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Identification of Guideline-Based Components for Innovative Science Curricula

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ABSTRACT

In both Korea and the U.S., science education leaders and specialists insist that there is a shortage of curricula to address the new national science education guidelines in support of reform. This paper addresses development of new curricula for science education reform in the hopes of facilitating further development of guideline-based curricula. We examine Korean and U.S. thematic-based (Korean Science Field Trip at Cultural Sites Program and U.S. Graduate Teaching Fellows in K-12 Education) and project-centered (Korean Teachers for Exciting Science and U.S. Foundational Approaches in Science Teaching Program) programs. Using the criteria of rationale for curriculum, content and scope, processes of implementation, and assessment strategies, we identify the curricular components that are common across four successful secondary science programs and determine which of these components address the national guidelines. Our findings indicate that common components of these four programs meet the expectations of the science guidelines being used to revamp science education in both countries. Therefore, these programs not only engage secondary students and teachers in practicing successful science education, but also lead to successful science education practices that can be incorporated in the future development of curriculum to support secondary science reform.

Key words: science curriculum, guideline-based components for curriculum, rationale for curriculum, content and scope, processes of implementation, assessment strategies

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I. Introduction

The rationale for science education guidelines for reform varies little across countries, and there seems to be an international awareness that development and introduction of guidelines into the educational arena constitutes one of the most effective and fundamental strategies for stating expectations in accord with education reform (Bybee, 1997; The Presidential Commission on Education Reform [PCER], 1997).

The newest reform guidelines for science education in both Korea (National Curriculum) and U.S. (national standards) are constructivistic and integrative in nature, emphasizing inquiry and creativity as central themes (American Association for the Advancement of Science [AAAS], 1993; Son & Lee, 1999; National Research Council [NRC], 1996; PCER, 1997). However, in both countries, there is a growing agreement that new curricula aligned with these guidelines are not sufficient (Bradley, 2000; Pak, 1997).

Korea and the United States are employing their individual approaches to providing guideline-based instruction and learning, but the product programs of both countries rarely provide classroom encounters that enable teaching to fully meet the guidelines (Bradley, 2000; Pak, 1997). In both countries, however, groups have begun to explore and use techniques that complement or replace usual classroom science methods and allow students to experience the larger intent of the guidelines.

1. Purpose

The purpose of this paper is to compare four science guideline-based programs (Korean Science Field Trip at Cultural Sites program, SFT; Korean Teachers of Exciting Science, TES; U.S. Graduate Teaching Fellows in K-12 Education, GTF; U.S. Foundational Approaches in Science Teaching Program; FAST) that have gone beyond the usual teaching methods in order to search for characteristics that can be advisory to curriculum development. Prior papers (Bergman *et al.*, 2001; Pottenger *et al.*, 2001) have described a pair of Korean and American thematic-based programs and a pair of Korean and American project-centered programs that seek to more fully meet the intended vision of their national guidelines.

2. Method

This paper provides a deeper analysis of the Korean and U.S. programs. First, it identifies how they meet common and unique characteristics of national guidelines. And then it compares the programs according to TIMSS factors of curriculum, teaching, lives of students, and lives of teachers (TIMSS, 1997). Finally, a finer-grained analysis is made of the programs, using the key criteria of the 1) rationale for curriculum, 2) content and scope, 3) processes of implementation, and 4) assessment strategies as suggested by Posner & Rudnitsky (1997). From this comparative work a set of considerations that may prove useful to curriculum developers in designing new curricula is identified.

Ⅱ. Standardizing Korean and American science curricula

To get a feeling for the significance of the programs studied here and the motivation of their authors, it is worth while to test them according to the philosophical, theoretical, and political setting in which they have been developed. This section explores the practical and theoretical influences on development and then turns to how they match up with national standards.

1. Practical and theoretical influences

The current science education guidelines of both Korea and the United States are the product of a long-standing general unease about how much secondary school graduates know and how they can use what they know. In the United States the prime mover was a perception that the nation's educational system was not filling students with sufficient knowledge to compete in the world of the 21st century. In Korea the concern was over how well students could use the knowledge poured into them as they start to compete in the world of the 21st century. In addition, there were a host of other motivators (AAAS, 1993; Kim *et al.*, 1997; NRC, 1996) including concerns about 1) how to increase the number of students pursuing science study and careers in science and science education by students, especially women and minorities (Lewis, 1997; Lynch, 2000; O'Neil, 1995; Science Literacy is national concern, 1995); 2) how to enhance communication between scientists, technologists, teachers, students, and the general public (Kling, 1999); 3) how to upgrade teachers and potential science teachers to be knowledgeable in the new guideline-based content strategies, and assessment techniques (AAAS, 1998; Watson, 1996); 4) how to get guideline-based curricula for the classroom (Bradley, 2000; Pak, 1997; White & Frederiksen, 1998); 5) how to ensure acquisition of critical thinking skills (Anholt, 1994; Choi, Cho & Cho, 1998); 6) how to integrate understanding of the interaction among science, technology and societal interaction (Noh, Cha, Kim & Choi, 1998; Redefining technology and the new science literacy, 1993; Son & Lee, 1999); 7) how to bring ethics and ethical practice and handling, care, and use of subjects into the classroom (Cho & Choi, 1998; Hann, 1997); and 8) how to incorporate inquiry and constructivist approaches into curriculum (Schwab, 1962; Yager, 1997; Young, 1997).

Constructivism

A major influence on the guidelines of both countries was the body of philosophy and theory, called constructivism. The constructivist asserts that learners build their own understandings that are complex, highly organized, and strongly tied to specific subject matter. Learners construct their own knowledge by making connections between new information and their pre-existing knowledge (Pottenger *et al.*, 1998). Reinforcing aspects of Vygotsky's sociocultural theory are called on in terms of the teaching-learning processes, the social interactional nature of learning in mediating childrens thought, and the interplay between everyday and scientific concepts (Hodson, 1998).

Inquiry

The emphasis of professional science associations and recent research findings about learning and teaching are leading reform efforts to focus on teaching science as inquiry (Young, 1997). This is in companionship with the reforms new vision of scientific literacy that enfolds science, technology and the realm of interfacing societal problems. The idea of inquiry is continuing to be refined, and distinctions in species earlier recognized are now being put into practice. The techniques of exploration, guided discovery, free discovery, invention, guided experimentation, open-ended experimentation, and technological problem solving are finding their way into guidelines and curriculum.

Integration

Integration of the sciences has come to mean a bringing together and an inclusion not just of physics, chemistry, biology, and earth science but the everyday contexts in which science operates in technology, the environment, and sociey (Holman, 1990). While disciplinary divisions are valuable to practicing scientists, their isolated study may restrict the utility of science for students because many concepts and solutions of practical problems involve knowledge of two, three, or more science disciplines as well as other subject areas. For this reason, particularly in secondary education, concepts that apply to more than one discipline are widely used to understand the interrelationship among the science disciplines (Dowling, Benson, Chandler & Bethke, 1992; Ellis & Fouts, 1997).

Curriculum Organization

There are numerous approaches to curriculum organization, many of which have a long history in the literature. The framers of the new guidelines have endorsed curricula that are organized to provide students with as authentic a science experience as possible through their grappling with characteristic problems. Two of these organizational approaches are the "thematic-based" and "project-centered" programs described here. It has been noted that curriculum imbedded in meaningful and realistic themes stimulates interest and provides students and teachers with the opportunity to experience the types of situations that experts encounter in societal problems (Costa & Garmston, 1994; Feldman & Kropf, 1999; Hargreaves & Moore, 2000; Posner & Rudnitsky, 1997; The Cognition and Technology Group at Vanderbilt University, 1992). Project-centered approaches involve students and teachers in inquiry that is similar to or is an engagement in the actual research experience of practicing scientists (Posner, 1995). Engaging secondary students in scientific research has a special quality because the experience authentically teaches scientific methodology (Katterman, 1994) and often stimulates interest in further science study (When kids do science, 1999). However, secondary science education programs such as those described here that actually afford students the opportunity to design and carry out their own scientific experiments are extremely rare.

2. National curriculum in Korea

Since Korea has a centralized education system, most educational policies and curricular decisions are determined by the central government. The National Curriculum affords some flexibility for schools to pursue individualizing objectives. The curriculum has been revised periodically to meet various demands both from inside and outside schools: to take into account new and rising domestic and international needs, changes in social trends, national transitions, and academic advancement.

There are three different levels of school curriculum implementation: the national level, the metropolitan/provincial level, and the school level. The Ministry of Education & Human Resources Development has overall responsibility for development and the control of the curriculum. The National Curriculum prescribes different goals, subject matter, extra-curricular activities and time allotment for elementary school, middle school, and high school. The National Curriculum provides the objectives, contents, guidelines for instruction and assessment. The Metropolitan/Provincial Guidelines provide for school curriculum implementation, and the school curricula are implemented based on national curriculum and the guideline.

Since the Republic of Korea was established in 1945, the National Curriculum has been revised seven times. The Sixth National Curriculum is now being replaced by the Seventh National Curriculum, which sets new benchmarks dedicated to the democratization and localization of education in Korea. More autonomy is given to schools at regional and local levels in order to meet individual school needs. The new curriculum (the Seventh National Curriculum) was developed in 1997 and became operational for the first, second, third, and fourth grades of elementary school and the seventh of middle school starting in 2001. Curricula for other grades will be gradually implemented starting in 2002. The revised curriculum introduces a basic common curriculum that covers the first ten years of schooling - from primary school to the first year of high school and for the final two years of high school, an elective curriculum.

In determining the objectives of science education, students' abilities and their cognitive development levels are two important factors to be considered. In addition, the following five dimensions are also taken into consideration: knowledge (i.e., facts, concepts, principles, theories, and explanation), science process skills (e.g., observing, measuring, experimenting), the development of scientific knowledge, the relationship between science and technology within the relevant social context, and value/ethics in science education.

The instruction section of the curriculum offers general guidelines for science teachers. It shows them how to develop a lesson plan, how to prepare and use teaching aids, what to emphasize in a "process-oriented" class, and how to handle equipment and instruments safely in conducting a science class.

The curriculum requires that student assessment must focus on the students' understanding of basic concepts, their ability to initiate and conduct investigations, their willingness to pursue science inquiries, and their attitude toward and appreciation of scientific endeavors. It also prescribes that, depending on the content and purpose of the assessment, one can use a variety of assessment methods such as written tests, classroom observation, reviews of students' reports and performance assessment.

Six objectives for science curriculum have been developed (Ministry of Education & Human Resources Development, 1998), and it is informative to compare these with the formal statements of the American National Science Education Standards (NSES; NRC, 1996) and the Benchmarks for Science Literacy (AAAS, 1993) and to test the four programs against these common statements (Table 1).

The Korean National Curriculum is addressed to the totality of curricular needs of the school. The segments sampled speak to the development of the graduate aware of values of tradition and culture and committed to responsibilities of national citizenship in a global environment. Concern for culture and traditions are particularly reflected in the Science Field Trip (SFT) - Korea program, and Hawaiian tradition and history is a theme used in the Graduate Teaching Fellows (GTF) U.S. - program. Culture and tradition are not an explicit component in either of the American guideline documents though they are resident in particle and technological problems targeted by both sets of guidelines. The common conceptual inclusions of the Korean science objectives and the American guidelines are reflected in SFT and GTF as well as Teachers for Exciting Science (TES) and Foundational Approaches in Science Teaching (FAST).

3. National science education standards in U.S.

In the United States, education is the responsibility and right of the separate states. This

Table 1. Korean science objectives compared with NSES and the Benchmarks showing their inclusion in the four programs

Korean National Science Objectives	American: National Science Education Standards (NSES)/ Benchmarks for Science Literacy	SFT	GTF	TES	FAST
• Students will have interest and curiosity in natural phenomena and objects and understand the framework of scientific knowledge.	It is the role of the teacher to encourage curiosity and personal interests. NSES, Science Teaching Standard B (pp. 33-37) Encouragement of curiosity about and interest in natural phenomena are given highest priority. Benchmark, Habits of Mind 12A (p. 285)	X	X	X	X
• Students will learn inquiry methods that lead to a correct view of nature.	Inquiry as process or method leading to the answer of questions is central. NSES, Content Standard A (pp. 121-123) Scientific Inquiry is a complex process leading to a reasonably accurate picture of the view of science. Benchmarks, Scientific Enterprise1B (pp. 9-10)	X	X	X	X
• Students will understand the basic concepts of science through inquiry into nature and apply them to every day life.	Scientific knowledge can be applied in solving problems that meet human needs. NSES, Content Standard E, Science and Technology (p. 161) Scientific knowledge is used in the solving of the practical problems of technology and technology is seen as providing the goods and services of society. Benchmarks, Technology and Science 3A (pp. 41-49)	X	X	X	X

Table 1. continued

• Students will develop an ability to inquire scientifically into nature and apply their knowledge to every day life.	See NSES, Content Standards A (pp. 121-123) and NSES, Content Standard E (p. 161) above. See Benchmarks, Scientific Enterprise 1B (pp. 9-10) and Benchmarks, Technology and Science 3A (pp. 41-49) above.	X	X	X	X
• Students will have interest and curiosity in regard to natural phenomena and objects and build a positive attitude toward scientific resolution of the problems of everyday life.	See NSES, Content Standards A (pp. 121-123) and NSES, Content Standard E (p. 161) above. See Benchmark, Scientific Enterprise 1B (pp. 910) and Benchmarks, Technology and Science 3A (pp. 41-49) above.	X	X	X	X
• Students will correctly recognize the influence of science upon the development of technology and society	See NSES, Content Standard E (p. 161) above. See Benchmarks, Technology and Science 3A (pp. 41-49) above	X	X	X	X

X: Identifiable in program

is guaranteed by the United States Constitution. However, out of concern for flagging test scores, the National Research Council (NRC) was funded by the federal government in 1991 to write the National Science Education Standards to act as guidelines for the states in the crafting of their own standards. Under federal pressure, it has been left to each state to accept, adapt, and localize the new standards and to improve their educational systems. This has been or is now being done and is resulting in an array of science guidelines that describe the states' curricula and their plans and requirements for achieving a standard-based education for all citizens.

Prior to the funding of the NRC, the American Association for the Advancement of

Science (AAAS) in 1989, had undertaken the task of writing a document called Benchmarks for Science Literacy. Its 12 chapters describe what students should know and be able to do by the end of grades 2, 5, 8, and 12. The intent was to specify thresholds rather than average or advanced performance (AAAS, 1993).

In the spring of 1991, the National Science Teachers Association president, with support from various professional groups, the U.S. Secretary of Education, and others, encouraged the NRC to coordinate development of national science education standards. Shortly thereafter, major funding for NRC to develop national standards in science was provided by the American Department of Education and the National Science Foundation. Thus, the NRC became the agency officially responsible for writing the National Science Education Standards (NSES) reflecting America 2000 Goals (NRC, 1996). Following extensive national review, the final NSES document was printed in December 1995. Unlike Benchmarks, the NRC document includes six categories of standards: teaching, professional development, assessment, content, programs, and systems. As with Benchmarks, there is a significant emphasis throughout the standards on humanizing science education.

NSES provides both imperative statements of what must be done (the standards or end points) and statements about the direction that science education must be moved in order to achieve the standards (what should be more emphasized). It is the statements of emphasis that give the clearest picture of what teachers and curriculum developers must do, and it is these that have been looked to test the four programs reported here. Three of the categories of national standards are directly applicable - science teaching standards, assessment standards, and content standards (Table 2, 3, 4, & 5).

The insights about the nature of science and technology of the Benchmarks are particularly helpful in getting a fuller picture of what a curriculum for "all" should be. Treated as complements to the NSES, a small selection of additional points from the Benchmarks that illuminate special additional characteristics of the programs are touched on here. These selections are taken from the chapters on Nature of Science and Nature of Technology.

Nature of science

> The Scientific Word View: Scientific investigations often fail to find convincing answers to the questions they purse. The claim that science will find answers always carries the implied disclaimers, "in many cases" and "in the very long run" (p. 5).

Comment: The level of open-ended inquiries of the four programs causes students to confront the reality of research where results are not clear and where further work must be done or the work of others looked to for guidance in lifting uncertainty.

Table 2. NSES teaching standards and coverage in four programs

Science Teaching Standards (NSES, p. 52) Change in emphasis and movement toward desired educational status	SFT	GTF	TES	FAST
• Understanding and responding to individual students interests, strengths, experiences, and needs	X	X	X	X
• Selecting and adapting curriculum	0	0	0	0
• Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes	X	X	X	X
• Guiding students in active and extended scientific inquiry	X	X	X	X
• Providing opportunities for scientific discussion and debate among students	X	X	X	X
• Continuously assessing student understanding	X	X	X	X
• Sharing responsibility for learning with students	X	X	X	X
• Supporting classroom community with cooperation shared responsibility and respect	X	X	X	X
• Working with other teachers to enhance the science program	X	X	X	X

X: Identifiable in program

O: Not identifiable in program

Table 3. NSES assessment standards and coverage in four programs

Assessment in Science Education (NSES, p. 100) Change emphasis and movement toward desired educational status	SFT	GTF	TES	FAST
• Assessing what is most highly valued	X	X	X	X
• Assessing rich well structured knowledge	X	X	X	X
• Assessing scientific understanding and reasoning	X	X	X	X
• Assessing to learn what students do understand	X	X	X	X
• Students engage in ongoing assessment of work and that of others	X	X	X	X
• Teachers involved in the development of external assessment	O	X	X	O

X: Identifiable in program

O: Not identifiable in program

Table 4. NSES content standards and coverage in four programs

Science Content Standards (NSES, p. 113) General change in emphasis and movement toward desired educational status	SFT	GTF	TES	FAST
• Understanding scientific concepts and developing abilities of inquiry	X	X	X	X
• Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science	X	X	X	X
• Integrating all aspects of science content	X	X	X	X
• Studying a few fundamental science concepts	X	X	X	X
• Implementing inquiry as instructional strategies, abilities, and ideas are learned.	X	X	X	X

X: Identifiable in program

Table 5. NSES content standards and inquiry promotion and coverage in four programs

Science Content standards (NSES, p. 113) Change emphasis to promote inquiry and movement toward desired educational status	SFT	GTF	TES	FAST
• Activities that investigate and analyze science questions	X	X	X	X
• Investigations over extended periods of time	X	X	X	X
• Process skills in context	X	X	X	X
• Using multiple process skills - manipulation, cognitive, procedural	X	X	X	X
• Using evidence and strategies for development or revising of explanation	X	X	X	X
• Communicating science explanations	X	X	X	X
• Groups of students often analyzing and synthesizing data after defending conclusions	X	X	X	X
• Doing more investigations in order to develop understanding ability, values of inquiry, and knowledge of science content	X	X	X	X
• Applying the results of experiments to scientific argument and explanations	X	X	X	X
• Management of ideas and information	X	X	X	X
• Public communication of student ideas and work to classmates	X	X	X	X

X: Identifiable in program

> Scientific inquiry: Students should be actively involved in exploring phenomena that interest them both in and out of class. An important apart of students' exploration is telling others what they see, what they think, and what it makes them wonder about (p. 10).

Comment: The voluntary nature of the Korean programs, the open-ended, outdoor research of the American programs, the community nature of all four programs helps ensure a sense of fun and excitement.

> The scientific enterprise: It is important for students to understand how science is organized because, as adults in a democracy, they will be in a position to influence what public support will be provided for basic and applied science (p. 14).

Comment: In all four programs students have the explicit experience of a community enterprise. They are held to high performance standards by the scrutiny of peers and teachers and become aware of how scientists and technologists contribute to public affairs.

The nature of technology

> Technology and Science: By undertaking design projects, students can encounter technology issues even though they cannot define technology. They should have their attention called to the use of practical knowledge to solve problems before the underlying concepts are understood (p. 43).

Comment: Since each program has a problem-solving component, the functions of technology are apparent. In each program there is a joining of practical and applied knowledge.

> Design and systems: Children should design and make things with simple tools and a variety of materials. They should identify a need or opportunity of interest to them, and then plan, design, make, evaluate, and modify the design with appropriate help (p. 49).

Comment: In all programs students have an extended experience in using simple tools and materials as they plan, make or operate on, and modify their devices and other products.

> Issues in technology: Understanding the potential impact of technology may be critical to civilization. Technology is not innately good, bad, or neutral. Typically, its effects are complex, hard to estimate accurately, and likely to have different values for different people at different times (p. 53).

Comments: The social impact of technology is most extensively studied in GTF and FAST, which have a focus on environmental impact of human interaction with natural and artificial environments. The SFT gives students a unique picture of the historical import of technology being built around study of historically important technological artifacts.

Ⅲ. Analysis of TIMSS factors contributing to student achievement

Before proceeding, insight about factors that may contribute to more effective guideline-based curricula can be gotten by comparing the programs on the basis of the four factors reported in the TIMSS literature as distinguishing science and mathematics curricula. No effort is made here to relate TIMSS findings to the reported programs in the present paper. However, the TIMSS categories have on analysis proven useful in pointing up substantial structural and functional difference and similarities in the programs.

1. Curriculum

Each program described in the proceeding papers has a distinctive and carefully organized structure while retaining the characteristic of its thematic or project style.

- Thematic program GTF and SFT are less defining than the project program TES and FAST. Themes require the students to identify the problems to be solved. The project programs define the original problem allowing the student to identify and confront subordinate problems as the project develops.
- Project programs TES and FAST and the thematic curricula of GTF and SFT, both are characterized by their intent to produce products. Neither the thematic nor the project experience is complete until there is a product.
- The Korean TES and SFT program are out-of-school programs while the American GTF and FAST program are in-school programs.
- Comparing typical Korean and American classroom science activities with the four programs, the latter require far more input from the student in terms of duration of engagement and far more creativity from the student in terms finding solutions and are more closely related to the operations of professionals dealing with real-world problems.

2. Teaching

The activity of teaching associated with the four programs shares many similarities but differs considerably from typical classroom teaching practices.

- Comparing teaching in the four programs, the roles of teachers are very similar, the teachers identify the theme or project and then step back into the roles of mentor, facilitator, and psychological supporter. But the FAST program only is delivered the regular teacher. The other three programs involve outside teachers delivering all or part of the instruction.
- Comparing teaching in typical Korean and American classrooms with that in the four programs, the four programs require more time in preparation, in part, because of the unknown nature of student needs.

3. Lives of students

The four programs describe two very different kinds of impacts on the lives of students. The two Korean programs, TES and SFT, engage students during out-of-school time, club time, vacations, after school, and weekends. The two American counterpart programs, GTF and FAST, are partially or wholly oriented to the school day with a homework component. This has consequences.

- Comparing students' commitment to the program, the TES and SFT are voluntary and the GTF and FAST are part of the regular school program.
- Comparing students' control over time, the TES and SFT can control the amount of time devoted while the GTF and FAST students are required to put in a base-line number of hours. The latter students, of course, have the option of expanding the time of commitment in the at-home period.
- Comparing students' rewards and recognitions, TES and SFT students are given external public recognition for their participation, while GTF and FAST students receive only the personal satisfaction of participation and the recognition of peers and teachers. The TES students developing activities for a science festival publicly teach younger students. Later they can be further recognized by designated as mentors, and they have opportunities to share their knowledge with others in their schools.

4. Lives of teachers

Teachers involved in laboratory work or research programs usually must make a greater commitment of time than teachers relying on typical didactic delivery of curriculum. When the curriculum is of a thematic or project nature, the time commitment is usually markedly increased because resources must be found and acquired, not just picked out of a pre-existing inventory. The additional time requirement is universal, but there are other individuating features revealed in these curricula.

- Comparing commitment to the program, the TES teachers were volunteers while the SFT, GTF, and FAST teachers were teaching under assignment or teaching as part of a university course. It is certainly possible that volunteer and regularly assigned teachers can be highly committed to a program, but in the main the volunteer has an extra commitment.
- Comparing teachers' rewards and recognitions, TES and SFT teachers were give external public recognition for their participation. GTF and FAST teachers received only the satisfaction of a job well done and occasional thanks from parents of students. Korean teachers not only work with students but are recognized by local peers in workshops as well as by international peers through journals.

Ⅳ. Analysis of programs using key criteria

To get at the structural details of the four programs, analysis was made using key criteria suggested by Posner & Rudnisky (1997) - rationale for curriculum, content and scope, process of implementation, and assessment strategies (Table 6, 7, 8, & 9)

The key criteria provide a very revealing view of the programs.

- Two of the programs are designed as outside augmentation of the school curriculum (SFT and TES). One is an in-school augmentation (GTF), and one a part of the regular curriculum (FAST).
- All programs but TES are interdisciplinary. TES is multidisciplinary in that each activity deals with a single discipline or single technology, and there are several disciplines and technologies represented.
- All programs have students engaged in some kind of individual or group research.
- A variety of techniques are used to stimulate students research, including structured field trips (SFT, GTF), viewing of relics (SFT), teacher suggestions (SFT, TES), and specific program-designated projects (FAST).
- The SFT, GTF, and FAST programs are designed to be used with a small number of students, a class size group. In contrast TES program is designed to reach well over a thousand students when all of its different components are summed. Student numbers involved in SFT, GTF, and FAST can be multiplied by simply replication of the experience.
- Working groups in all four programs are 4-5 students.
- The SFT and TES programs are designed to recruit volunteers, while the GTF and FAST programs are designed to be delivered to groups of regular students in an existing classroom.

Table 6. Comparison: rationale for curriculum of the four programs

Criteria	SFT	GTF	TES	FAST
Rationale for Curriculum	• SFT is designed to be an out-of-school, informal, interdisciplinary, theme-centered curricular experience joining scientific inquiry and sociocultural study. • SFT isdesigned to involve students in research on a science-related historical theme that serves as an instructional guide to generate scientific questions that are solved in integrated open-ended inquiry. • SFT is designed under university and museum leadership.	• GTF is designed to be an in-school program. • GTF is designed to engage students in a cluster of formal and informal theme-centered interdisciplinary curricular experiences joining scientific inquiry with technological and societal problem solving and sociocultural study. • GTF is designed to be delivered by disciplinary-degree graduate fellows as part of a program to develop professional commitment to science education from K through the graduate level. • GTF is designed to give university fellows a flavor of work in partnership with secondary schools.	• TES is designed to be an out-of-school, informal, project-based curricular experience providing multidisciplinary experience in science and technology. • TES is designed to engage secondary students in developing science activities to teach elementary students about science and technology in a festival format. • TES is redesigned each year under the leadership of an association of teachers.	• FAST is designed to be a formal, in-school project-based interdisciplinary curriculum joining scientific inquiry with technological and societal problem solving. • FAST is designed to involve students in doing science by conducting laboratory and field investigations to solve technological problems. • FAST is a nationally disseminated secondary curriculum incorporating project-based activities.

Table 7. Comparison: content and scope of the four programs

Criteria	SFT	GTF	TES	FAST
Content and Scope	• SFT uses artifacts and relics in historical places and museums as subjects and contexts for inquiry. • SFT uses a science-cultural theme to encourage students to understand relationships among science, technology, culture, and history through research into the operation and use of technological artifacts. • SFT reached a research group of students over a period of 10 or more hours (including home assignment). • SFT student researchers are organized into working groups of 4-5 persons. • SFT students are volunteers.	• GTF uses school laboratories and field-visitation sites as contexts for inquiry. • GTF uses various environmental themes to encourage students understanding of ecological interactions between humans, other organisms, and the physical environment. • GTF reaches 10-30 students over a period of 3-4 weeks per graduate fellow working in partnership with a classroom teacher. • GTF students are organized into working groups of 4-5 persons. • GFT students are a regular classroom mix.	• TES uses school laboratories and classrooms and other sites for research and presentation. • TES uses a large selection of student and teacher-suggested projects to stimulate development of activities appropriate for elementary school children to carry out in a science festival format. • TES reaches some 125 student activity developers and student mentors and is delivered to some 775 elementary students in a science festival, using the services of 16 guide teachers and 8 evaluator teachers. • TES activity developers are organized into working groups of 4-5 persons. • TES students are volunteers.	• FAST uses school laboratories and classrooms and nearby fields for research. • FAST uses a variety of curriculum-designated projects calling for students to invent devices and devise solutions to technological and societal-impacting problems. • FAST reaches 25-30 students per classroom in some 25-40 days of instruction per year directed by a single teacher • FAST students are organized into working groups of 4-5 persons. • FAST students are a regular classroom mix.

Table 8. Comparison: processes of implementation of the four programs

Criteria	SFT	GTF	TES	FAST
Process of Implementation	• SFT has university and museum direction. • SFT students are recruited from schools. • SFT is selected by museum and university staff on the basis of recommendations. • SFT teaching is done by graduate students who have undergone training. • SFT has 4 phases: a) Preparatory phase involves staff teachers in outlining expected work and reviewing needed knowledge. b) Research planning phase involves instruction about artifacts, field trips to view artifacts, decision about the artifacts to investigate, generation of individual hypotheses about artifacts. c) Open-ended investigation phase involves carrying out investigation. d) Reflection phase involves presentation of investigation and discussion and reflection.	• GTF has school-university direction. • GTF students are regular students in partnership schools and existing science enrichment programs. • GTF Fellows are teaching associates to the classroom teacher. • GTF Fellows have undergone training. • GTF has 4 phases: a) Preparatory phase involves fellow and teacher in outlining the theme and establishing the teaching role of the fellow. b) Research planning phase involves the fellow in leading field trips and the students in planning research. c) Open-ended investigation phase involves students in carrying out investigations based on their themes in the lab and on field trips d) Reflection phase involves presentation of investigation and discussion and reflection.	• TES has professional teacher-association direction. • TES teachers undergo training. • TES activity developer and mentor students are recruited volunteers from past festival participants. Elementary school students are volunteers. • TES developer and mentor students are selected by association teachers. • TES has 4 phases: a) Preparatory phase involves teachers in setting up research teams of supervising teachers, student mentor assistants and beginner activity developers. b) Development phase involves development teams creating festival activities. Activities are demonstrated, evaluated, modified. and selected. c) Festival phaseinvolveselementary students in carrying out activities in a science festival format. Activity developers teach in the festival. d) Dissemination phase involves student mentors introducing past activities to non- • TES students. Association teachers report their work in their professional journal.	• FAST has regular classroom teacher direction. • FAST students are regular students in schools using the FAST curriculum. • FAST teaching is done by a regular classroom teacher who has undergone two weeks of in-service training. • FAST has 4 phases: a) Preparatory phase involves teachers in setting out the structure of problems to be researched or solved. b) Research planning phase involves students in defining the problem, inventing solutions, and developing work plans. c) Open-ended investigation phase involves students in carrying out investigations and making inventions, or developing their solutions. d) Reflection phase involves presentation of inventions, research or solutions, discussion, and reflection.

Table 9. Comparison of assessment strategies of the four programs

Criteria	SFT	GTF	TES	FAST
Assessment Strategies	• SFT student assessment is based on evaluation of student-created records of investigation of each project, transcriptions of student interviews, taped student presentations, discussion, and field notes. • SFT program evaluation is based on student and staff assessment. • SFT reports strong measure of success by all evaluators.	• GTF student assessment is based on written and operational evidences. a) Written evidence includes student journals and portfolios, concept maps, and knowledge inventories. b) Operational evidences includes participation in discussion, appropriate care of living organisms, and demonstration of ethical behavior. • GTF program evaluation is based on students assessments and partnership teachers and fellows assessments. • GTF reports strong measure of success by external evaluators, students, and teachers.	• TES student assessment is based on multiple methods according to the groups involved. a) Activity developers Data is systematically gathered about students ability, understanding, interactions with colleagues, and their teaching. b) Mentors: Data are collected on dissemination of activities and their mentorship. c) Elementary festival participants Data are collected on perceptions of effectiveness of activities in achieving specified objectives. d) Teacher evaluators Data are collected on their evaluation of project activities. • TES program evaluation uses all the above evaluation in evaluation of program. • TES reports strong measures of success by all evaluators.	• FAST student assessment is a dynamic part of its teaching methodology. The ongoing formative evaluation process includes observation of student participation in whole-class and small-group discussions, critiques of student projects, and performance of laboratory investigations as well as tests, interviews, and self-rated scales completed by each student. • FAST program evaluation is multidimensional, involving national studies using standardized test data, in-class observation, and comparative studies of FAST and non-FAST students of TIMSS. • FAST reports a strong measure of success on all evaluations

- The SFT and GTF programs use university graduate students as organizers and deliverers of program and this implies the support of a university faculty. TES and FAST rely on classroom teachers.
- Each of the four programs employs a 4-phase structure of program delivery. Identifiable in the SFT, GTF, and FAST programs are 1) a preparatory phase or orientation and introduction to the theme or project; 2) a planning phase or time of hypothesizing, inventing, and designing; 3) a research or construction phase or time to carry out the plan: 4) and a reflection phase or time to present products and to reflect on their significance. The TES program has 1) a preparatory or orientation phase; 2) a development phase where planning, invention, and research are joined, 3) a public presentation phase where student-invented activities are taught in a science festival format; and 4) a dissemination phase where the activities once used in the festival are shared with other students.
- Assessment of students in all four programs is intensive, involving ongoing formative appraisal of products and behavior.
- Assessment as part of reflection in all four programs causes the student to become introspective as they operated as scientists and technologists.
- Students are involved in product assessment in all four programs.
- Each program has undergone summative evaluation by staff and outside evaluators.

V. Considerations for program development

The authors advance all generalizations from the analysis of the four programs as hypotheses. However, in this role these hypotheses may be useful to the community of curriculum developers, for they cast light on two curricular approaches that because of their open-ended structure have the capacity of providing experiences in science that satisfy both the language and the intent of the guidelines. Though this study began with the assumptions that it would be commonalties that would provide the most valuable insights for building future guideline-based programs, on reflection it has been found that dissimilarities give as much or more guidance since they suggest a range of opportunities. In the section that follows there are listed characteristics of the four programs that offer hypothetical considerations that may prove of value to future curricular designers.

1. Adherence to national guidelines

There is a remarkable cross-national adherence to curriculum guidelines shown by the four programs. Analysis indicates that all four programs evidence satisfaction of the Korean science objectives as well as the content, teaching, and assessment standards of NSES. It is apparent that program conceptualizers and developers have employed techniques that allow students to experience science and technology as envisioned in the guidelines.

Consideration: Thematic-centered and project-based designs are sufficiently robust to support the guidelines for the science objectives of Korea and the assessment, content, and teaching standards set out in NSES.

2. Flexibility in factors of organization and audience

There are difference in when, how, by whom, and to whom the four programs are to be addressed.

- Programs may be successfully used in both in-school and out-side of school time. The former is found in the two Korean programs, the latter in the two American programs.
- Programs may be augmentations of the regular curriculum or be as part of the ongoing regular curriculum. The former is found in the two Korean programs, the latter in the two American programs.
- Programs may be delivered by regular teachers, specialists (for example, graduate students) or by a combination of a regular teachers and specialists. There was no preferred way in either country.
- Programs may be directed at volunteer students or regular classroom mixes of students. The former is found in the two Korean programs, the latter in the two American programs.

This mix of address would seem to indicate that the process-rich thematic and project approaches can be delivered by regular teachers or specialists, inside or outside, as an augmentation or part of the regular curriculum, to students of all abilities and still meet the guidelines. It is hypothesized that apparent national preferences in address are accidents of opportunity and situation and not dictated by any substantive limiting factors.

Consideration: The organizations of factors of address (in-school or out-side of school, regular or augmented curriculum, regular or special teacher, volunteer or regular students) are not determinants in satisfying standards when using thematic-centered or project-based approaches.

3. Teaching effort

Descriptions of the four programs indicate that thematic-centered and project-based programs require considerably more effort to deliver than the classical didactic or standard laboratory methods of delivering instruction. This stems from the open-ended nature of the thematic and project activity that is founded in the unknown. Represented here are two out-of-school programs designed to give a volunteer population of students an in-depth understanding of research and technology demanding long hours of mentoring, and two in-school programs that also require extended time to cope with the unprogrammable context.

Consideration: In selecting a thematic-centered or project-based curricular approach, the issue of the additional effort required of teachers or the use of specialist should be factored into any design.

4. Teacher/specialist and roles

In the thematic-centered and project-based programs described, the role of the teachers/specialist is changed from that of deliverers to students of didactic instruction to that of deliverers of students from the bonds of didactic instruction through mentored research and construction. Teacher/specialist become facilitators providing contexts, facilities, and resources to support the students' studies. The traditional burden of knowledge generation, through didactic instruction is removed from the teachers/specialists and placed on the student through their personal and group research. Teachers take on a role of colleague or one that is colleague-like in a common drive for product. These roles are often new to the teacher/specialist who must be trained in their workings.

Consideration: In selecting a thematic-centered or project-based curricular approach there is a need to train persons in the new roles of teacher/specialist, and this should be factored into the in-service support projected in the original design.

5. Student and roles

In these four thematic-centered and project-based programs, the students are engaged as researchers or technologists carrying out tasks that are characteristic of science and technology; thus, science and technology are practiced. Further, the student is asked to make judgments as a citizen about technological impacts. By playing out these roles the intent of authenticity of experience expressed in the guidelines is met. In this authentic environment the students receive the recognition of both peers and teacher and in some cases a much wider public acclaim.

Consideration: in selecting a thematic-centered or project-based curricular approach, designers should anticipate that students will need to be trained in these new roles and that reflection on them needs to be explicit and ongoing.

6. Assessment

Ongoing formative assessment is used in all four programs to keep the student aware of progress and the special nature of science and technology. Assessment is a joint enterprise of teacher and students with students learning how to assess and communicate about the validity of research, its modifiability as well as the functionality, and the quality of products.

Consideration: In selecting a thematic-centered or project-based curricular approach, designers need to provide training in assessment and for ongoing feedback to individual students and groups of students through intentional student-student assessment and teacher-student assessment.

Ⅵ. Conclusion

This study has been motivated by a prevailing concern that presently few curricular programs are adequately satisfying the imperatives of the science guideline of Korea and the United States (Bradley, 2000; Pak, 1997). Of deep concern is the attainment of guidelines for inquiry, the nature of science, and the nature of technology. Successful evaluated programs do exist that clearly satisfy these specific guidelines, and four of these, two from each country, have been described, tested against the national guidelines of each country, and analyzed into their organizational parts. Commentary of similarities and dissimilarities accompany each analysis and provides a series of considerations for curriculum designers desiring to use these approaches.

As a final note, it is important to recognize that these four programs have utilized two of the most effective curricular organization variants-the theme-based and the project-centered approaches available to explicate the multiple dimensions of the enterprise of science and technology. This analysis points up that the power of these approaches is in engaging students in doing science and technology.

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