Reaching Beyond the Science Education Guidelines: Project-Centered Approaches

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ABSTRACT

Two project-centered secondary school programs were studied as part of an effort to elucidate successful components for science reform-based curriculum development. The Teachers for Exciting Science (TES), and Foundational Approaches in Science Teaching (FAST) programs in Korea and U.S., respectively, are project-centered programs because their curricula are centered on the activities initiated and engaged in by the students. Students serve as principal investigators in their projects, and teachers serve as guides. Both programs were analyzed based on criteria such as curriculum design, teaching, lives of students, lives of teachers, evaluation of program, from the Third International Mathematics and Science Study (TIMSS). In the programs, teachers and students directed the development of curricula and their implementation. Students assumed teacher roles as mentors of other students. And emphasis was on development of communication skills through student-delivered talks and written papers, and professional development of teachers as educators and scientists. Participation in TES stimulated secondary school student interest in science, encouraged inquiry thinking, increased achievement in learning science, and promoted better awareness of science related to real life. FAST students practice laboratory and field techniques, experimental design, hypothesis formation, generalization, and practical implications of research as academic and applied disciplinarians. These project-centered programs have been successfully implemented in field, lab, and classroom curricula for secondary science education. Comparison of these programs will provide an opportunity for identifying key elements instrumental in successful implementation of guidelines for science education, as measured through successful outcomes.

Key words: project-centered approach, The Teachers for Exciting Science (TES), Foundational Approaches in Science Teaching (FAST)

I. Introduction

Science education reform is a global issue. The newest reform guidelines for science education in both Korea (national curriculum) and the United States (national standards) are constructive and integrative in nature, emphasizing inquiry and creative abilities as central themes (AAAS, 1993; Kim *et al.*, 1997, NRC, 1996). However, in both countries, there is growing sentiment that

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there are few curricula aligned with these new guidelines (Bradley, 2000; Pak, 1997). In fact, according to Pak (1997), although the use of inquiry approaches in instruction has been encouraged for more than 30 years in Korea, few curricula have been developed along these lines. Likewise, more U.S. inquiry-oriented curricula are needed to assist students in developing awareness and their own inquiry skills (White & Frederiksen, 1998).

While Korea and the U.S. both exhibit their typical educational approaches attempting to focus on providing guidelines-based instruction and learning opportunities, these programs rarely provide the procedures that enable teachers to actually meet the guidelines (Bradley, 2000; Pak, 1997). Recently, however, the development of a number of innovative programs indicate that both countries have begun to practice alternative approaches to curriculum characterized by teaching science as inquiry (Young, 1997) and integrative elements that complement traditional modes of instruction.

Integration means bringing together not just the disciplines of science, but the everyday contexts in which science operates in technology, the environment, and society (Holman, 1990). While disciplinary boundaries are valuable to practicing scientists, they have frequently restricted the science learning process because many concepts and solutions of practical problems involve knowledge of two, three, or more science disciplines as well as other subject areas. Concepts that apply to more than one discipline can be used to understand the interrelationship among the science disciplines (Dowling, *et al.*, 1992; Ellis & Fouts, 1997). The science programs we describe here exemplify the integration of the disciplines.

There are many places other than the formal school where students can study science. It is reported that the number of students interested in informal or out-of-school science education programs is growing (Jones, 1991), and this trend increases the importance of assessment of the efficiency of informal science activities and programs as vehicles of science education (Friedman, 1995). Studies of student experiences at science centers and museums and on tours of industrial science-technology sites indicate that these experiences are as effective or more effective than the experience in formal school in developing knowledge of science. This has been attributed to the fact that students in these informal environments observe the knowledge of science and technology in its application (Feher, 1990; Russell, 1996). Further, it is noted that teachers can increase the efficiency of students' development of experimental skills, sciences knowledge, and understanding through engaging the students in science festivals, fairs, and science competitions (Gowen & Marek, 1993). And students who experience science festivals and fairs are more likely to major at the collegiate level in science and look for jobs related to science (Galen, 1993).

Students find science activities outside the classroom cause interest and stimulate imagination and curiosity. It appears that formal science study is enhanced by the simultaneous use of informal science study. However, there is concern. Science must be seen as a serious enterprise and lessons, both formal and informal, though enjoyable, must be more than a time for fun. To prevent this trivializing of science, teachers must very systematically prepare their teaching plans, set goals, anticipate management problems, and engage in personal assessment of effectiveness.

Ⅱ. Objectives and Methods

1. Objectives of research

The primary purpose of this paper is to describe, compare, and evaluate two innovative science education guideline-based programs, one in Korea and one in the United States. In addition, this study aims to analyze common components to design, develop, and operate science education programs, which fit in the effective project-centered approaches.

The two programs have curricula characterized by elements of project-centered organization, an emphasis on the teacher-student teams directing investigations, and learning science through an inquiry approach. Both were implemented for the purpose of improving the science education experience and meeting new science education guidelines. They focus on critical issues in science education reform, including improving critical thinking skills (Anholt, 1994; Choi, *et al.*, 1998), integrating science, technology and society (Noh, *et al.*, 1998; Son & Lee, 1999), developing and incorporating inquiry (Schwab, 1962; Young, 1997), and using a constructivist approach (Young, 1997).

Comparison of these programs will provide an opportunity for identifying key elements instrumental in successful implementation of guidelines for science education, as measured through successful outcomes.

2. Methods

The programs described here are the *Teachers for Exciting Science* (TES), established in Seoul, Korea, and *Foundational Approaches in Science Teaching* (FAST), developed at the University of Hawaii.

TES is composed of K-12 science teachers and students, college of education graduate students, and representatives from the general public. Teams of teachers and students in after-school settings carry out TES project activities. Secondary-school students prepare a series of hands-on science activities that are presented at a science festival for younger students.

The following section describes how these science festivals work and how teachers and student developers interact. In analyzing and comparing these two approaches we use the following factors identified by the Third International Mathematics and Science Study (TIMSS, 1997) as contributing to student achievement: curriculum design, teaching, lives of students, lives of teachers, evaluation of program. Evidence of success is assessed for each program from data on indicators available including student attitudes, student-generated end products, teacher judgments, and national/international recognitions.

Ⅲ. Analysis of Teachers for Exciting Science (TES)-Korea

1. Curriculum Design

Teachers for Exciting Science (TES), an association of K-12 science teachers in and around Seoul, has been popularizing science and developing science education materials, advocating accurate and exciting science for all, since 1992. TES has held a science festival for elementary and secondary school students every winter since that time. Generally, the TES Science Festival has been held for 3-5 days during each winter vacation. The TES Science Festival is an event outside the formal classroom, which increases the effectiveness of the study of science.

The objectives of TES Science Festivals are seen in Table 1 below.

Table 1. TES Science Festival objectives

	TES Science Festival objectives are to enable students to
1	actively participate in science activities
2	have increased interest in science through their experiences in exciting science activities
3	discover the science principles involved in the activities through inquiry into authentic questions
4	understand that science is closely connected with daily life
5	identify principles and concepts of science involved in the activities correctly

In the 2000 TES Science Festival, 129 TES students (58 male students and 71 female students) in middle school or high school took part in organizing, preparing and presenting the activities. For preparing a science festival, TES students developed science activities, each in their own school, and then they presented their science activities to TES teachers every Tuesday. During the presentation, TES teachers commented on their science activities, and based upon TES teachers' comment, TES students modified and supplemented their science activities. This student-teacher cooperation activity has been executed continually for a period of years now. As time has passed, TES student members have been able to change existing members to new members, but TES teachers have been continually modifying and supplementing those science activities with new student members.

768 students (531 elementary school students and 237 middle school students) attended the 2000 TES Science Festival. Students who attended the event engaged in 4-6 activities, selecting from 5 contest activities and 23 open (non-competitive) activities, for a total of 28 activities (see Table 2). Sixteen teachers acted as evaluators. Each student attending the festival could select classes of various low and high levels suitable for them. Generally, TES middle school students presented science activities to participating elementary school students during the festival, and also TES high school students guided and presented science activities to participating middle school students. TES students were involved in all parts of the festival, as organizers, preparers, and presenters, and as managers in the 2000 science festival. At this festival, TES teachers only acted as guiders and promoters.

Preparation for each year's festival begins with the assessment of the goals, activities, and other factors that influenced the results of the previous year's festival. Assessment and application of findings are done in three stages, as shown in Fig. 1.

[Collecting materials]	[analyzing materials]	[application]
• Students in participation (by questionnaires) • Teachers in evaluation (by score book)	• Selecting the high-scored activity and low-scored activity for each objective	• Extracting the factors that affect attaining objective (by questionnaires)

Fig. 1. The processes of collecting and analyzing materials for evaluation and their application

Factors influencing achievement of the goals of the festival are drawn out of a systematic analysis of records of the different events. Evaluators prepare an assessment for each activity. When participants complete an activity, questionnaires that use a Likert scale (strongly disagree, 1; disagree, 2; neutral, 3; agree, 4; strongly agree, 5) are handed out. These questionnaires are also handed out to guide teachers, and to students who have been involved in the presentation of the activity. Collectively, these same questionnaires are used to assess the festival as a whole.

Creation of a science activity for a TES festival is done in four steps: (1) development, (2) presentation, (3) verification, and (4) approval. In the Development Step, a topic suggested by teachers is given to students to develop into an activity. In the Presentation Step, a developed science activity is presented and discussed in academic meetings held on Saturdays. At these meetings, the activities are modified and improved, as needed. In the Verification Step, an improved activity is tested either in the Saturday meetings or during other out-of-class time. Other teachers also try the activity with their students. Finally, in the Approval Step, successful activities are identified for use in the festival.

2. Teaching

A major role of the teacher in TES is to encourage and guide teams of students in the development of new activities. These activities are introduced to other teachers and students at academic meetings held every week. Written materials are exchanged through an internet web site (http://www.tes.or.kr).

There are three kinds of student involvement, as mentor assistants who have already successfully gone through the program's activity development phase, as new activity developers who create activities with teachers and experienced mentor assistants, and as festival participants.

It is characteristic of TES activities that student mentor assistants serve as instructors to less-experienced students. These student mentors assist beginners in all aspects of the development of festival activities.

3. Lives of Students

As students plan and organize festival events with their teachers, they develop the skills to communicate with their colleagues, teachers, and the general public. Students manage their own time because they attend the TES program after school or during other non-school hours.

TES student mentor assistants and experienced activity developers from past years introduce activities developed in previous years to non-TES students to motivate the latter to create and conduct their own investigations. All TES students have a responsibility to present to others in their own school what they have learned from the TES program. In this way, science activities developed in prior TES festivals are spread throughout the region. Because TES students help non-TES students, they must understand what they are about. Through this process of a student acting as teacher, the teaching student gains an understanding of scientific principles beyond the usual level of student experience.

4. Lives of Teachers

In addition to their roles with students, TES teachers publish materials they create with students and describe their activities in newsletters and educational journals and have a teacher exchange program with Japan. TES teachers meet weekly to present new science activities, designed with their students, to other TES teachers, who share these activities with their own students. TES teachers place activities from previous festivals on the web site. It is here that TES teachers meet non-TES students on the Q & A section in their web site.

As an alternative to knowledge-centered science education, TES teachers seek to develop experiment-based activities to improve scientific literacy. They are involved in an in-service training program for non-TES teachers, and there is a special program for non-TES teachers during winter vacation. This program is a training course for using science activities, and about 50 non-TES teachers participate in it every year.

5. Evaluation of Program

Most of the students and teachers who attended the 2000 science festival were satisfied that activities met the TES objectives. The number of student respondents was 768 and the number of teacher respondents was 16. The average rating scores were as follows: Objective 1-students 3.90, teachers 3.83; Objective 2-students 4.76, teachers 4.00; Objective 3-students 4.37, teachers 3.78; Objective 4-students 4.60, teachers 4.18; Objective 5-students 4.55, teachers 4.00 (see Table 1 & 2). For comparative purposes the rating scores were classified into 3 groups: high (scores≥4.25), middle (4.25<score> 3.75), and low (score≤3.75).

Objective 1: To get active participation

Throughout the remainder of this paper, participants who were students in the festival are called "students" and teachers evaluating the activities are simply called "teachers". Of the 28 activities in the festival, only one activity, 'Raising the Titanic', was rated high by both students and teachers on Objective 1. There were 3 activities that both teachers and students rated low, 2 activities that students rated high but teachers rated low, and 3 activities that students rated low and teachers rated high. For the remaining activities, the rating of teachers and students were close-high and middle, or middle and low.

'Raising the Titanic' involved raising and submerging a small plastic bottle in a tank of water to illustrate competition between gravity and buoyancy. The process of making the device was relatively simple, but the activity had a special character that came out in experimentation and resulted in variable outcomes. For example, experimental changes included the amount of powdered Alka-Seltzer used to produce gas and the hole size on the plastic cover over the bottle. There was not much time needed to modify the quantity of materials or the hole size; therefore, the students could concentrate on finding suitable amounts and sizes. Also success or failure of the experiment could be observed quickly, and students could readily make new trials.

On the other hand, 3 activities that were rated low by both participating students and teachers primarily involved busy work (cutting, pasting and other repetitious work) and did not include much experimentation. This indicates that participants and teacher evaluators want an active

Table 2. The degree of attainment of objectives

Activities	Objective 1		Objective 2		Objective 3		Objective 4		Objective 5	
	S	T	S	T	S	T	S	T	S	T
Let's Observe Radiation	3.80	4.00	4.67	4.00	4.06	4.00	4.42	4.00	3.99	3.00
Making a Crystal	3.90	4.00	4.81	4.00	4.32	3.00	4.47	4.00	4.47	4.00
Drawing a Sensory Map of the Human Body	3.91	5.00	4.46	4.00	4.49	5.00	4.58	5.00	4.65	4.00
Making a Moiré Scale	4.28	3.35	4.90	2.50	4.54	2.50	4.64	4.00	4.74	4.00
Coloring Using Natural Dyes	3.80	3.00	4.35	4.00	3.70	3.00	4.17	5.00	3.98	3.00
Identifying Things Reflected in a Cylindrical Mirror	3.91	2.67	4.79	4.33	4.27	3.00	4.53	4.00	4.35	3.33
Making a Periodic Watering Machine Using Siphon and Capillary Action	3.89	4.00	4.86	5.00	4.44	5.00	4.65	5.00	4.69	4.00
Generation of Electricity Using Mouth-Blown Air	3.46	3.00	4.85	4.00	4.38	3.25	4.63	4.00	4.63	3.75
Isolating Rays Using Cellophane Paper	3.48	3.75	4.74	3.75	4.17	3.50	4.52	4.25	4.45	4.00
Magic Mirror	4.59	3.50	5.00	3.50	4.66	4.50	4.76	5.00	4.66	4.00
Pocket Heater	3.96	3.00	4.83	4.00	4.38	4.00	4.66	5.00	4.60	4.00
Making DDR	3.56	4.33	4.92	5.00	4.56	4.33	4.72	4.67	4.65	4.33
Plating the Veins of a Leaf with Nickel	3.42	4.33	4.74	4.33	4.52	3.33	4.65	3.33	4.61	3.33
Top Secret	3.80	3.00	4.70	3.00	4.20	3.50	4.27	3.50	4.17	3.00
Making a Mini-Merry-Go-Round	3.92	2.67	4.91	3.67	4.51	3.67	4.67	4.00	4.70	3.67
Cooking a Hot Cake Using an Electric Wire	4.17	3.33	5.00	4.67	4.68	2.67	4.94	5.00	4.49	4.00
Making a Buzzer to Signal Rain	3.53	3.50	4.65	4.00	4.16	3.50	4.57	4.00	4.50	4.00
Air Cannon	3.90	3.50	4.94	4.00	4.42	3.00	4.72	3.50	4.55	3.50
Making Edison's Electric Bulb	3.83	4.33	4.84	3.67	4.44	4.00	4.66	4.33	4.50	3.67
Secret Letter	3.83	4.00	4.57	4.00	3.83	4.00	4.39	4.00	4.37	4.00
Let's Find a Hidden Theory in Animation	3.67	4.50	4.85	5.00	4.52	3.50	4.69	4.50	4.60	4.00
Newton's Car	4.26	4.00	4.56	4.00	4.53	3.75	4.68	4.00	4.66	4.75
Making Herron's Engine	3.97	4.50	4.58	3.00	4.20	3.50	4.62	3.50	4.58	4.50
Making a Siphon Timer*	3.78	4.00	4.61	3.00	4.39	4.00	4.50	4.00	4.44	5.00
Making a Sound Box*	3.74	4.00	4.71	4.50	4.37	4.00	4.25	5.00	4.66	5.00
Raising the Titanic*	4.52	4.25	4.89	4.50	4.84	4.75	4.73	3.50	4.78	4.25
Dance, Dance, Diode*	4.17	4.50	4.75	4.50	4.42	4.50	4.83	3.00	5.00	5.00
Exploring the Geography of the Ocean Floor Using Supersonic Waves*	4.17	5.00	4.75	4.00	4.42	5.00	4.83	4.00	5.00	5.00
Average	3.90	3.83	4.76	4.00	4.37	3.78	4.60	4.18	4.55	4.00

S: Evaluation of student festival participants *Contest activity
T: Evaluation of teacher evaluators

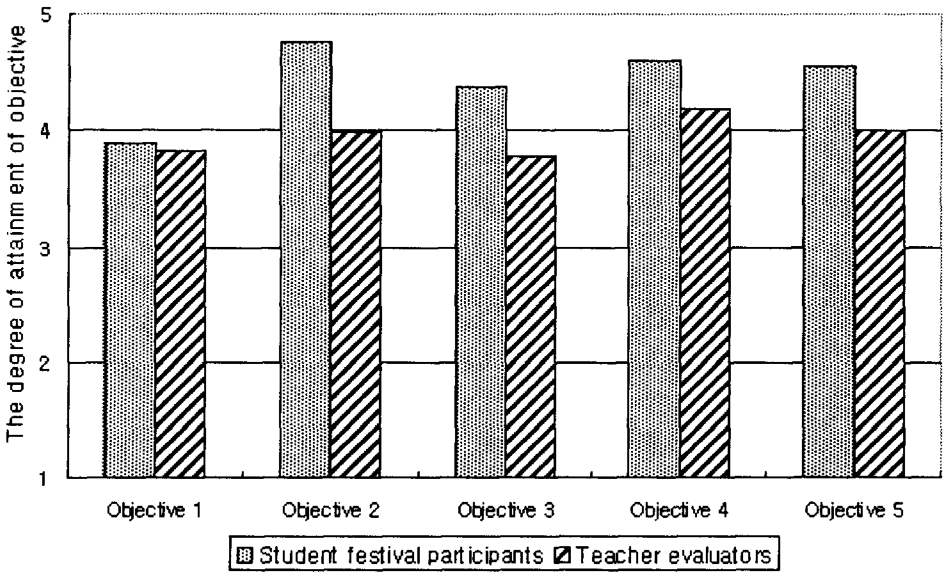

Fig. 2. The comparison of perceptions of the degree of attainment of objectives by students and teachers

mental experience involving experiments in which there are controlled variables.

The activities of 'Making a Moiré Scale' and 'Magic Mirror' were rated high by participating students, but rated by teachers as being easy activities that could be done by just following cookbook instructions. The students found hidden values in learning basic science skills in these activities. Even though they were easy, these activities seemed to look like the operation of scientists and were prized by participants.

In the case of the other three activities that students rated low and teachers rated high, teachers thought that the activities involved important scientific concepts and inquiry skills that might induce students' active participation. But students thought the activities were simple tasks, as found in 'Making DDR' and 'Plating the Veins of a Leaf with Nickel'.

Objective 2: To increase interest in science

All 28 activities were generally successful in achieving Objective 2. Among them, 9 activities were rated more than 4.25 points by students and teachers. The high level of interest in these 9 activities is verified in the large number of the participants who volunteered to try them. Most of the activities were about technologies, or used content that could not be found in textbooks or school laboratory activities.

The high-rated 9 activities used materials or subjects that involved well-known current issues or some competitions. 'Raising the Titanic' excited participating students' curiosity with its interesting and well-known title, and the active nature of the experimentation. One activity called 'Making DDR' was based on Dance, Dance, Revolution, a famous dancing computer game of South Korea. It had an attractive title, and it created a sense of enjoyment when lamps lit up as a plate was pressed down. Adding to the attractiveness of this activity was the fact that participants were allowed to take their product home. This provided a feeling of achievement. In an activity called 'Cooking a Hot Cake Using an Electric Wire' students expressed a feeling of expectation and satisfaction when they could eat food they made in the same place they made it.

In some cases, students rated activities high, but the teachers rated them low. For example, in the case of the activity 'Making a Moiré Scale', teachers expected the activity would not be attractive to students because it involved only simple measuring skill. The students, however, were excited, not by the measuring activity, but by the pattern changes of the scale in this activity. Even though the activity 'Making Edison's Electric Bulb' was simple, students were quite excited by the violent reaction of a filament made of pencil lead. We now see how important it is to be concerned about students' interests.

Objective 3: To stimulate discovery of principles through inquiry

The 7 activities rated high by students and teachers required active involvement and thinking of students. These activities required inquiry processes such as measurement, data analysis, and data processing. In the case of 'Exploring the Geography of the Ocean Floor Using Supersonic Waves', participants predicted and drew the shape of the ocean floor by using the result of supersonic generated profiles. They felt that this was what a scientist would do. 'Drawing a Sensory Map of the Human Body' also involved common inquiry processes as in the prior activity, but discovering how a sensory map can be made for various parts of the body was very appealing to the students. The activity 'Coloring Using Natural Dyes' gives students a chance to think about the science of dyeing, which is normally associated with the field of art.

For Objective 3, students rated 10 activities high that the teachers evaluated low. This difference may be due to different areas of focus by students and teachers. For example, in the activity 'Let's Find a Hidden Theory in Animation', the teachers thought that this activity did not cause sufficient inquiry since the activity was a simple construction job and did not include many inquiry processes. But students were very interested in the activity because it included the phenomenon of after-image, and they searched for ways that pictures could be moved, as in a movie. This was a different principle from the one intended.

In the activity 'Generation of Electricity through the Use of Mouth-Blown Air', the students were very curious about the investigation and tried to solve the inquiry problems by themselves. But, in the process of solving the problems, some students were interested in phenomena that teachers did not intend to be the focus. Therefore, the findings of students varied; some answers were correct and some were wrong.

Objective 4: To make connections with everyday life

More activities were rated high on Objective 4 than on any other objective by both the students and the teachers. This resulted from intentional structuring of the activities to connect with the lives of participants. Most of the activities used subjects and materials that were commonly known by the participants. Further, most examples involved common phenomena that could be observed around them.

Among the high-rated activities, 'Making DDR' was the most popular. This was not surprising because DDR is extremely well known by South Korean students. 'Pocket Heater' (a small hand-sized bag that can be kept in a pocket to warm one's hands in the wintertime) is also popular. It gave students a chance to make a thing that they have been using in their daily lives. Two other activities that rated very high were 'Drawing a Sensory Map of the Human Body', involving a topic that had a direct personal connection, and 'Cooking a Hot Cake Using an Electric Wire', which involved a technique that could be used at home.

'Raising the Titanic' and 'Air Cannon' were rated high in their connection to daily life only by the students. The difference in rating is due to a difference in understanding of the meaning of the term 'connections with everyday life'. The teachers focused on how often a scientific principle used in the activity can be found in daily life. But the students recognized connections when they used materials found in daily life. Quite obviously, there is a problem in understanding the intent of the objective. In the future, the search for connections with everyday life will include not only hidden science principles but also the way materials and familiar subjects are connected.

Objective 5: To identify principles and concepts involved in the activity

The students were generally satisfied with Objective 5, which involved the identification of science concepts, principles, and theory in the activities. Activities that were rated high by both students and teachers clearly presented objectives and gave explanations step by step. These helped students in their understanding and gave them a feeling of achievement. Still, 'Newton's Car', for which the underlying theory was not known to the students, successfully inspired spontaneous inquiry.

But some activities, such as 'Plating the Veins of a Leaf with Nickel', were rated high by students, while the teachers rated them low. As before, this difference resulted from different viewpoints of students and teachers. The students rated the activity high because they learned how to make prints of the veins of leaves, and the principles of printing and properties of chemicals were explained. Also, the students ranked the activity 'Making a Mini-Merry-Go-Round' high because they thought they knew already that the plastic bottle was rotated by magnetic force. But when teachers closely analyzed the worksheet and observed what was actually occurring, they found the activity had some missing steps needed to lead students to a proper understanding.

Two activities, Dance, Dance, Diode' and 'Generation of Electricity Through the Use of Mouth-Blown Air', used an electromagnetic induction concept. The principles and concepts involved were similar, but the teachers rated 'Dance, Dance, Diode' higher than 'Generation of Electricity Through the Use of Mouth-Blown Air'. This would indicate that the method of organizing an activity, and the materials used, influence the degree of perceived satisfaction.

Generally, it is assumed that science activities done outside school are more interesting, and can give students a greater sense of the rapid changes in science and technology, than lessons in the classroom. But in such activities, there is the danger that students may remember only the interesting and novel results of such activities, not the inherent science.

The TES Festival described here was designed to capture the positive features of the out-of-school science experience, while endeavoring to ensure that the intrinsic science is not lost. Participants in the festival were elementary and secondary school students from around Seoul, in

Korea. In the festival, participants worked through a selection of exciting science activities that were developed by students who formally went through the TES program. This student work was supervised by a group of volunteer TES guidance teachers.

Reflecting on the many dimensions of the festival, the affirmative effect seems to be on the students who have worked in the project-centered component, both those who have developed activities, and later those who have acted as mentors. These students have been engaged in the rigors of a research community producing the festival activities, refining them, teaching them, evaluating them, and later, sharing them with peers. The success of this part of the program is seen in the number of students that have volunteered each year to become developers and mentor assistants.

Ⅳ. Analysis of Foundational Approaches in Science Teaching (FAST)-U.S.

1. Curriculum Design

The FAST program was begun under the sponsorship of the Hawaii Science Curriculum Council. Development of FAST began in the summer of 1967 and continues under the aegis of the Curriculum Research & Development Group of the University of Hawaii. Since its first pilot trials in 1970, an ever-expanding number of teachers and students have participated in the program. The historical analysis shows that the FAST project survived and thrived over the past 30 years within the University of Hawaii' s CRDG/Lab School unit supported by a steady source of State funds and a stable staff curriculum development process of the FAST program (Yamamoto, 1996). FAST is an integrated, multidisciplinary, inquiry science program developed for students, ages 11 to 15, in the regular middle grades. The program consists of a three one-year sequences of activities that integrate the content of physical, chemical, biological, and earth sciences. FAST seeks to help students develop positive attitudes toward science and useful problem-solving approaches by providing them with a variety of activities relevant to the world unfolding before them. Some 6,000 teachers in 36 states in the United States, and 10 foreign countries, are using FAST. It is has been translated for use by science clubs in Japan, and into Braille for use in U.S. Translations are being used in schools in Russia and Slovakia (CRDG, 2000).

For the past 30 years at the Curriculum Research & Development Group (CRDG) of the University of Hawaii, the science section has been working on creating science programs and experimenting with new approaches to teaching integrated science. In this effort, CRDG has employed an engineering approach, taking the best available research on learning and teaching and crafting it into practical, workable applications in classrooms. The measures of success are whether the programs work in real classrooms and whether they are acceptable to practitioners.

- Developers have struggled with the same concerns and issues identified by Chisman (1990).
- Validly representing the factual and theoretical knowledge of the disciplines of science.
- Engaging learners in the processes of scientific inquiry and developing scientific habits of mind.
- Involving students in direct experiences in both laboratory and field studies.
- Developing positive attitudes toward science among both teachers and students.
- Engaging students authentically in studies of the relationships of science, technology, and

society.

- Resolving the tension between the wish to provide for science literacy for all, and the need to prepare future scientists and technologists.
- Concerns over the disintegrative nature of content-based standardized testing.
- Limitations of teacher preparation systems, and the need for continuing professional development (Young, 2000a).

In the process, a K-12 sequence of integrated science programs that rely on the disciplines of knowledge (King & Brownell, 1966) for guidance in curriculum theory, and constructivist learning theory for insight into how to organize instruction to meet the needs of learners in schools, has been developed. Young (1997) describes some common characteristics the programs share.

- They are all inquiry-based, with teachers and students asking questions about nature, and students doing investigations about 80% of the time.
- They are student-centered with students constructing their knowledge of the world from the investigations they do.
- They are based on a constructivist philosophy, which asserts that knowledge construction is incremental. Instruction is designed in sequences that help students connect new knowledge to what they already know.
- In these programs, students interact with one another. We want them to talk to one another, to share their ideas and their data, and discuss different points of view in an open manner.
- The teacher is a facilitator and learns along with students as they co-construct their knowledge.
- Students learn science by studying first their own local environment-whatever that may be-then comparing their understanding to other environments. There is a continual movement from local understanding, to global applications, to local implications.
- A variety of teaching strategies based on the best research on learning and teaching are incorporated into the design. Sometimes students work individually, sometimes in small groups, and at other times with the whole class. Throughout, there is an emphasis on teamwork and collaboration.
- The programs emphasize integration-building connections among the disciplines of science, other subject areas, and out-of-school experience. Students study a variety of sciences each year in an interconnected way, rather than isolating chemistry, physics, or biology.

FAST students develop a scientific world view by doing science-generating questions, designing and carrying out experiments, collecting and analyzing data, researching, drawing conclusions based on evidence, writing reports, and communicating findings.

As scientists, students design many of their own experiments. In a physics unit, for example, students formulate theoretical models of heat and light and test their models. They also invent and build tools and instruments for their investigations. As technologists, students apply recently mastered scientific principles, such as the concepts of buoyancy and density in designing and constructing a working model of a submarine. By experiencing multiple roles (scientist, engineer, technologist, politician, and citizen), students practice and reinforce skills from many areas, including mathematics, written and oral communication, and social studies. FAST meets the standards and goals for science education set by the NRC (1996) and AAAS (1993). Alignments have been verified by both project staff and independent, external evaluators.

FAST uses a project-centered approach throughout the three years of the program. In some cases, the teacher may pose a problem or task for the student team investigation, while in other cases, the questions for investigation are generated by students.

2. Teaching

In its commitment to modeling the experience of practicing scientists, FAST relies on students working on projects in research teams to generate the theoretical content of the program. To achieve successful group generation of an acceptable conceptual structure, between 70% and 80% of the students' time is spent at the laboratory bench or in field studies. The remainder is devoted to data analysis, small group or class discussion, literature search, and report writing. The teacher becomes the research director, a colleague who stimulates and facilitates ever deeper probing into problems. Students become researchers who create hypotheses, design and conduct experiments, organize and analyze data, and develop a team consensus on conclusions upon which study will progress.

The FAST research team approach can tolerate misconception because the contexts of investigation are carefully sequenced so that hypotheses and conclusions, once developed, are constantly retested. In FAST, students learn that science proceeds through a process of constant reconstruction of explanation in light of new findings. As counterweights to the dynamics of theoretic evolution and revolution, foundational concepts of science, once defined, are seen to generally remain intact. Out of these foundational concepts has come the building of our present scientific enterprise.

Instead of disseminating information, the teacher directs the learning process by defining tasks, asking questions, giving suggestions for further investigations, and maintaining an atmosphere of collaborative inquiry.

The *FAST* teacher

- is the research director-facilitator who coordinates activities, sets tasks, encourages, prods, and keeps inquiry open.
- focuses students' attention on laboratory and field techniques, experimental design, hypothesis formation, generalization, and practical implications of research.
- provides materials and directs an efficient, safe classroom/laboratory facility.
- arranges for access to the laboratory, field, and other sources of information, and provides adequate opportunity to complete assigned work.
- provides incentives and equipment for students to pursue open-ended experimentation, is alert to the intellectual difficulties of students, and arranges task assignment, grouping, and presentation to foster development of each student's potential.
- engages students in self-evaluation.
- encourages mutual sharing of ideas and labor (Young & Pottenger, 1992)

3. Lives of Students

FAST is based on a constructivist philosophy of learning. Among the constructivist assumptions are the beliefs that all learners construct their own knowledge and understanding from their experiences, that this knowledge development is incremental, and that the knowledge we hold in common is developed and clarified through interactions with others.

Translated into classroom practice, these beliefs mean that students in FAST engage in experiential, hands-on learning. Investigations are carefully sequenced and connected to previous knowledge, both in school and out of school, to enable students to build their knowledge. Further, FAST investigations conducted in small groups enable students to share data, ideas, and experiences. Class discussion following each investigation is essential to identify and clarify generalizations and to make sense of data.

The FAST student

- is the researcher working to explain the raw data of experimentation and the implications of findings.
- observes, formulates hypotheses, designs experiments, and seeks the practical significance of research.
- maintains a safe and functional experimental environment.
- uses research as a primary source of concept development, and knows that research may be done in field, laboratory, or from published resources.
- explores a given idea as extensively as time allows.
- accepts challenges and works to extend personal capacity.
- seeks to evaluate personal achievement.
- develops the attitudes of a participant in scientific community (Young & Pottenger, 1992).

4. Lives of Teachers

CRDG provides a full complement of support services, including

- pre-implementation planning at the school/district level,
- pre-implementation professional development for teachers,
- implementation support, including continuous professional development, assistance with local adaptations, assistance with program evaluation, and on-line technical assistance.

A proven professional development component prepares teachers to teach in ways consistent with the science standards. The professional development component is aligned with the NRC (1996) and the National Staff Development Council's standards for professional development. Components that impact the lives of teaches and what they do include:

- Initial Training: The CRDG requires teachers implementing FAST to participate in a 10-day, 70-hour institute prior to teaching FAST. There are separate institutes for each of the three FAST courses. Institutes are most often delivered on site. Participants receive a full set of materials including all teacher and student instructional guides. Instructors use an institute manual provided by the developer to guide instruction. Teachers are engaged as learners, conducting the investigations like their students will do. Participants work through the year's course spending approximately 50% of the time developing understanding of content and 50% developing understanding of inquiry methodology through modeling, discussion, and practice.
- Follow-up Coaching: CRDG offers an extensive program of support services for teachers to

ensure successful implementation. A local coordinator, with support from CRDG, provides frequent classroom coaching and science team meetings the first year. Long-term institutionalization includes professional development seminars, network support, and a teacher-as-researcher component, in which teachers collect, analyze, and publish findings on classroom activities leading to student improvement.

- Networking: CRDG provides ongoing professional development support through a toll-free phone number and the Internet (electronic newsletters, Web site, e-mail question and answers, etc.). Teacher institutes include mastery of these networking skills as a key feature.
- Implementation Review: The local coordinator, with support from CRDG, monitors implementation progress through observation, discussion, and teacher surveys. The local coordinator uses the data to diagnose the necessary adjustments, provide support as appropriate, and give feedback into the planning process for ongoing improvement (Son, *et al.*, 2001; Young *et al.*, 2000).

5. Evaluation of Program

Numerous multi-state, impact evaluation studies over the last twenty years have been conducted on FAST, including pre-test, post-test, comparison group designs using norm referenced, criterion referenced, and performance measures. The student populations represented both urban and rural schools and a wide range of ethnic diversity. Selected classrooms represented diversity by student achievement levels, family income levels, and teacher background and experience. Several studies examined the impact of grouping for instruction on student achievement (Allen, 1977; Dekkers, 1978; Shelly, 1989; Gore & Pogrow, 1991; CRDG, 2000; Pauls *et al.*, 1999; Young, 2000b).

Findings from these studies consistently show FAST students to have

- significantly higher gains in manipulative, laboratory skills, using the performance-based Laboratory Skills Test.
- significantly higher science achievement (California Achievement Test)
- significantly higher performance on basic thinking and problem-solving skills (California Achievement Test)
- significantly higher performance on creative thinking measures (Torrance Tests of Creative Thinking)
- significantly higher achievement among students in Slovakia (TIMSS international testing)

In addition, FAST has been independently evaluated by numerous external agencies. Among the recognitions given it, FAST has been

- described as both a curriculum aligned with national science standards, and a results-based professional development by the Eisenhower National Clearinghouse in Ideas that Work: Science Professional Development in 1999 (Young, 1999).
- included as an effective teacher learning program for improving student learning in the National Staff Development Council's What Works in the Middle: Results-Based Staff Development in 1999 (National Staff Development Council, 1999).
- described in Best Practices from America's Middle Schools as a successful instructional

practice in 1999 (Watson, 1999).

- identified as one of three research-based, effective science "skill and content" reform models in a nationwide search by the Northwest Regional Educational Laboratory for the U.S. Department of Education's Catalog of School Reform Models in 1998 (U.S. Department of Education , 1998).
- identified as one of five effective science programs in Results Based Practices Showcase 1997-1998, a nationwide search by the Kentucky Department of Education in 1997 (Kentucky Department of Education, 1997).
- described in Promising Practices in Mathematics and Science Education, published by the U.S. Department of Education, as addressing Goals 2000 and meeting the new standards in science education in 1994 (U.S. Department of Education, 1994).
- cited and described in Crossing the Tracks: How Untracking Can Save America's Schools as an exemplary program in science for heterogeneous student classes; called the "best of the American science materials currently available" in Middle School Exemplary Curricula: Top-rated Thinking-in-Content Curricula for All Middle School Students in 1991; validated as an effective science program by the Program Effectiveness Panel (PEP) of the U.S. Department of Education in 1986 (Son et al., 2001; U.S. Department of Education, 1998; Young, 1998).

V. Findings and Conclusions

TES and *FAST* each employ a project-centered approach to learning which engages teams of students in designing and carrying out their own investigations. TES is an after-school or out-of-school activity that engages those interested in science in collaborative projects with teachers and other students to design and conduct inquiry activities for new learners. Both the students who create the learning activities, and those who participate in them, benefit.

FAST, on the other hand, is a comprehensive, in-school program that attempts to engage all learners in scientific inquiry. *FAST* instructional strategies value students learning through inquiry, as well as learning about inquiry.

While the two programs are different, they both demonstrate an impact on learning that indicates the project-centered approaches are effective in achieving some of the goals of guidelines-based instruction. Among the common elements are the following:

- Teaching and leaning science as inquiry
- Teacher-student teams
- Emphasis on communication of what has been learned to others through seminars, papers, or teaching/learning activities
- They are inquiry based with teachers and students asking questions about nature and students doing investigations.
- They are student-centered with students constructing their knowledge of the world from the investigations they do.
- They are based on a constructivist philosophy which asserts that knowledge construction is incremental.
- Students interact with one another, sharing ideas and data, and discussing different points of view in an open manner.
- The teacher is a facilitator or research director rather than disseminator of knowledge.

- Sometimes students work individually, sometimes in small groups, and at other times with the whole class. But, throughout there is an emphasis on teamwork and collaboration.
- The programs emphasize integration-building connections among the disciplines of science, other subject areas, and out-of-school experiences.
- Investigations are also focused on interactions of science and society by dealing with both local and global applications.

The project approach also reflects how science operates, including:
- its questioning nature
- seeking evidence vs. opinion
- collaborating-drawing on the best ideas of all
- replicating-not focusing on single events, but looking for patterns and relationships
- predicting and testing of ideas against evidence
- decision-making based on the best available data.

Thus, we find that the project-centered approaches, such as those described and analyzed here, can contribute significantly to achieving the goals of guidelines-based instruction, both in the classroom and outside of it.

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