Investigating Earth Systems and EarthComm: The Research Base

Colin Mably – November 2004

Introduction

The American Geological Institute (AGI) develops, produces and publishes inquiry-based Earth science curricula. Currently, these include *Investigating Earth Systems* (IES) at middle school level, and its high school counterpart, *Earth System Science in the Community*, commonly known as *EarthComm* (EC).

IES and EC are both Standards-driven curricula. That is, the scope and sequence of each series is derived from, and driven by, the *National Science Education Standards* (NSES), published by the National Research Council in 1995, and the American Association for the Advancement of Science (AAAS), Project 2061's *Benchmarks for Science Literacy* (BSL) in 1993. These carefully researched and crafted documents specify content standards that students should know by the end of grade eight for middle school students and grade twelve for high school students.

Both NSES and BSL are informed by the highest level of scientific and pedagogical expertise, educational philosophy, critical thinking, and practical school experience. As such, they represent the most exhaustive national and international research base for science education to date. IES and EC, in turn, have been directly developed from, and informed by, this extensive research base. They have been further refined through pilot testing and field testing with classroom teachers.

This paper details this crucial relationship between AGI's development of IES and EC and their scientific research base.

History

Both IES and EC were developed by the American Geological Institute (AGI) as part of the organization's mission to educate the general public about the importance of the geosciences. AGI is a nonprofit federation of 43 geoscientific and professional associations, representing the nation's geologists, geophysicists, geoscience educators and other Earth scientists. Founded in 1948, AGI provides information services to geoscientists worldwide, serves as a voice of shared interests in the geosciences, and strives to increase public awareness of the vital role the geosciences play in society's use of resources and interaction with the environment.

AGI and Earth Science Curricula

AGI has played a major role in strengthening geoscience education since introducing its first high-school curriculum *Investigating the Earth* in 1970, through a National Science Foundation (NSF) funded project. AGI also led the way in producing Earth science educational standards by publishing *Earth Science Content Guidelines, Grades K-12 in* 1991. This effort preceded initiatives from the other scientific organizations, in particular the BSL (1993), and the development of the NSES (1996), in which AGI members played an active role. In so doing, AGI folded its initial *Earth Science Content Guidelines* into the development of the NSES.

Curriculum Components

In common with many science curriculum developers, AGI sees development as having three interacting dimensions. The first is that set of specific science concepts that constitute the "body of knowledge" to be learned, often referred to as the "content." The second is the set of actions within which science questions are identified, investigated, clarified, and verified to provide evidence of their scientific integrity, thereby developing the understanding of science concepts. It is the processes of "doing" science, usually referred to as "scientific inquiry." Scientific inquiry is not just limited to processes. It has its own set of "content" reflecting its historical development, enterprise, rules and procedures (Lederman, 1986). The third player in curriculum is pedagogy, that is: the teaching and learning strategies that are developed or chosen to best implement the curriculum in the classroom or laboratory. Curriculum development is the crafting of these seemingly separate components in one homogenous whole that assists students and their teachers along the pathway to understanding. There are other elements involved in curriculum, such as assessment, materials, information sources and the results of pilot and field testing. But, content, scientific inquiry and pedagogy are key.

Curriculum Content

Curriculum content serves two fundamental purposes. First, it must represent the collected scientific concepts that citizens need to understand to be scientifically literate. Second, it must represent those scientific concepts that provide building blocks for those who may later wish to study that discipline at a higher level, for scholarship or for their careers. This perspective, for K-12 education, was made clear by AGI as part of its goals for Earth science literacy in 1991.

> *These goals, developed by a consensus-building process, state that for all students to become literate in science and Earth science they need to:*
>
> - *Become stewards of the Earth. Stewardship means making informed decisions about using the Earth's resources and maintaining a high-quality environment*
> - *Develop a deep aesthetic appreciation of the history, beauty, simplicity, and complexity of the Earth*
> - *Understand ways in which Earth scientists investigate the Earth*
> - *Understand essential Earth science concepts including geologic time, evolution, change, scales, cycles, and resources.*
>
> Earth Science Education for the 21st Century: A Planning Guide (AGI 1991)

AGI's broad conception of Earth science curricula is reflected in the AAAS's Project 2061 publication *Science for All Americans* (Rutherford 1990) and was further supported by its subsequent *Benchmarks for Science literacy* (1993), which stated:

> *The full picture requires the introduction of such (geoscience) concepts as temperature, the water cycle, gravitation, states of matter, chemical concentrations, and energy transfer. Understanding of these concepts grows slowly as children mature and encounter them in different contexts.* (p. 66)

By using a comprehensive research base, BSL was able to clarify the components of Earth science curricula into a series of closely related conceptual areas:

> ***The Physical Setting:*** *The Universe; The Earth; Processes that Shape the Earth; Structure of Matter; Energy Transformations; Motion; Forces of Nature.*
> ***The Living Environment:*** *Diversity of Life; Heredity; Cells; The Interdependence of Life; Flow of Matter and Energy; Evolution of Life.*

In establishing the metaphor of "benchmarks," Projects 2061's BSL perhaps sought to soften the blunt statement of outcomes others were establishing as "standards" (e.g., NCTM 1989). However, the National Research Council was already at work producing a similar tool - the *National Science Education Standards* (NSES 1996).

Within NSES, the Earth science section delineates content standards for grade levels K-4, 5-8, and 9-12. At middle school level (grades 5-8) they are divided into three: *The Structure of the Earth System*; *Earth's History*; *Earth in the Solar System*. At high school level (grades 9-12) they are further developed into: *Energy and the Earth System*; *Geochemical Cycles*; *Origin and Evolution of the Earth System*; *Origin and Evolution of the Universe*.

From a content point of view, the differences between BSL and NSES are relatively small. What is important is that the two combined represent a collective state-of-the-art, research-based view of what Earth science content should be included in curriculum and at what grade levels; a view fully endorsed by AGI and thereby the considered thinking of the geoscience community.

Scientific Inquiry

From the outset, IES and EC were designed to be "inquiry-based" science curricula. Both BSL and NSES have much to say about scientific inquiry. BSL emphasizes scientific inquiry though a range of perspectives as these examples from the middles school grades show:

The Nature of Science Inquiry: *Grades 6 through 8*

- *At this level, students need to become more systematic and sophisticated in conducting their investigations, some of which may last for several weeks. That means closing in on an understanding of what constitutes a good experiment. The concept of controlling variables is straightforward, but achieving it in practice is difficult. Students can make some headway, however, by participating in enough experimental investigations (not to the exclusion, of course, of other kinds of investigations) and explicitly discussing how explanation relates to experimental design.*
- *Student investigations ought to constitute a significant part—but only a part—of the total science experience. Systematic learning of science concepts must also have a place in the curriculum, for it is not possible for students to discover all the concepts they need to learn, or to observe all of the phenomena they need to encounter, solely through their own laboratory investigations. And even though the main purpose of student investigations is to help students learn how science works, it is important to back up such experience with selected readings. This level is a good time to introduce stories (true and fictional) of scientists making discoveries – not just world-famous scientists, but scientists of very different backgrounds, ages, cultures, places, and times.*

(p. 12)

In promoting scientific inquiry as a key component in science education, BSL is able to draw upon its own well-established research base (Ch. 15, 327-377). It notes that previous research into students' understanding of the nature of science has a history spanning more than thirty years citing early studies that investigated understandings about scientists, the scientific enterprise and general methods and aims of science (Mead & Metraux, 1957; Cooley & Kopfer. 1961; Kopfer and Cooley, 1963; Welch & Pells, 1967; Mackey, 1971). BSL notes that more recent research studies have added students' understandings and "experimentation" and notions of "theory" and evidence" based on extensive research literature reviewed in Lederman (1992).

The strong BSL case for scientific inquiry as a body of knowledge that students should understand draws upon an array of studies conducted in the late seventies through the early nineties. These include those looking at students' understanding of experimentation (Carey et al., 1989; Schauble et al., 1991; Solomon, 1992), their ability to see experimentation as the testing of ideas (Carey et al., 1989; Solomon et al., 1992), their notions about "fair" or "controlled testing"

(Wollman 1977a, 1977b; Wollman & Lawson, 1997), and students' difficulties in interpreting covariation and noncovariation evidence (Kuhn, Amsel, & O'Loughlin, 1988) along with the tendency for this to mitigate over time (Schauble, 1990).

NSES endorses and extends the BSL view by including scientific inquiry as its first content standard. It also makes very clear the particular student abilities it sees as important:

> ***Content Standard A*** - *As a result of activities in grades 5-8, all students should develop:*
>
> - *Abilities necessary to do scientific inquiry*
> - *Understandings about scientific inquiry*
>
> The fundamental abilities and concepts that underlie this standard include:
>
> ***Abilities Necessary to do Scientific Inquiry***
>
> - *Identify questions that can be answered through scientific investigations*
> - *Use appropriate tools and techniques to gather, analyze, and interpret data*
> - *Develop descriptions, explanations, predictions, and models using evidence*
> - *Think critically and logically to make the relationships between evidence and explanations*
> - *Recognize and analyze alternative explanations and predictions*
> - *Communicate scientific procedures and explanations*
> - *Use mathematics in all aspects of scientific inquiry*
>
> (pp. 145-148)

AGI, the first to produce Earth science "standards," has thrown its weight behind these ideas and the application of these scientific inquiry principles has become a cornerstone of its curriculum development.

Pedagogy

Research supporting a scientific inquiry approach to science education comes from several other sources, in particular cognitive psychology and child development studies. This formidable body of international research is historically long, having its first impacts on European pedagogy in the early sixties from the work of the Swiss school of psychology (Piaget,1952. Piaget & Inhelder, 1972), through Vygotsky (1962 and 1978). This early research, and the pedagogy it spawned, led to what is now known as *constructivism*, or the psychosocial construct that knowledge is actively constructed by the learner, not passively received from the environment or simply absorbed as instructional information. A more radical view of constructivism is expressed as: Coming to know is a process of dynamic adaptation towards viable interpretations of experience (von Glasersfeld, 1982). To this can be added the U.S. impact of Thomas Kuhn's work (1962/1970a), and the many educational thinkers, researchers and developers (von Glasersfeld, 1983; Kilpatrick, 1987; Cunningham, 1991; Perkins, 1991; Duffy & Duffy, 1991, and others continuing this research) who together have made constructivism today's instructional buzzword, with its emphasis on an active role for the student in the learning process and learning in collaboration with others to help develop multiple perspectives that can be used together to solve problems.

By definition, constructivism advocates curricular approaches and pedagogy that place the learner at the center of the learning enterprise and rejects the traditional view of the teacher as the sole imparter of knowledge whether that be by direct teaching or through a teacher-surrogate textbook. Direct teaching is not ruled out (BSL, p. 12), but instead becomes one of the many tools that can be used in combination with inquiry activities such as focusing on real-world situations, hands-on experience, generating scientific questions, investigating, observing, predicting, testing, problem-solving, and working in cooperative groups.

AGI itself has spent much time and effort in designing and testing curriculum materials that exemplify the scientific inquiry promoted by BLS and NSES and has used the collected data to inform and refine its curricula.

AGI's Curriculum Development Approach

One glance at a Student Edition of either IES or EC will quickly show evidence of how these curricula have been developed from the multiple research bases shown above. A look at a Teacher's Edition will confirm that this connection is implicit in every piece of advice offered to teachers. In this regard, IES and EC have been specifically designed to reinterpret the cutting edge educational and scientific research into practical implementation in the nation's classrooms. In so doing, AGI has incorporated three crucial dimensions: Research into the nature of science; research into science concepts appropriate for instruction at certain grade levels; and, research into appropriate pedagogic methods of instruction to ensure students gain scientific understandings. Moreover, as will be shown below, this development also relied heavily on AGI's own research in pilot and field testing phases of development to ensure this outcome.

National Science Foundation

IES and EC were developed with funding from the National Science Foundation (NSF). It should be noted that securing funding from NSF is no easy matter. To be considered, proposals must:

- Present an exemplary case that clearly demonstrates the need for the envisioned curriculum development
- Show that the project's design is tied to current scientific research and educational philosophy
- Display well-argued and innovative approaches to solving teaching and learning problems
- Specify pilot and field testing procedures that will include appropriate tools and instruments administered by an independent evaluator
- Outline strategies for publishing and dissemination of the completed curriculum to schools.

Only proposals that satisfy these requirements to a very high level become recipients of these government grants. In view of the exacting review process, it is fair to say that both IES and EC started life from the most rigorous of scientific and educational bases.

IES and EC – Developmental Research Base

IES and EC were developed in parallel, both starting in 1996. From the very beginning, they were developed from the contemporary research base established first by AGI's own research efforts (AGI 1991a, 1991b) quickly supplemented by those compiled for BSL and NSES. It was from these bases that the component ideas concerning content, scientific inquiry and pedagogy for both were developed producing working modules for testing.

Investigating Earth Systems

Pilot testing for IES was conducted by the University of Minnesota with Fred Finley, Ph.D., as the independent evaluator. The stated goals of the pilot test were to:

- Determine how well the activities worked in the classroom
- Examine the effectiveness of each investigation included in the module

- Determine the teacher's perspective of student performance
- Determine if the investigations worked in the classroom setting and had an appropriate material list to facilitate teacher preparation.

In all, forty-five teachers spread across eleven representative states (GA, MD, NH, NJ, NV, NY, OH, OR, PA, TX, and VT) formed the pilot test program which took place over a period of twenty-four months in 1997 – through 1999 (Smith 2000). They each used the module materials in their classrooms to accumulate information on the progress and effectiveness of the modules in relation to student understanding. Data categories included: *module investigations; teaching; materials; assessment;* and *teacher's guide;* with sub-categories of: *investigation description; positive comments; criticism;* and *suggestions.* The data collected were carefully analyzed by the evaluators who then generated annotated lists of changes needed in the materials. In addition, quantitative data were also gathered from pre- and post-tests to determine student learning, the analysis of which showed evidence of student progress and, more importantly, evidence of where learning difficulties were taking place. All these data helped to reshape and further develop the nine IES modules and also provided key information and ideas for developing the accompanying Teacher Editions.

Between May, 1999 and April, 2000, the nine revised modules, Teacher Editions and material kits (now close to their commercial editions) were field tested by thirty teachers (27 new, and three original) across nine states (GA, LA, MD, ME, NY, OH, PA, RI, and WV). An important part of this test was the acquisition of more targeted student impact data. To this end, an additional independent evaluator, well-experienced in qualitative data techniques, was commissioned, and validated test instruments were used in pre- and post-testing. This research was driven by the following questions:

- Are the students learning the major concepts and unifying themes addressed in the modules (content standards)?
- Are students learning to think and act in scientific ways (inquiry standards)?
- What is the students' perception of the modules?
- How do the modules affect students' general attitudes toward science?

The results of this research were positive:

> *Based on the data from two assessment instruments, students made gains in their understanding of Earth science as a result of working with the (IES) modules. These gains are statistically significant and apply at both the cohort and classroom levels*.
>
> (Rosenbaum, 2000)

These data, along with those concerning student and teacher attitudes to the materials, led to final refinements and editing for the commercial editions of IES, which were released to the school markets on a roll-out basis between 2000 and 2002.

EarthComm

The pilot and field-testing process for EC, though conducted quite separately, mirrored that of IES. Initial curriculum materials were generated, teachers recruited to test them in high schools, and an independent evaluator commissioned to conduct evaluative research. Twenty-five teachers from twenty-two states (AR, CA, CT, CO, DE, FL, IA, ID, IL, IN, MD, MI, NC, NE, NY, OH, PA, TN, TX, VA, VT, and WI) participated in the test, the demographics of which are shown in this table:

Demographic Data: Module One Field Test of EarthComm	
Teachers	
Number of teachers in the test sample	27
Years of teaching experience	mean 13, range 1 to 33, (1 to 5 years of experience, 17)
Years of teaching Earth science	mean 7, range 1 to 33, (1 to 5 years of experience, 17)
Number of Earth science courses in college	mean 10, range 0 to 31
Student/School	
Number of students in the test sample	1169
Class size	mean 22, range 11 to 35
School location	rural 8, suburban 7, urban 12
School size	mean 1360, range 350 to 3200, <1000: 9
Percentage minorities	mean 25%, range 0 to 91%, less than ten 10
Student ability level	about one-third each of below average, average, and above average abilities

While much of the pilot-test evaluation concentrated on the workability of the materials in terms of teacher perceptions, the evaluator also used a questionnaire, a modified version of an instrument developed by Inverness Research, to gather quantitative data on teacher views, and a pre- and post-test to measure student learning.

Data analysis and results showed that teachers were supportive of the materials while the pre- and post-tests showed little difference, most likely as a result of selecting highly qualified Earth science teachers who viewed their ability to cause students to learn Earth science as high (Enochs, 1999).

This evaluation information was used to refine and adjust the curriculum materials toward the problems identified and the success shown, and a program to train teachers to take part in the field testing stage was put in place during the summer of 1999.

The revised field test editions of EarthComm were produced and distributed to sixty five teachers in twenty one states (CA, CO, GA, IA, IL, KS, MD, ME, MI, MO, NC, NE, NH, NJ, OH, PA, RI, TN, WA, and WI) to be tested in sequence. Three new evaluators were commissioned for the field-test program and the EC modules were set to operate on a "roll-out" basis for the publisher.

The results from the teacher cohort to test the first EC module (twenty seven teachers in fifty three classes involving 1169 students) were encouraging:

> *When all the sources of information from the field test were considered it became clear that Module 1 of the EarthComm curriculum worked effectively in the field test classrooms. Almost all of the field test teachers were very favorably impressed by the high quality of the science content, the module components, many of the hands-on activities, the inquiry approach, the group work, and the relevance to the community.*

> *Most teachers also reported student interest in the overall program to be moderately high and very high in many of the activities. Furthermore, the data collected indicated that the students had learned the material and accomplished many of the goals covered in Module 1.*
>
> (Bernoff, 2000)

From here, the remaining four modules were submitted to the same procedures and, after content review and technical checking delivered for commercial publishing. EarthComm was released to the educational market in 2001.

Evidence from current users of IES and EC

At the time of this report (December 2004), both IES and EC have enjoyed much success in the educational marketplace. Many school systems, large and small, have invested in either one or both of the curricula. In many cases, this has been accompanied by Professional Development programs led by the current staff of AGI, including some who were part of the initial or ongoing development team. In working closely with several very large school systems, a body of evaluative evidence is being collected on a systematic basis. These data will play a major role in the first revisions of both products. In this regard, the relationship between school systems using these curricula, the publisher, and AGI share a common bond and determination to make IES and EC the best curricula they can be.

Colin Mably
December 2004

Colin Mably is a former teacher and college educator with extensive experience as a curriculum writer and developer. He was the project director for Investigating Earth System from 1996-1999 and an informal advisor to EarthComm. Since then, he has been a player in several National Science Foundation curriculum programs ranging from K-12 though college level, co-authored a college-level science education textbook, produced a range of science related educational videos including a recent broadcast program, and worked as a project/curriculum evaluator.

References:

American Association for the Advancement of Science – Project 2061, (1963). *Benchmarks for Science Literacy*. Oxford University Press.

American Geological Institute, (1991). *Earth science education for the 21st century: A planning guide.* Alexandria, VA.

American Geological Institute, (1991). *Earth science content guidelines, grades K-12*. Alexandria, VA.

Bernoff, R. A. (2000). Evaluation report for the field test of EarthComm module one - Earth's Dynamic Geosphere. Internal report to American Geological Institute.

Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1989). An experiment is when you try it and see if it works: A study of Grade 7 students' understanding of the construction of scientific knowledge. *International Journal of Science Education, 11, 514-529*.

Cohen, E. G. (1994). *Designing groupwork: Strategies for the heterogeneous classroom.* New York: Teachers College Press.

Cooley, W., & Kopfer, L. (1961). *Test on understanding science, Form W*. Princeton: Educational Testing service.

Cunningham, D. J. (1991). Assessing Constructions and Constructing Assessments. *Educational Technology, 31(5).*

Duffy, T. W. &. D. H. J. (1991). Constructivism: New Implications for Instructional Technology. *Educational Technology, 31(5*).

Enochs, E. G. (1999). EarthComm project: spring 1999 pilot testing - final evaluation report. Center for Mathematics and Science Education Research – to American Geological Institute.

Kagan, S. (1993). The structural approach to cooperative learning. In Holt, D. D. & McHenry, D., Cooperative Learning: A Response to Linguistic and Cultural Diversity. *Delta Systems and Center for Applied Linguistics, pp. 9-19*.

Kilpatrick, J. (1987). What constructivism might be in mathematics education. In J. C. Bergeron, N. Herscovics & C. Kieran (Eds.), *Proceedings of the Eleventh Conference of the International Group for the Psychology of Mathematics Education (pp. 2-27)*. Montreal: University of Montreal.

Kopfer, L & Cooley, W. (1963). Effectiveness of the history of science cases for high schools in the development of student understanding of science and scientists. *Journal of Research in Science Teaching, 1, 35-47*.

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). *The development of scientific thinking skills*. San Diego, CA: Academic Press.

Kuhn T. (1962/1970a), *The Structure of Scientific Revolutions*, Chicago: University of Chicago Press (1970, 2nd edition, with postscript).

Lederman, N. (1986). Students' and teachers' understanding of the nature of science: A reassessment. *School Science and Mathematics,* 86(2), 91-99.

Lederman, N. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29, 331-359.*

Mackey, L. (1971). Development of understanding about the nature of science. *Journal of Research in Science Teaching, 8, 57-66*.

Mead, M., & Metraux, R. (1957). Image of the scientist among high-school students: A pilot study. *Science, 26 384-390*.

National Research Council (1996). *National Science Education Standards*. National Academy Press, Washington D.C.

Perkins, D. N. (1991). Technology Meets Constructivism: Do They Make a Marriage ? *Educational Technology, 31(5).*

Piaget, J. (1952). *The Origins of Intelligence in children*. New York: International Universities Press.

Rutherford, J. F. & Ahlgren, A., (1990) *Science for all Americans*. Project 2061 – American Associations for the Advancement of Science.

Rosenbaum, H. (2000). Field test evaluation report, Investigating Earth Systems. Internal report to the American Geological Institute.

Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence. *Journal of Experimental Child Psychology, 49, 31-57.*

Schauble, L., Klopfer, L.E., & Raghavan, K. (1991). Students' transition from and engineering model to a science model of experimentation. *Journal of Research in Science Teaching, 28, 859-882*.

Smith, M. B. (2000). Final report of the AGI Earth science sourcebook project. American Geological Institute. Submitted to National Science Foundation

Solomon, J. (1992) Images of Physics: How students are influenced by social aspects of science. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in Physics learning: Theoretical issues and empirical studies (pp 141-154),* Keil, Germany: Institute for Science Education and the University of Kiel.

von Glasersfeld, E. (1982). An interpretation of Piaget's constructivism. *Revue Internationale de Philosophie* 36 (142/143): 612—635.

von Glasersfeld, E. (1983). Learning as a constructive activity. In J. C. Bergeron and N. Herscovics (Eds.), *Proceedings of the Fifth Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education (pp. 41-69)*. Montreal: University of Montreal.

Vygotsky, L.S. (1962). *Thought and language.* Cambridge, MA: MIT Press. (Original work published 1934).

Vygotsky, L.S. (1978). *Mind in Society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Welch, W., & Pella, M. (1967). The development of an instrument for inventorying knowledge of the process of science. *Journal of Research in Science Teaching, 5, 64-68*.

Wollman, W. (1977a). Controlling variables: Assessing levels of understanding. *Science Education 61, 371-383*.

Wollman, W. (1977b). Controlling variables: A neo-Piagetian developmental sequence. *Science Education, 61, 385-391*.

Wollman, W. & Lawson, A. (1997). Teaching the procedure of controlled experimentation: A Piagetian approach. *Science Education, 61, 57-70*.