonics, students are introduced to continental drift and the plate concept in grades 6-8 to get familiar with various geological phenomena, and then they explore the mechanics of plate movement including volcanism, earthquakes, mountain building, and metamorphism in grades 9-10. Based on these experiential groundworks, students in grades 11-12 investigate plate tectonics theory to understand how plates move along with the historical evolution of the theory. On the other hand, for the coordination of science content SS&C proposes two models: integrated courses organized around great ideas of science or an STS pattern of integration around modules; and discipline-based courses taught in series or taught in parallel.

Yet, regardless of the excellent themes of the reformers and the changes of curriculum, it is hard to bring about the desired level of change effect on student learning of science without change of teacher education, assessment tasks, resources and support (Matthews, 1994). The educational reform efforts of the 1980s, carried on into the 1990s, have to overcome the barriers to achieve the essential goals for all students. Among the barriers to change are (1) the beliefs and values on the part of everyone involved, (2) the lack of teacher preparation to teach constructively, (3) the need to reeducate students to their role in learning constructively, (4) the need for new instructional, curricular and assessment materials and high learning outcomes and expectations to support the teaching and learning changes, and (5) the tensions of instituting the new while operating in the old education system (Anderson, 1996).

One of the most important lessons learned from the NSF-funded curriculum reform projects of the late-1950s through the early 1970s is that the classroom teacher is the key (Matthews, 1994; Duschl, 1990). That is, the failures of the NSF-funded curricula were caused by inadequate logistic support for school teachers as well as the inadequate training of teachers such as lack of knowledge of subject matter, failure to appreciate the psychological requirements for science learning, particularly the need for experience and familiarity with reality to precede theory and concepts, and poor inservice courses (Matthews, 1994). To achieve the goal of meaningful learning by students, first of all, teachers have to overcome their commitment to a specific traditional instructional practice, prior values and beliefs about educational practices, limited ability to teach constructively, and the challenge of new roles. Anderson (1996) contends that reformed education is characterized by students occupying new roles and doing new forms of work. The contemporary reform efforts demand constructivist learning on the part of students, which, in turn, demands constructivist teaching on the part of the teacher. In other words, the major goals of these reform efforts (e.g., learning to think, a constructivist approach to learning and learning fundamentally important information at higher levels of understanding on the part of students) require teachers' reconceptualization of teaching such as generating constructivist learning among students, developing the role of facilitator, and assessing their students learning from a constructivist orientation (Anderson, 1996). Without the fundamental change of teachers' beliefs through inservice as well as preservice teacher education, it is hard to meet the nation's goals. Grounded in these efforts on the teacher's side, the reform outcomes for students are:

1) More students are engaged in significant learning of subject matter and frequently for a longer time;

2) Students are developing and practicing thinking skills;

3) Students are experiencing those skills in an embedded, applicable context, which will provide more direct transfer to their future lives and work; and

4) Students are developing a new role as life-long, self-directed learner (Anderson, 1996).

Against this historical background of the US science education reform movements since 1957, in the last section we will briefly describe science curriculum reform movement in Korea, from the first national science curriculum in 1963 to the contemporary seventh curriculum revision in 1997.

Curriculum Reform Movement in Korea

The Science curriculum has been revised at the national level six times in 1955, 1963, 1974, 1981, 1988, 1992, and 1997. Since the third national curriculum, Earth science curriculum has been strongly influenced by the ESCP, one of the NSF funded alphabet curricula. However, upon meeting the criticism of highly discipline-centered inquiry or discovery approach to teaching and learning, there was an attempt to complement this theoretical, discipline-centered curriculum, which stresses the structure of the disciplines. As a compromise, the fifth national science curriculum revision (implemented in 1989) incorporated STS curriculum components. Consequently, by adding social issues to the existing science syllabus, which was already overstuffed, the amount of learning goals and contents were increased. Regardless of the endorsement of the STS orientation in the fifth national curriculum revision, the backbone of the science curriculum has remained discipline-centered rather than student-centered throughout three subsequent curriculum revisions.

With the influence of the US science curriculum reform movement toward scientific literacy, Korea went though the sixth science curriculum revision in 1995 (implemented in 1996 at high school level). The features of the sixth national science curriculum in Korea can be summarized as follows:

First, with the influence of SS&C (NSTA, 1992), the 6th science curriculum revision entails teaching across the four science disciplines, rather than drawing stark boundaries between the disciplines. That is, as a required course in the 10th grade, the sixth curriculum newly established a common science course that has an interdisciplinary characteristic, providing integrated approaches to science teaching.

Second, by dividing (Earth) science I (the literary course, for non-science major students) and (Earth) science II (the science course, for science major students), the science courses are geared to educate scientifically literate people, especially for the non-science major students. Third, by incorporating the historical, ethical, technical, and social dimensions of science (the STS orientation), it presents science as a more liberal enterprise than was the case in the professional and technical curricula developed since the third national curriculum. Fourth, considering the past science curriculum in Korea was overstuffed and some topics were taught over and over again in needless detail, the content is reduced by ruling out topics mainly of technical interest (i.e., the less is more principle). Fifth, the focus of learning science shifts to students by reinforcing students activity such as discussion, experiments, and observations.

To keep up with a rapidly changing world, Korea went through the curriculum revision in 1997. The main features of the latest curriculum reform can be summarized as follows:

First, the new curriculum places great emphasis on the sequencing of courses across school levels (elementary, middle, and high school), which aims to reduce previously existing leaps in terms of content difficulty. Second, the content is reduced by ruling out technical topics. Third, with a variety of optional courses, students can deepen and widen their science study according to their learning abilities and needs. On the other hand, it also offers the national common basis science (for grades 3 to 10) for all students. Fourth, there is a heavy emphasis on inquiry learning, which is to enhance students' problem-solving skills in their everyday life situations.

These features reflect and resemble the recommendations of the US reform movement. On the other hand, it is important to note that throughout the history of curriculum revision in Korea, there have been continuing pendulum swings between a theoretical, discipline-centered curriculum and a liberal, humanistic, and student-centered curriculum, which pays more attention to students in terms of their interest and psychological preparedness. In conclusion, the sixth and seventh national science curriculum revisions reflect rather a student-centered movement by reducing technical and sophisticated topics, taking constructivism learning theory into consideration, and adding more STS related topics. With more emphasis on STS topics, students (especially non-science major) can find a personal and social relevance in science learning.

Possible Future Direction of Curriculum Reform

Based on this review of the major paths to change in science teaching and learning and the history of science curricular reforms in Korea and the US, future reform directions can be predicted.

First, before initiating any more reforms, we need to define the ideal characteristics of a scientifically well-educated person. What kind of future citizens do we (science educators) want to produce via the school science curriculum? Depending on the desirable images and status of our future citizens, we need to redefine the goals of science education.

Second, in Korea, regardless of great effort to reduce the content covered in the science curriculum, there is still too much to learn on the consumer's side and too much to teach on the teacher's side to keep up with the rapidly increasing knowledge base. Therefore, we need to shift the primary goal of science education from knowledge (scientific concepts) acquisition and understanding to other directions, such as scientific attitudes and scientific inquiry. Accordingly, we need to define what aspects of science we desire our future citizens to know. Depending on the possible demands on future citizens, the goals of science education could be varied. Possible alternative goals of science education can be learning how to locate necessary information and facts, how to think scientifically as well as logically, and how to process information.

Third, there is an urgent need to provide the necessary student motivation for an effective science education reform effort. Beyond overcoming students anti-science attitudes, we need to find ways to motivate and increase students interest in science learning.

REFERENCE

American Association for the Advancement of Science (AAAS), 1989, Project 2061: Science for All Americans. Washington, DC: Oxford University Press. 272p.

American Association for the Advancement of Science (AAAS), 1997, Resources for science literacy: Professional development. New York: Oxford University Press. 118 p.

Anderson, R.D., 1992, Perspectives on complexity: An essay on curricular reform. Journal of Research in Science Teaching, 29(8), 861–876.

Anderson, R.D., 1996, Study of curriculum reform. Washington, DC: U.S. Department of Education. 106p.

Bybee, R.W., 1991, Science-Technology-Society in science curriculum: The policy-practice gap. Theory Into Practice, 30(4), 294–300.

Champagne, A.B., and Newell, S.T., 1992, Directions for research and development: Alternative methods of assessing scientific literacy. Journal of Research in Science Teaching, 29(8), 841–860.

Cuban, L., 1995, The hidden variable: How organizations influence teacher responses to secondary science curriculum reform. Theory Into Practice, 34(1), 4–11.

DeBoer, G.E., 1991, A history of ideas in science education: Implications for practice. New York, NY: Teachers College Press. 269 p.

Duschl, R.A., 1990, Restructuring science education: the importance of theories and their development. New York, NY: Teachers College Press. 155 p.

Hurd, P.D., 1991, Closing the educational gaps between science, technology, and society. Theory Into Practice, 30(4), 251–259.

Klopfer, L.E., and Champagne, A.B., 1990, Ghosts of crisis past. Science Education, 74(2), 133–154.

Matthews, M.R., 1992, Constructivism and the empiricist legacy. In National Science Teachers Association (NSTA), Scope, Sequence and Coordination of secondary school science. Vol. II. Relevant research. Washington, DC: NSTA. 270 p.

Matthews, M.R., 1994, Science Teaching: The role of history and philosophy of science. New York: Routledge. 287 p.

National Research Council (NRC), 1995, The national science education standards. Washington, DC: National Academy Press. 262 p.

National Science Teachers Association (NSTA), 1992, Scope, Sequence and Coordination of secondary school science. Vol. II. Relevant research. Washington, DC: NSTA. 270 p.

National Science Teachers Association (NSTA), 1992, Scope, Sequence and Coordination. Washington, DC: NSTA 132 p.

Raizen, S.A., 1991, The reform of science education in the U.S.A. Deja Vu or De Nova. Studies in Science Education, 19, 1–41.

Roth, K.J., 1992, Science education: Its not enough to do or relate. In National Science Teachers Association (NSTA), Scope, Sequence and Coordination of secondary school science. Vol. II. Relevant research. Washington, DC: NSTA. 270 p.

Shymansky, J.A., and Kyle, W.C., 1992, Establishing a research agenda: Critical issues of science curriculum reform. Journal of Research in Science Teaching, 29(8), 749–778.

Shymansky, J.A., *et al.*, 1990, A reassessment of the effects of inquiry-based science curricula of the 1960s on student performance. Journal of Research in Science Teaching, 27, 127–144.

Wasley, P.A., Donmoyer, R., and Maxwell, L., 1995, Navigating change in high school science and mathematics: Lessons teachers taught us. Theory Into Practice, 34(4), 51–59.

Wirth, A.G., 1991, Issues in the reorganization of work: Implications for education. Theory Into Practice, 30(4), 280–287.

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