EarthComm Professional Development Program - Key Concepts of EarthComm

Introduction

EarthComm differs from many existing Earth science curricula in important ways. Four key concepts drove the development of the instructional design: relevance, community, systems, and inquiry. The explanations below will help you understand the role of each concept in EarthComm, how each interacts with the others, and how the EarthComm approach differs from other approaches to Earth science.

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Relevance

Earth science is all about context and relevance. Earth scientists seek to understand the where, when, and how of a process or event and to use that understanding to make wise decisions. Earth science has exceptionally broad scope. After all, everything on Earth and in space is affected by and related to Earth science.

This broad scope challenges teachers and curriculum developers to make the Earth science curriculum manageable for students. For example, volcanoes interact with the atmosphere and living things in important ways, yet these interactions become obscured by teaching weather as one topic, volcanism as another topic, and living things in a completely different course (life science). The Earth systems science focus of EarthComm enables teachers to help students form a chain of connections from nearly any Earth science phenomenon to many other ideas, and eventually back to the students' immediate world. EarthComm uses such chains of connections to highlight the relevance of Earth science to the learner.

The traditional solution to teaching Earth science is to subdivide it into discrete subjects (geology, meteorology, oceanography, space science, etc.) and topics (rock cycle, volcanoes, ocean currents, moon phases, seasons, etc.) Unfortunately, disconnecting the topics from each other and from any specific place and time undermines the holistic character of Earth science. Traditional curricula present Earth science as a set of generic ideas that can be applied in various circumstances. Presenting topics without reference to place and time often strips Earth science of both context and personal relevance. Volcanoes become generic objects divided into broad types, and examples given to illustrate general principles often ignore the specific setting, effects, and history of a particular volcano. This is inconsistent with the National Earth Science Teachers Association (NESTA) position paper, The Importance of Earth Science Education. The NESTA paper argues that Earth science is important because students "need only step outdoors to observe and find relevance in concepts learned in the Earth Science classroom" and "students who study Earth Science are better prepared to discuss issues and make informed, responsible decisions." Similarly, the National Science Education Standards call for a change in emphasis from learning science content areas "for their own sake" to learning in ways that makes science relevant in personal and social perspectives.

The concept of relevance permeates the EarthComm curriculum. It is made explicit as each chapter is introduced, and it is maintained through the attention given to the Chapter Challenge. Any EarthComm chapter can be used to demonstrate this effectively. For example, in "Volcanoes and Your Community," the first thing the students read in the chapter is the question, "Can a volcano that erupts on the other side of the world affect your community?" The answer, of course, is that it can. In completing the investigations within the chapter, students determine the kinds of effects that they might experience. This focuses their attention on the relevance that apparently distant Earth processes have upon their immediate world.

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Community

EarthComm addresses Earth science instruction by focusing on communities. EarthComm is designed to relate directly to the student's neighborhood, town, state, region, and so on-the student's community taken at a variety of levels. The idea of a community is first and foremost a biological concept, and its use in EarthComm demonstrates the emphasis on crossing traditional disciplinary boundaries. A community is, in essence, a group of varied living things interacting in some ways. (In one perspective, biologists might speak of living things being organized from cells, to tissues, to organs, to organ systems, to organisms, to populations, and to communities.) In human terms, we think of communities as involving some form of deliberate social organization, such as cities and counties, making it a political and cultural concept, too. The result is that we can think of varied communities such as neighborhoods, towns, states, countries, and so on. Earth science phenomena affect communities in many and varied ways. The social relevance of Earth science and the role Earth science plays in the design and function of communities becomes clear through the explicit attention EarthComm gives this concept.

The idea of community overlaps with the geographic concept of regions, because living things (biotic factors) are affected by and affect non-living things (abiotic factors), making the physical setting important. Ideas such as climate and topography become important in understanding communities, which brings this into the Earth sciences. A mountain may have a community of living things on it, which are affected by both the topography and climate of the region. At the same time, that community is part of a larger community, the mountain range, which overlaps with the community encompassed by the watershed, and so on. The same would be true in a grassland, desert, or ocean. This demonstrates that it is possible to conceive the organization of a community at several levels, such that the idea of what constitutes a community crosses and extends political boundaries and physical barriers.

This image demonstrates that communities can be thought of in many ways, which may overlap with each other. The various surface coverage types are biological communities. These overlap with the counties (political communities), which are also shown on the map.

Communities can themselves be considered systems and subsystems. Both systems and communities can be taken as units of analysis, with boundaries that are decided by the purposes of those analyses. Finally, the overlap between the community concept and the concept of a region is appropriate and necessary because of the interactions between and among biotic (living) and abiotic (non-living).

Community in EarthComm is apparent in many activities that make use of resource materials, such as maps, to describe how Earth processes affect the students' community. For example, in the first activity in "Volcanoes and Your Community", students use a map of volcanoes to begin to get a sense of where volcanoes are found relative to their community. The notion of various levels of "community" is important. Do the students answer this question in terms of their city or town, their county, or their state? Students' responses will depend on both the prevalence of volcanoes and the level of "community" being considered. The question can be raised, too, as to whether political boundaries are the most important ways to consider community in this case. It might be more important to think in terms of a geographic region and how volcanoes affect that region.

Another example of the community concept in EarthComm is the first activity in "Water Resources And Your Community." Here the extent of the community is defined by the information available, which will most often be given by county. Conceiving of the community as a county has both benefits and limitations. There are enough data put together to allow meaningful analyses. Yet, the effect of a drought on different municipalities (which may or may not be listed separately) may be lost as data are aggregated. Any particular definition of "community" will have similar benefits and limitations.

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Systems

EarthComm uses a systems metaphor to develop Earth science understandings - the Earth system is like a living system. In this systems metaphor, the idea that "everything is connected to everything else" becomes a central framework for developing the curriculum. This metaphor differs from a mechanistic metaphor. In a mechanistic metaphor, nature is seen as a machine, in that large-scale phenomena can be understood through analysis of smaller parts. So, for example, students might study a volcano by looking at the lava, the cone, the magma chamber, and so on, and then bringing that information together. The classic example of mechanistic thinking is to see a phenomenon as a clock. If one understands the parts of a clock, and how they interact, then one can understand the functioning of the whole machine. A systems approach is more holistic, considering interactions between subsystems. Separating the subsystems-studying them in isolation-gives an inaccurate picture of the whole because the actions of one subsystem actually change the other subsystems as the activity occurs. While subsystems can be defined, their ongoing interactions with other subsystems must be constantly considered. This is the kind of thinking that EarthComm promotes. Toward that end, Earth science phenomena are considered to be operating within five major subsystems or "spheres" that interact with and affect each other. The "Earth Systems" diagram, which appears inside each Student and Teacher Edition of EarthComm, represents this way of thinking.

Nebraska Watersheds in the Missouri River Basin and Counties Input and Output:

Input and Output: The property of a river or stream that reflects the change in inputs and outputs is the river flow. Examples of natural input include precipitation, overland runoff, and ground water inflow. Rivers and streams can also lose water (output) by evaporation and by the loss of surface water to ground water.

Feedback: An example of feedback for a surface water system is when the surface water levels rise, the ground water levels adjacent to the stream rise. As the stream levels decline with decreasing input, the ground water stored adjacent to the stream may return as input back into the stream. Examples from Nebraska above illustrate systems in specific locations. Instructions for developing a similar image for any area in the United States can be found in the "Resources" section of this manual. Of the key concepts used in the design of EarthComm, the systems concept is often least familiar to teachers. Reading the essay "Why Use An Earth Systems Approach?" will help you to stress the importance of the concept to workshop participants.

To fully appreciate the systems metaphor, several ideas have to be understood. Systems have parts and properties that make them identifiable. Systems also have inputs and outputs of energy and matter, leading to interactions among those parts, the results of which are governed by the properties of the system. This means that systems have feedback networks in which changes in one part of the system bring about, directly or indirectly, changes in other parts. The boundaries of a system are, therefore, never entirely fixed. We may talk about a particular system, such as a desert ecosystem, for example. But that system may be part of a larger system, and may be made up of smaller, overlapping systems. Another way to say this is that every system is made up of other systems-subsystems-and is itself a part of, or a subsystem of, a larger more comprehensive system.

Rain forests, which have become familiar to many people through recent media attention, can be used to provide a suitable example of an Earth system. In a tropical rain forest, rain is the input, and water vapor rising from the forest is the output. On average this feedback loop keeps the rainfall at about the same level year after year. In the case where a rain forest is burned, there is a response to that change. This results in a modification of the feedback loop that results in less water vapor being returned to the air above the forest, which, in turn, results in fewer clouds because of less water vapor, which, in turn, means a reduction in rainfall.

Activity two (How Does Your Community Maintain its Water Supply?) in the Water Resources And Your Community chapter illustrates the components of a system. In this activity students set up an apparatus in which hoses allow water to flow from a coffee can to a soda bottle (filled with sand) and from the bottle into a pan. The conditions of one part of the system, such as the level of water in the coffee can, affect the flow rate (output) that goes to another part of the system (input), which has other conditions (sand and soil) that affect the flow rate to the pan. Additional examples are given below and in the "Additional Workshop Activities" section of this manual.

Identifying Components of A System: Watershed Examples

The properties as well as the inputs and outputs to a system are easy to identify in some cases, such as with a rain forest. However, the individual parts of Earth systems are numerous and the connections are sometimes unclear because we often have incomplete knowledge of what constitutes a properly functioning natural system. Surface water systems related to rivers and streams can be used to illustrate the systems approach to natural environments, with the caveat that the feedback between many of the parts and processes involved are not completely understood.

Nebraska Surface Cover and Counties

Characteristic parts and properties of the system:

Determining the parts and properties of a system depends upon the extent to which we can define the boundaries of the system. Once the boundaries are established, we can begin to collect information about the system. In the context of a surface water system, some of the key parts and properties for which data and information would need to be collected are river flow (discharge), precipitation, evaporation, overland runoff, transpiration, and groundwater input.

Boundaries of the system:

One of the most challenging aspects of using a systems approach is determining the boundaries of the systems. In the image titled "Lancaster County, NE and Associated Watersheds," the city of Lincoln, NE resides in Lancaster County. Its political boundaries overlap parts of four distinct river basins (identified by numbers), that represent natural Earth system boundaries related to water. Although these four river basins can be identified as distinct hydrologic systems, they are also subsystems of the much larger Missouri River basin system (the dark area on "Nebraska Watersheds in the Missouri River Basin & Counties"). It should be apparent that establishing boundaries is strongly dependent upon what you are interested in. If you are interested in stream flow in Lincoln, you will need to know something about the behavior of the hydrologic basin number 10200203 (Salt Creek). In contrast, an interest in the water system for Lancaster County requires that you know the system dynamics for all four river basins.
Examples from Nebraska above illustrate systems in specific locations. Instructions for developing a similar image for any area in the United States can be found in the "Resources" section of this manual.
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Why Use An Earth Systems Science Approach?

In the summer of 1969, when the Apollo astronauts looked back at the Earth from the Moon, the image of the Earth changed for all who shared this new vantage point. Seeing the Earth as an object in space illustrated in a dramatic way the interconnectedness of the planet's many elements, bringing into perspective the unity and diversity of our planet. Over the past three decades since the Apollo missions there have been tremendous advances in our understanding of the planet Earth. Changes in our understanding has led Earth scientists to reevaluate the relationships between the various parts of the Earth - the land, oceans, atmosphere, and life - which were once considered individually. This change in perspective has required reinterpreting the relationships between the various scientific disciplines and their modes of scientific investigation. These changes are documented in the Bretherton Report, which was developed by a committee of scientists representing various government agencies with mandates for Earth science research (Bretherton, 1988). Through subsequent discussions between scientists and educators, a new focus and philosophy for Earth science education has emerged, Earth System Science (Mayer et al.,1992).
Earth system science is an important tool for not only understanding the complexities, ambiguities, and uncertainties of the processes that control and shape the planet, but also for understanding the relationship between humans and the Earth. Using a systems approach to science education recognizes that the natural and designed world is complex; large, complicated, and contains parts that cannot be understood entirely in isolation from each other. Many types of systems are familiar to us: the solar system, our system of government, the school system, a car's ignition system, and the human body system. These systems all contain parts that are interconnected and function as a whole. Thinking and analyzing any these systems requires that we know how the parts are related. We also need to know the input into the system that makes it go, and the output that may result. The complexity of a system means that at some level in every system its behavior is predictable, while at other levels it is not (and may never be). Students can develop an understanding of the regularities in systems and gain an appreciation for the role of chance events. Through this understanding they can develop an understanding of basic laws, theories and models that explain the world.
As pointed out in a recent summary by Ireton et al. (1996), the famous geneticist T. Dobzhansky once said, "nothing in biology makes sense except in the light of evolution." The evolutionary paradigm has had an extraordinary impact on organizing the thoughts and ideas related to the understanding of biological processes. In a similar fashion most aspects of the Earth are explainable in the context of the Earth systems, operating at various time scales and over widely variable scales of space.
Another important attribute of Earth System Science is that it provides a scientific framework for local, national, and international cooperation because environmental and resource issues transcend political boundaries. Water availability, climate variability, and mineral resource development are global natural resources issues that link Earth resources to their users. Only through an understanding of resource renewal and consumption rates, and an assessment of cultural values, can necessary balances be developed to deal with shortages and protect the system from damaging exploitation (Ireton et al., 1996). A systems view of the Earth provides an explanatory power that enhances our ability to understand our planet and to improve our capacity to use its resources appropriately to ensure our survivability on Earth.

References:

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Inquiry

EarthComm is designed to encourage authentic inquiry. Authentic inquiry features questions for which the answers are not already entirely known by the students, teachers, or publishers before the learning begins. EarthComm establishes the centrality of inquiry through the "Chapter Challenge". The challenge motivates students to ask how the Earth science ideas that are being learned relate to the specific communities they are considering.

Inquiry is central to advancing personal and collective scientific knowledge. EarthComm supports this inquiry approach with a variety of activities in each chapter. Some are open-ended, some place the students in the position of interpreting data, some help to illustrate phenomena so that students can assess the impact the phenomena might have on their communities-but all support the emphasis on inquiry-based learning.

In considering how to teach using inquiry, it helps to understand that scientific inquiry is not a specific set of steps that can be used to grind out new knowledge. The process of scientific inquiry is often presented as a single "scientific method" to students, looking something like the diagram below:

This diagram can only serve as a model of the practice of science, and will always leave out many possibilities. For example, unexpected results can lead to new problems as well as contribute ideas about problems under study. Aspects of scientific practice, like the importance of communicating with other scientists, are often left off of such diagrams, too. In that there are many such diagrams of "The Scientific Method" that may be familiar to teachers, it is not worthwhile to spend time discussing the particular differences between one depiction and another. The general ideas about these representations remain the same. While models of scientific inquiry are worthwhile, they have to be understood for the limitations as well as their benefits. As noted in Science for All Americans (AAAS, 1991):

Scientific inquiry is not easily described apart from the context of particular investigations. There simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge. (P.4)

Scientific inquiry is a multifaceted activity that involves many skills and a healthy dose of creativity. Observation, question posing, and other skills are important to scientists, but do not occur in any pre-determined order in an investigation. The reasoning used to gather information and develop and test a hypothesis is more important than any particular procedure, and reasoning is also where creativity often takes a central role.

Science educators may disagree about the exact set of skills used in inquiry, how the process of inquiry is broken into steps, and what constitutes an "experiment" rather than an "activity". The list given below for Science A Process Approach (an NSF-funded curriculum project developed in the 1960's) is one of many such lists. The list provided in the National Standards (NRC, 1996) is part of the matrix of standards addressed in EarthComm (see "Science as Inquiry" in the matrix on the next page.)

Inquiry in science education is related to "hands on science". Science educators recognize how students benefit from "hands-on science" (activities that involve students in directly manipulating non-text materials). These activities allow students to see scientific principles in action, which helps students to gain experience with processes that may be difficult to comprehend solely through reading. Hands-on activities also motivate students. Students enjoy working with various supplies used in hands-on activities and seeing the results, which often surprise them.

The structure of hands-on activities often mimics an inductive investigation. Some activities are authentically inquiry-based; others, however, lose the essential character of inquiry-asking questions and finding ways to answer them based on evidence. This happens when students or the teacher already know the outcome of an activity. Thus, although hands-on activities offer many benefits in science education, they do not always equate with authentic inquiry.

Outcomes of inquiry that go beyond simply experiencing the results of an activity are those that enable students to see a scientific idea in action. The list of inquiry-based outcomes shown below includes ideas about how students relate to science and how they use information. The list makes it easy to imagine the kinds of activities that students need to be doing to be taking part in authentic inquiry. EarthComm highlights these outcomes by focusing student activity and learning on creating a product, usually informational or persuasive, which uses the information that students gather in the activities and applies it to their communities.

There are several barriers to teaching through authentic inquiry. These barriers can be divided into instructional and administrative issues. Administrative issues like rigid time schedules that don't allow for necessary revisions of investigations must be dealt with on a local level. Instructional issues include a lack of information regarding how the phenomena relate to specific contexts, inaccessible primary source material, and insecurities regarding the direction in which students might take open-ended investigations. EarthComm has addressed each of these barriers. Consistent with the National Standards, EarthComm promotes inquiry in science instruction. Students actively investigate systems, natural phenomena, and how the phenomena affect their community. The EarthComm lessons are organized to encourage students to develop their own explanations and reasoned arguments based on evidence.

While many science educators understand the nature of inquiry, this aspect of EarthComm may offer the most practical difficulty for educators. It is tempting to say that the difficulty results from logistical problems like obtaining, storing, and maintaining equipment. Although those are important concerns, many effective ways of addressing them have been developed and successfully implemented. Nor can it be said that inquiry-based instruction might present problems because it is so new. Many teachers have entered the profession since the time the emphasis on inquiry first began. In fact, even though the concepts of systems and community are relatively new to Earth science education, they may be easier to implement than inquiry. Past efforts in inquiry-based instruction can detract from the intent current efforts.

While hands-on inquiry is part of many activities in EarthComm, it stands out as ideas are applied to the students' community. Following each activity, a section called "Preparing for the Chapter Challenge" encourages students to consider the local implications of what they have learned. Because the implications differ for each location where EarthComm is taught, there can be no entirely pre-existing answers, which adds to the authenticity of the inquiry.

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Bringing It Together in EarthComm

In EarthComm, the focus on relevance-of working with ideas as they relate to communities at various levels-raises the importance of inquiry-based instruction. Direct instruction, teaching by telling students information, can work against this focus on relevance and inquiry. It is unlikely that students will recognize the relevance of Earth science concepts if presented as already fully developed, already organized, and with their meaning already carefully determined and described. Simply exposing students to ideas does nothing to actively facilitate the students' understanding of how those ideas relate to their personal lives, or the everyday and long-term workings of their communities. EarthComm makes community relevance the focus of instruction by making it the focus of the inquiry that the students undertake in each chapter. The "Chapter Challenge" calls on the students to engage with the topics, to investigate how those topics affect their lives and communities, and to express their conclusions to others through some concrete product. In this way the concepts of relevance, community, systems, and inquiry-based teaching support each other, and provide focused and motivating opportunities for learning.

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