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Development of the K-12 Science Literacy Education Program focused on the Earth System and Environment

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Abstract: The purpose of this study was to develop a program based on the Earth system based program to help students achieve science literacy. This program was designed to be connected across grade levels, and contents of the program were constructed to have meaningful interdisciplinary context. All the activities in the program were inquiry-based, and understanding of the nature of science was considered essential throughout the program. In addition, appreciation and stewardship for the Earth system were systematically emphasized on any grade level. Design of the program applied U.S. National Science Education Standards for the quality of and conditions for school science programs.

Keywords: Earth system, science literacy, nature of science, Earth appreciation, stewardship

Introduction

Science literacy refers to scientific knowledge and understanding that the general public needs to know to make informed decision for various issues (Kim *et al.*, 1999). For many years and in many countries, educating future citizens to achieve adequate science literacy has been considered an important goal of science education. Many previous studies have however repeatedly reported that students and adults fail to possess adequate science literacy in spite of the emphasis on it (Marshall *et al.*, 2002; McComas *et al.*, 1998; National Science Board, 1996). Based on these reports, the need for a new approach for achieving science literacy emerged in school science education.

This study was conducted as one of those new approaches to achieve science literacy in school science education by developing a theme-based science literacy education program focusing on appreciation and stewardship for the Earth system and environment. According to the National Science Education Standards (NRC, 1996), a science education program should place less emphasis on textbook and lecture-driven curriculum and deemphasize broad coverage of unconnected factual information. At the same time, a science education program should place more emphasis on curriculum that includes natural phenomena and science-related social issues which students encounter in everyday life, connecting science to other school subjects such as mathematics and social studies, and coordinating the science program across grade levels (NRC, 1996). To meet these demands, the program developed in this study was constructed focusing on the central theme, the Earth system, which can connect science to other subjects and can include natural phenomena and science-related issues in everyday life. This program, named the Earth System and Environment Program (ESEP), was also designed to be adaptable across grade levels.

Rationale

Why a person needs to be scientifically literate is closely related to what science literacy is. Science is immensely inter-woven into people's life and society in today's world. Thus a person needs to possess enough knowledge and understanding about science to make relevant and responsible decisions for various issues which he/she faces in everyday life (AAAS,

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1989; Hazen and Trefil, 1992; Kim *et al.*, 1999; NRC, 1996). In addition to this basic need, a person needs to be scientifically literate to enjoy intellectual and aesthetic enrichment of life or to appreciate any deep intellectual understanding of the world (Hazen and Trefil, 1992). Just as illiterate people are cut off from an enriched and intellectual world, scientifically illiterate people would also have limited access to such a world. Thus, to possess adequate science literacy is important to quality of life and the effort to possess it should be pursued from cradle to grave.

Studying about the Earth system could help to achieve science literacy because understanding of the Earth system brings not only knowledge about it but also appreciation and stewardship for it (Mayer *et al.*, 1992). Appreciation and stewardship for the Earth system, that is also our environment, can in turn foster relevant and responsible decision-making for many important issues concerning human life and environment (Fortner and Constantinou, 2003; Orion and Fortner, 2003). Moreover, appreciation, stewardship and knowledge for the Earth system will certainly provide a solid foundation to enjoy the enrichment of the world.

Knowledge, inquiry and attitude were suggested as three aspects of science literacy by Zeitler and Barufaldi (1988). Studying Earth systems science could contribute to each of these aspects. As Mayer (1991) pointed out, Earth Systems Education could make philosophical, methodological and conceptual contributions to science education. With the advancement of technology, human knowledge about the Earth has been increasing. Along with knowledge has come a realization that conceptual change is required to have holistic and systematic understanding about the natural world (Assaraf and Orion, 2005). The National Science Educational Standards advise that scientific knowledge should be taught and be understood in meaningful context (NRC, 1996), that is, in relation to processes and events students regularly encounter. Just as daily events do not happen in isolation, neither do science processes derive from single disciplines or unconnected sequences. Thus holistic and systematic understanding will surely make a conceptual contribution to the knowledge aspect of science literacy.

The importance of scientific inquiry in science education has been repeatedly emphasized, for inquiry based science teaching is an essential part of science education (AAAS, 1989; NRC, 1996). However, misunderstanding about scientific methods has been persistent, too (Frodeman, 2000; Mayer, 1991; McComas, 1998). Although various methods are used in scientific investigations, conducting proper experiments was often mistaken as the one and only scientific method. To study the Earth system, non-experimental methods such as descriptive, interpretive narrative, or historical method are used as much as experiments (Kim, 2002). Thus, studying the Earth system could provide opportunities to learn and use many different scientific methods and it will make methodological contribution to inquiry area of science literacy (Frodeman, 2000; Mayer, 1991).

By studying the Earth system, philosophical contributions could accrue to the attitude component of science literacy. Understanding deep time and the vastness of the universe could impact humans' view toward nature, providing different angles to see the world and to think about the place of human beings in it (Mayer, 1991). Historically, anthropocentric world views have been responsible for many global issues of resource use, development, and short-term solutions. A worldview centered on the health of the planet is fostered by Earth systems science.

Development of the Program

The first step to develop the ESEP, a new science literacy education program, was to choose the central theme that can connect science and other school subjects and include science issues in everyday life. The Earth system is our environment, where we live, and it is studied in many fields of science as well as across the curriculum. Therefore, choosing the Earth system as a central theme makes it possible to connect many contents of science in meaningful context, both

Table 1. Earth Systems Understandings (ESU), the framework of the Earth Systems Education (abbreviated. For complete framework, see Mayer and Fortner, 1995, 39 p)

ESU #1	Earth is unique, a planet of rare beauty and great value.
ESU #2	Human activities, collective and individual, conscious and inadvertent, affect Earth.
ESU #3	The development of scientific thinking and technology increases our ability to understand and utilize Earth and space.
ESU #4	The Earth system is composed of interacting subsystems of water, rock, ice, air, and life.
ESU #5	Planet Earth is more than four billion years old and its subsystems are continually evolving.
ESU #6	Earth is a small subsystem of a solar system within the vast and ancient universe.
ESU #7	There are many people with careers that involve study of Earth's origin, processes, and evolution.

academically and conceptually (Orion and Fortner, 2003).

The next step was to build a framework for the program. The framework consisted of three criteria, each related to one of the aspects of science literacy suggested by Zeitler and Barufaldi (1988): context, inquiry, and the nature of science.

The first criterion was context because scientific knowledge should be understood in the meaningful context of human experience (NRC, 1996). The Earth Systems Understandings (ESU) was used to build the meaningful context for the program (Table 1). The Understandings were suggested by the Earth Systems Education program, a curriculum reform effort of the 1990s, as a framework to understand the Earth, our environment, better (Mayer *et al*, 1992). Since this new program was focused on the Earth system and environment, these seven ideas worked well to build a meaningful context.

The second criterion was inquiry. Focusing on the inquiry criterion was mainly done to dispel the myth of 'the scientific method' as the only way to do credible science. Program components clearly demonstrate applications and values of investigative methods that do not involve experimentation only.

The third criterion was the nature of science. The nature of science typically refers to the values and assumptions inherent in scientific knowledge and the development of that knowledge (Lederman and Lederman, 2004). Understanding the nature of science is an important component of achieving science literacy (AAAS, 1989, NRC, 1996). Although the specific aspects and issues about the nature of science are not unanimously agreed among scholars (Lederman *et al*., 2002), a consensus of key ideas of the nature of science appropriate for K-12 students has been agreed in some degree (Lederman and Lederman, 2004). Thus, the ESEP was based on those key ideas of the nature of science for K-12 students. Understanding the nature of science could help to make a bridge between the knowledge of the Earth system and relevant environmental decisions because, in many cases, disputes arise not from the lack of knowledge but from an inadequate understanding of the nature of science (Spray and McGlothlin, 2002).

Once the framework was built, the next step was to structure the program and design it based on the framework. The ESEP was built with vertical and horizontal connections. Three modules, focused on elementary school, middle school, and high school level, were designed. The module for elementary school was designed to explain that science is a human endeavor and to introduce various scientific enterprises. The module for middle school was designed to introduce the Earth system and the module for high school was designed to teach the nature of science explicitly. The content and methodology sequences match the criteria for achieving science literacy. Students are first introduced into science through various human activities related to science and then, learn about our environment in a systematic view through inquiry. Finally students learn about the nature of science.

Each module contains four units, also aligned in sequential context, although each unit works well individually. The first unit of each module focuses on appreciation of the Earth and nature, the first of seven understandings of the Earth system. The second and

Table 2. Description of sample units in high school level, focusing on Earth appreciation and stewardship

Unit Title	DaVinci Code?	Interpret the Environment
Focus	Earth Appreciation	Stewardship for the Earth
Purpose	Students will learn that appreciating nature's beauty can foster better understanding of it.	Students will learn that a relevant interpretation of various environments can help both the community and environment.
Procedures (abbreviated)	1. Place students into groups of four members. Each member has a different role of web navigator, coordinator, writer, and webmaster. 2. Let each group search internet for artworks about the nature. 3. Let each group construct the web gallery with selected artworks. The display should contain scientific messages. 4. The web gallery should also include written stories or descriptions to convey the scientific message. 5. Let each group search internet for satellite images and repeat the step 2 to the step 4.	1. Place students into groups and let each group decide the particular environmental circumstance such as national parks, an environmental organization, and a local learning center, which needs an interpreter. 2. Each group should determine why the interpreter is needed and what kind of interpreter is required. 3. Ask each group to create a position opening announcement including job description, qualification and expectance. 4. Place an announcement and let each student apply for a position. 5. Each group should interview applicants and hire one. All applicants should explain their vision for the job.
Products	Students create the web gallery of artwork and of satellite images.	Students create various interpreting jobs for environments.

Table 3. Modules, units, and activities in ESEP

Module	Unit	Core activity	Extended	Link
Into the Science Enterprise	Messages in Volcanoes	Fire goddess of Hawaii	Mt. Paik Doo	Volcanoes in Movies
	Explorers	Draw scientists, Find Scientists	Scientists in Movies	Be creative
	LEGO Fossils	LEGO Dinosaurs	Missing and Mixing	Why Dinosaurs disappeared
	Save the Wildlife	Extinction	Design the Web	
Getting to know the Earth System	Earth Songs	Write a Song	Earth in Literature	A Poet and A Painter
	Systems in Systems	System Questions	Time and Space	How systems function
	Matter cycles, Energy flows and Life webs	Sun, Plants and the Cow	If something happens ..	What do you do for it?
	Think Globally, Act Locally	More or Less	Antarctica	
To the Nature of Science and beyond	DaVinci Code?	Stories from Art	Stories from Satellites	Interpretation!
	Interpret the Data	H-R Diagram	NOS Quiz	Scientific Laws and Theories
	Mystery Lines	Mystery Lines	Examples	The role of Scientific Theories
	Interpret the Environment	Tsunami	Create the Job	

the third unit are science content, with the second unit in more explanatory mode and the third unit in more hands-on experience. The last unit in a module is always based on the second Earth system understanding, stewardship for the Earth. Thus, these units lead students from appreciating our planet to learning more about it, then to taking responsibility for the planet. Table 2 describes two sample units based on Earth appreciation and stewardship respectively. Each unit contains three different types of activity: core activity, extended activity, and link activity. The core activity holds the basic science contents for the academic

Unit 3. LEGO Fossil

Materials

-LEGO set for each group, packed in plastic bags with no information about what form it will be when it is built.

-Different LEGO set for each group and each set has either missing pieces or mixing pieces with other sets. (for extended activity)

-Internet Access, Books and other resources about Dinosaurs

Procedure

-Core Activity-

Part one: Dinosaur Appearance

1. Ask students to draw dinosaurs and ask how they know what dinosaurs look like.
2. Place students into expert groups and let them search for information about dinosaurs such as their looks, skeletons and fossils found.
3. Place students into base groups. On the basis of their expert research, ask them to imagine how scientists know the looks of different dinosaurs from fossils and bones.

Part Two: LEGO Fossils

1. Give each group a set of LEGO pieces. There must be no box, manual, picture or any other information about what the product might look like.
2. Tell students to imagine that these LEGO pieces are fossil-bones found in some place.
3. Let students build the LEGO creature using their logic and imagination.
4. After some time, ask them to stop, and let them draw what their creature looked like based on the evidence (whether they finish building or not).
5. Let students compare this activity to how scientists construct dinosaurs from fossils.

-Extended Activity-

1. Give each group a set of LEGO pieces and explain that when fossils are found, there usually are many missing pieces and sometimes different fossils are mixed.
2. Remind students that this set of LEGO has either missing pieces or mixing pieces.
3. Repeat step 3 to 5 in core activity part two.

-Link Activity (Brainstorm)-

1. Ask students why dinosaurs disappeared. Discuss what they know about it.
2. Discuss if there have been other life forms that have disappeared (extinction).

Fig. 1. An example of unit design: LEGO Fossil, the third unit of the elementary level module.

purpose of the unit. The extended activity is a kind of elaborated and enriched activity related to the core activity. The link activity is designed to serve as a pre-organizer for next unit. Table 3 shows the complete set of modules, units, and activities.

Figure 1 shows the compact version of one unit, LEGO Fossil, as an example. LEGO Fossil is the third unit of the elementary level module. Based on the fifth Earth system understanding about Earth history, it was designed to teach children how scientists use their logic and creativity to construct what dinosaurs were like, based on fossil evidence. Therefore this unit was intended to introduce descriptive, interpretive methods in science and the creative, subjective nature of science. Also LEGO Fossil was designed in sequential alignment from two previous units, focused on Earth appreciation and science as a human endeavor respectively, to the last unit of stewardship. The link activity concerning the extinction of dinosaurs was connected to the last unit, Save the Wildlife.

Evaluation of the Program

Once the program was developed, it was necessary to examine if it was appropriate and relevant as a school science program. National Science Education Standards (NRC, 1996) suggested the standards for the quality of and conditions for school science programs; therefore the ESEP was evaluated based on these

Table 4. Description of how high school level units meet science content standards

Unit / Area of Standards	DaVinci Code?	Interpret the Data	Mystery Lines	Interpret the Environment
Subject Matter & Content	Science & art, Earth's subsystems (5-12)	Stars, galaxies, & universe, H-R diagram (9-12)	Origin & evolution of the universe (9-12)	Tsunami, earthquake (5-12)
Science as Inquiry	Thinking critically about evidence and explanation (5-12)	Formulating & revising explanation using logic & data (9-12)	Recognizing alternative explanations & models (9-12)	Formulating & revising explanation using logic & data (9-12)
Unifying Concepts & Process	Patterns in nature (k-12)	Patterns in nature (k-12)	Models, Evidence, Explanations (k-12)	Interactions, changes, balance (k-12)
Science & Technology		Technological advance alters human perspective of nature (9-12)	Understanding relationship of science & technology (5-12)	Understanding relationship of science & technology (5-12)
Science in Personal & Social Perspective	Cultural interpretation of natural phenomena (k-12)			Natural & human induced hazard, environmental quality (9-12)
History & Nature of Science	Historical perspectives of Earth (9-12)	Subjective nature of science (5-12)	Nature of scientific knowledge (9-12)	Subjective nature of science (5-12)

( ) = relevant grade level.

standards.

1) *Have clear goals and expectations.* The ESEP was designed to help students achieve adequate science literacy focusing on appreciation and stewardship for the Earth system. Each module, unit, and activity was designed according to this goal.

2) *Use a curriculum framework to select and develop units and courses of the program.* The ESEP was developed based on the framework of context, inquiry, and the nature of science.

3) *Include content standards relevant to the discipline.* To examine this, all the units were analyzed to know if they met content standards and necessary revisions were made. Table 4 shows the example of how high school level units meet standards.

4) *Emphasize understanding through inquiry.* Since scientific inquiry was one of the framework criteria, it was always emphasized through the development of the ESEP.

5) *Connect science to other school subjects.* In meeting this standard, the ESEP offered connections to social sciences, language arts, art and music because activities for the Earth appreciation and stewardship especially used interdisciplinary approaches.

In addition to these standards, teaching practice and assessment policy should also be considered. However these considerations were left for the further studies that will accompany implementation of this program.

Implication

The ESEP was developed not to replace the regular curriculum or classroom teaching but to assist them. The traditional curriculum in the regular school system leaves little freedom to teachers to try any new program. Therefore flexible adaptability of the program was considered from the beginning of the development. Although each unit and module in the ESEP is connected in sequential order, individual units or activities could be used in the classroom for any relevant science subject. Teachers can select any activity and use it in their science class or they can apply an entire unit if appropriate. Revision and differentiation of the program is certainly possible by individual teacher's necessity.

Some of activities in this program have already been used in the school science class and the part of the outcome had been applied to improve the program (Lee, 2005). The effectiveness and utility of the science teaching program will only be examined by actual usage of the program in school science class. Thus, further study needs to include teacher education in use of the philosophy and methods of the program, application of the program in classrooms and substantive assessment of the outcome.

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