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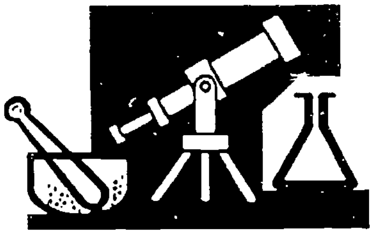
ABSTRACT

The Oregon vision for transforming science education is called concept/process-based science. It is not a program but a conceptual framework which presents goals for the direction of science program development. It focuses science programs on helping students develop basic scientific understandings through the use of the key processes of human problem solving. Section 1 of this document. "Elementary Science Education," consists of two subsections: "The Vision for Concept/Process-Based Elementary Science" and "Promoting the Development of Thought." The latter deals with coordinating five basic sources or factors which provide stimulation and support for students' cognitive growth. These are: (1) experience with objects; (2) social interaction; (3) beginning capabilities in initial conceptions; (4) language; and (5) development--coordinating the factors. Section 2, "Changes In Elementary School Science," consists of the following subsections: (1) "Changes in Curriculum"; (2) "Changes in Learning"; (3) "Changes in Instruction"; and (4) "Changes in Evaluation." Section 3, "School Support," contains information on (1) changes concerning program materials, support, and time allocation, and (2) changes in staff development, which concern teachers' understanding and practices. (PR)



Oregon Department of Education
SCIENCE EDUCATION
SCIENCE CURRICULUM CONCEPT PAPER #5

1992

Concept/Process-Based Science in the Elementary School

I. Elementary Science Education

A. THE VISION FOR CONCEPT/PROCESS-BASED ELEMENTARY SCIENCE

With the increasing importance of managing rapidly changing knowledge and technology, we must more and more depend on the development of our citizens' thinking — reasoning, problem solving, inventing, discovering, cooperating, coordinating, organizing, moral reasoning — to understand societal change. Educators thus face two problems. They must understand these societal challenges and address the diverse, unique needs of each learner.[1] The solution is not to take on and teach more, but to teach differently and smarter. By finding methods which focus on problem solving, we can empower students to take ownership for their own growth and to develop the capabilities and motivations of independent learning of all students.[2]

The Oregon vision for transforming science education is called "concept/process-based science." It is not a program but a conceptual framework which presents goals for the direction of science program development.[3] It focuses science programs on helping students develop basic scientific understandings through the use of the key processes of human problem solving and investigations. Science instruction based on the natural constructive powers of students solves important issues of equity by encouraging all students to meaningfully participate and develop to their fullest potential.[4]

Three foundational principles support elementary concept/process-based science: (1) students construct an understanding (2) of basic concepts of science through (3) the key processes involved in student hands-on investigation. Students' self-directed activity reveals that basic intellectual processes and concepts develop through stages

[1] There are many articles and reports stressing the fundamental importance of education to society such as the National Science Board Commission on Precollege Education in Mathematics Science and Technology report, *Educating Americans for the 21st Century* (Washington, DC: National Science Foundation, 1984); the report of the Commission on the Skills of the American Workforce, "America's Choice: High Skills or Low Wages!" (Rochester, NY: National Center on Education and the Economy, June, 1990) which was the basis for Oregon's 1991 reform legislation, "Oregon Education Act for the 21st Century"; see also the *Oregon Business*, March, 1991, issue on education.

[2] The foundational goal of promoting independent learning is widely supported and is promoted by NSTA. See, for example, John E. Penick, gen. ed., *Focus on Excellence*, vol. 1, no. 1: *Science as Inquiry* (Washington D.C.: National Science Teachers Association, 1983).

[3] The Oregon science program is *SCIENCE Comprehensive Curriculum Goals: A Model for Local Curriculum Development*. (Salem, OR: Oregon Department of Education, June, 1989).

[4] Christine Chaillé and Lory Britain in The Young Child as Scientist (Harper Collins, 1991, p. 15) suggest, "Anyone who is studying anything in a methodical way is a scientist." We would add, "to extend existing human knowledge." Science education is not a body of knowledge to be learned; it is learning to learn about the world. The Oregon Department of Education's Science Curriculum Concept Paper #4, "Concept/Process-Based Science," provides the research base and definition for Oregon science education (Salem, OR: Oregon Department of Education, 1990). See also a companion paper, "A Discussion of Concept/Process-Based Science" (Salem, OR: Oregon Department of Education, 1990).

of construction — not by simply learning completely formed understandings. These stages indicate the importance of understanding the constructive nature of students' scientific knowledge.[5]

Concept/process-based science is also goal focused by directing instruction toward understanding certain basic concepts. While there are many scientific concepts, some fundamental concepts used in basic scientific capabilities of investigation essentially define a literate citizen.[6]

Concept/process-based science uses key processes of students' activity to construct knowledge. Constructive processes are organized into investigations through problem solving cycles — finding and posing problems, proposing plans and methods, trying them out, and interpreting and reporting results. When elementary students learn how to plan and follow a method of problem solving, they can conduct simple, independent investigations into any area or problem and this capability can be developed into the richer, scientific experiments at the high school level. In-depth, independent inquiry is not only valuable in all areas of learning, it creates the life-long independent learner. Scientific knowledge is not something students *have*; it is what students *do*. The ability to independently investigate and construct an understanding of a new area of study begins with simple investigations in kindergarten and culminates in successfully contributing to a rapidly changing, technologically complex society.[7]

B. Promoting the Development of Thought

While the observable behaviors of hands-on activity are important, the goal of science is the development of mental activity. Affective factors provide the motivation and interest for students' mental activity while cognitive factors provide the sources for the development of students' activity. Besides considering the affective interests and motivations of students, teachers can consider five basic sources or factors which provide stimulation and support for students' cognitive growth.[8]

Experience with Objects. *Hands-on activities* mean students have objects (both living and inanimate) directly available for investigation. Being able to return to experiences with objects allows students to try out new ideas to see if in fact their developing ideas are correct. For example, when young students mistakenly assert that a clay ball weighs more when it is subdivided, teachers can pose the problem of how students might show that subdividing decreases weight. Thus teachers can encourage students to use experience with objects in a purposeful way.

The teacher can encourage this factor of using objects for verification by asking, "How do you know?" and "Can you demonstrate that?" Students must conduct many activities involving weight before realizing weight stays constant in spite of raising or lowering objects or altering its shape. Hands-on means learners have objects available so they can conduct investigations and directly gather facts and attempt to verify what they think they know. Using this factor of experience with objects leads to understanding the importance of scientific experimentation and verification.[9]

Social Interaction. A second factor of cognitive growth comes from student opportunities to share the logic of their viewpoint. Students need to hear the multiple viewpoints of others as they work out the logic of their own understanding. Student interaction, such as

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5 The field is gradually realizing the constructive nature of knowledge demonstrated by Piaget's research. See Science Curriculum Concept Paper #2, "Contributions of Piaget to Science Education" (Salem, OR: Oregon Department of Education, 1989) for these implications and Grayson H. Wheatley, "Constructivist Perspectives on Science and Mathematics Learning" in *Science Education* 75(n. 1, 1991): 9-21. A description of the development of understanding of weight, quantity, and volume are in Jean Piaget and Bärbel Inhelder *Child's Construction of Quantities*. (London: Routledge and Kegan Paul, 1952).

6 The AAAS has tried to describe the basic concepts of science in "Biological and Health Sciences: Report of the Project 2061 Phase I Biological and Health Sciences Panel" by Mary Clark and "Physical and Information Sciences: Report of the Project 2061 Phase I Physical and Information Sciences Panel" by George Bugliarello (Washington DC: American Association for the Advancement of Science, 1989). Oregon's basic concepts are described in "A Focus on Science Concepts: Science Concept Working Papers" by David C. Cox (Salem, OR: Oregon Department of Education 1989).

7 For an example of how the developmental sciences produce constructivist teaching, see Rheta DeVries and Lawrence Kohlberg, *Constructivist Early Education: Overview and Comparison With Other Programs* (Washington, DC: National Association of the Education of Young Children, 1987) or Darrell Phillips, *Structures of Thinking 2nd ed.*, (North Liberty: Insights Educational Materials & Consulting, 1991)

8 Chapter three of *Psychology and Epistemology: Towards a Theory of Knowledge* (Grossman, 1972) by Jean Piaget.

9 The key idea of concept/process-based science is that knowledge develops out of students' interaction with objects and does not come from a transmission through the senses or language as the textbooks would have it.

through cooperative learning activities or collaboration,[10] is logic in action. The very essence of knowledge is that it can be shared because it is composed of a rational, thoughtful conceptualization which others can understand.

Teachers encourage this factor when they ask, "Does everyone agree?" "Explain your position to others in your group." "Can you find out why others disagree?" Debate and discussion help students construct the logic of understanding and rational thought that makes shared meaning and cooperation possible. Social interaction means sharing reasons and explanations, and it leads students to understand the importance of the validity and public nature of scientific knowledge.

Beginning Capabilities and Initial Conceptions. Students bring initial capabilities and understandings to science activities and these shape their learning experience.[11] Rather than ignore these initial understandings, teachers can address them by helping students display and use their initial pre-conceptions, such as, their initial notions of weight. By working from the ideas students initially have available, rather than by simply presenting a completed and correct one, teachers can insure students reconstruct their pre-conceptions to form better ones. Helping students build upon their existing knowledge allows students to understand that science is a constructive process which begins with the current state of a field to build or rebuild carefully step by step.

Language. The development of thought also depends on having a system of representation so that mental activity can successively operate at higher levels of consciousness. Words are not meaning or thought itself; instead, words, like steps on a ladder, allow thought to partially represent itself so it can build on itself. Language is what thought can *see* and represent of its own activities. After a meaningful experience, students need language, symbols, graphics, and other forms of representation to represent the objects and actions they have organized and to share what they can see and can do with others. By allowing activity to operate on the level of representational activity of thought, language allows science to be a social or shared activity. When students make a finding or construct a new understanding, they need the socially acceptable names and ways of talking about their insights as they interact, construct understanding, and present results.

Teachers encourage the language factor when they help students find the proper words or symbols for what they understand. Representation includes more than the verbal. Students should be helped to use graphs, graphic symbols, models, maps, and so on, as scientific means of representation of their understanding. Attention to language leads students to understand the importance of being able to share and communicate thoughts clearly and concisely through scientific language and models.[12]

Development — Coordinating the Factors. The developmental factor is the fundamental cause of student growth because it reorganizes and fits all the other factors together into a new, equilibrated whole thereby making the above, individual factors more powerful. While these factors — hands-on experience, social interaction, language, and students' initial understanding — can stimulate changes in students' thinking, it is the developmental factor within students' thought itself which holds everything together maintaining a coordinated whole. The more diversity students can coordinate into a single, rational system, the more organized, inclusive, developed, and therefore advanced, is understanding. Theme based units, language integration, and extending previous knowledge to new applications all push on students to put diverse elements together in a larger, integrated understanding. The strong relationship of science to the language arts, mathematics, social studies and other areas indicates the value of integrated treatment of science with other curricular areas. The same "hands-on" science activities that promote intellectual development during the early school years simultaneously serve the development of reading, mathematical and social skills.

When all factors taken together result in the reorganization of thought into a new whole or paradigm, that qualitative change forms a new stage of development. This new way of understanding and seeing facts, either by

10 For example, see David W. Johnson and Roger T. Johnson, *Leading the Cooperative School* (Interaction Book Company, 1989); Johnson, Johnson, and E.J. Holubec, *Cooperating in the Classroom*, (Association for Supervision and Curriculum Development,1988); or Jean Piaget, *Psychology of Intelligence* (Littlefield, Adams, and Company, 1950): chapter 3.

11 James Wandersee, Joel Mintzes and Joseph Novak, *Handbook of Research on Science Teaching and Learning*, ch. 5. In press, 1994, Macmillan/McGraw-Hill, NY, NY.

12 See *What's Whole About Whole Language* by Kenneth Goodman (Scholastic-TAB Publications, 1986) or *Talking Science: Language, Learning, and Values* by Jay L. Lemke (Norwood, NJ: Ablex, 1990)

a slow understanding or a quick "aha" feeling of rapid insight, marks developmental growth and forms the basis for seeing student growth through qualitative evaluation. Teachers encourage development by providing students with opportunities to reflect on their activities *to figure out what it all means*. It is this reorganization of thought which comes from the attempt to fit together prior conceptions and empirical experiences — not simple learning and remembering — that marks the development of thought in students and leads them to understand how theories and paradigms shape, define, and mark the advance of scientific development.[13]

If completed knowledge cannot be pre-organized and transmitted to students in completed form regardless of the objects, language, social interaction, or logical forms used by the teacher, then teachers can only be responsible for establishing the conditions of growth so that students can do it for themselves. Elementary concept/process science is the activity of helping students generate and organize their learning activities and investigations by establishing these conditions of growth.

II. Changes in Elementary School Science

Two examples illustrate the transformation of elementary school science from textbook to concept/process-based science.

Textbook Example

A series of lessons from Unit 2 of an elementary science textbook on physical science began by stating, "Physical science is about things in the world around us. It is also about how things can be moved or changed. We can know about things in the world by using our five senses and by measuring."

The first lesson began with an activity for "learning that things take up space." Students were shown four pictures describing how they are to put rocks in a glass to see how the water level rises. It ended by directing students to "Think about why the marks are different."

Next came eight pages of text telling students that "things take up space...things that take up space are called **matter.** The amount of space that matter takes up is called **volume**...Things that take up space have **mass.**" Other terms in the text are "invisible," "states of matter," "solid," "liquid," "gas," "air," "change in volume and shape," "different kinds of matter," and "living and non-living." In the last activity, students placed an inverted cup with wrinkled paper into water. It asked, "Did the paper get wet? Why or why not?" The lesson ended with a three question test:

> 1. Which thing in each pair has more volume? Which has more mass? 2. If one thing has more volume than another, does it also have more mass? 3. Think! Name each thing in the fish tank and tell its state of matter.

The second lesson was titled "Matter Changes" and concerns change of state in water. The third lesson concerned "Measuring Matter," the fourth "Magnets," then "Light," "Shadows," and the final four pages concerned "Technology Today" and "Ask a Scientist."[14]

Concept/Process-Based Example

The teacher began the unit by posing a problem. "In your groups choose any object you like and think of all the different ways you can change it." The groups suggested making their object black instead of white, making it large, changing its shape, making it hot, changing it from glass to metal, moving the parts around, etc. The teacher next asked that students try to match up the changes with some quality. The change from white to black was matched to

[13] Piaget in *Psychology of Intelligence* lays out this explanation of intelligence as the successively more advanced groupings of mental operations.

[14] Charles Barman, et al., *Addison-Wesley Science*, grade 3 (Addison-Wesley, 1989) is used as a typical example.

the concept of color, changing from small to large was size, etc. The teacher allowed many mistakes but focused the discussion on generating various descriptive qualities.

The teacher then wanted to know if they had found all the qualities which could be used to describe differences among objects and when students said they didn't know, he asked how students might find out. Some students thought of asking experts, other teachers, or looking in textbooks. After helping them divide up the tasks to investigate and compare their lists to one of the data sources, the class met again. From this discussion students made several revisions in their lists.

Next the teacher helped students use their lists of qualities to describe a variety of objects. That raised new problems when the teacher used the board to help students display their assertions and see that they did not understand some concepts. The teacher then pulled out one of their concepts, "hot and cold." The teacher drew a line, placed the word "hot" towards one end of a line, and had students generate other words which would go along the line — "cold," "medium," "warm," ("how about *tepid*?" the teacher asked. "How about really cold?").

Following that, the teacher had students create a box above their scale to label the concept, "temperature." "How do we talk about objects as they move in this direction along the scale? And in this direction along the scale?" "Hotter," and then "colder." "How about the end points?" "Hottest." "Coldest."

Then came more discussions of what would have to happen to move an object along the scale, how one would know a change had taken place, how units could be created on the scale, and what units had already been created. This created more investigations, another sharing session, and resulted in unit gradations being placed on the measurement format along with a special arrow on the scale to show the freezing point of water, "a benchmark or anchor point," which physical scales have.

The students then had a plan, what the teacher called a "learning format," which they repeated in investigating other measurable concepts. When they completed an investigation, students presented their findings along with a demonstration of their concept and documented their investigation with a completed format. The number of concepts and the limits of students' understanding of particular concepts — length, color, mass, volume, weight, etc., — clearly showed in their work. Some of these projects were proudly presented by students to their parents at parent teacher conferences.[15] The teacher gave no grades but often used another set of student structured activities which created constructive student feedback, comparison of student to the group, and scales of self-evaluation.[16]

A. Changes in Curriculum

What students are asked to learn and understand is changing. The textbook example *covered* standard science information regarding matter by mentioning many concepts and having students do a displacement volume activity but the focus was not on the processes of developing an understanding of the key concepts. The concept/process-based science example had students clearly focused on constructing concepts and a system for organizing the concepts.[17] The teacher understood and used the students' conceptual processes and the constructive sequence which puts the understanding of temperature together. The curriculum was conceptual rather than verbal — a focus on the development of understanding rather than on verbal coverage.

The direction of change for the curriculum of elementary concept/process-based science is toward specifying key concepts, what mental processes must be organized to understand each concept, and how that system of mental processes is actually constructed by students[18]:

> In the unit on physical matter, examples of key concepts for describing physical properties of objects are quantity, weight, volume, mass, density, color, speed, velocity,

[15] For more ideas. see Nancy Little and Jon Allen, *Student-Led Parent Teacher Conferences*, (Lugus Productions, 1988).

[16] This vignette is a composite of observations of several outstanding teachers. See also John E. Penick, gen. ed., *Focus on Excellence*, vol. 1, no. 2: *Elementary Science* and vol. 1, no. 1: *Science as Inquiry* (Washington D.C.: National Science Teachers Association, 1983);and *Smart School, Smart Kids: Why Do Some Schools Work?* by Edward B. Fisk (Simon & Schuster, 1991.

[17] Karen C. Smith, "Integrated Curriculum: Review of the Literature" *Bridge* 3 (Fall, 1990):5-7 describes approaches to curriculum integration.

[18] The Holmes Group and others call for going beyond covering concepts to focusing on student understanding of concepts. Theodore Sizer of the Coalition of Essential Schools says "less is more" in the curriculum. See also "Rethinking Curriculum: A Call for Fundamental Reform", a report of the National Association of State Boards of Education Curriculum Study Group (Alexandria, VA: NASBE, 1988).

time, etc. An example of development would describe how the students' notion of temperature starts with polar opposites (cold or hot), then is a pre-conceptual notion having an ordered series of states (cold, medium, warm, hot), to a conceptual form made up of a system of ordered differences (cold*er*, hott*er*), followed by a conceptual form having measurable units and a benchmark.

Another example of the developmental sequence describes students' initial confusion of bigness, weight, and changes in position, e.g., "you are heavier when you're (crouching) down" on a bathroom scale in which weight appears on a scale of polar opposites such as heavy/light. Next students see several intermediate states of weight — light, heavy, "kinda heavy" but without relating all in a seriation. Students have difficulty with relating a weight in two directions at once to insert in a series such as "it's heavier than this one but lighter than that one so it goes right in between." Next they understand weight as clearly distinct from perceptions of size, and students conceptualize a full series of possible positions or differences in weight on a scale using vectors such as heavier and lighter. However, even though a whole weight when subdivided into parts is understood as necessarily equivalent to the whole, measurement units are not yet fully constructed. Finally, weight is unitized and abstracted as a mathematical concept — e.g., twice a double weight is equal to four single weights, etc.[19]

The trend toward teaching for understanding marks a change from behavioral objectives specifying skills and content to identification of the cognitive systems making up understanding and their developmental construction.

B. Changes in Learning

The nature of the learning activities students are asked to do is changing. Rather than pre-planning a disjointed series of activities for students as in the textbook example, the teacher using concept/process-based science integrated the learning activities into an overall cycle of investigation which helped students construct an understanding of the concept. To help students conceptualize their experiences with objects, the teacher asked students themselves to do the conceptual work of initiating and organizing an understanding. The teacher separated learning into two components: (1) experience — what was experienced in hands-on activity and (2) concepts — the conceptual system which students used to organize and understand their experiences.[20]

The textbook activity attempted to simply give students the concept of volume and it expected students to use the concept of volume to experience or *see* the displacement of water. The activity was not organized by students and it does not let the teacher see or work with how students actually understand volume. The activities are uncoordinated and one activity does not lead to the following activity nor do activities build upon previous activities nor is the sequence constructive. The activities seem to presume that the concept of volume is somehow made directly available and comprehended by students from the demonstration and words. The textbook violates research findings which clearly show that there are many constructive levels which students must complete in order to understand volume.[21]

In the concept/process-based science example, the teacher did not have students follow a pre-established laboratory or hands-on procedure. Instead, the teacher asked students to initiate, generate, and organize the concepts in the learning activities. The teacher shifted learning back and forth between the students' developing conceptualization and what the students experienced with objects. The concept was constructed through a logical framework which was visibly represented in the temperature scale.

The trend toward student constructive activity means learning activities do not simply demonstrate or present completed concepts but that students actively use their conceptions and coordinate their own investigations to actively explore a concept.

C. Changes in Instruction

In the textbook example, the source of knowledge for students was designed to be direct transmission by reading about things or by seeing a demonstration with objects. The instructional method was that of transmission

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[19] Piaget and Inhelder, *Child's Construction of Quantities*, ch. 2, 6, 10; and Jean Piaget, Bärbel Inhelder, and Alina Szeminska, *The Child's Conception of Geometry*, (New York: Basic Books, 1960) ch. 12, 13

[20] For ideas of representational structures students' naturally use, see D. Genter and A.L. Stevens (eds.), *Mental Models* (Hillsdale, NJ: Earlbaum, 1983) or work on concept mapping. Piaget provides a very precise, technical description of these 'assimilatory structures' students use which can form the basis for learning formats.

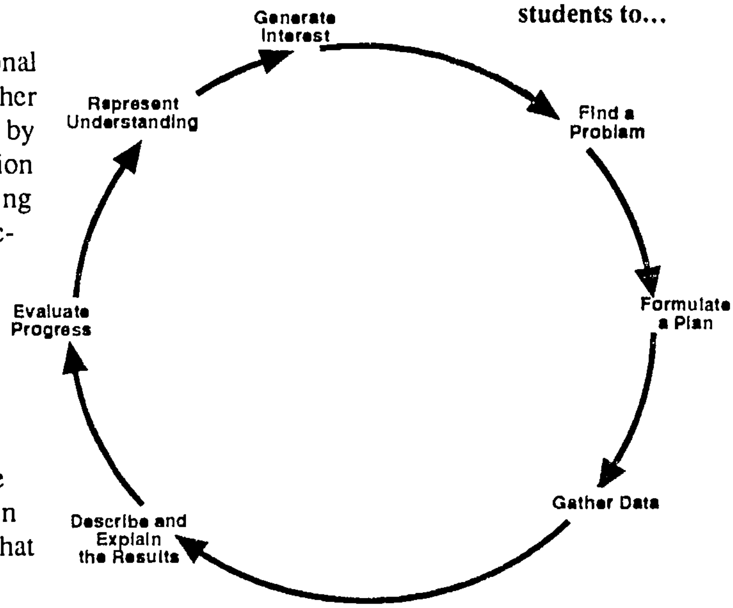
[21] Piaget and Inhelder, *Child's Construction of Quantities*, ch. 3, 6, 12 and Jean Piaget, Bärbel Inhelder, and Alina Szeminska, *The Child's Conception of Geometry*, (New York: Basic Books, 1960) ch. 12, 13.

of completed knowledge to students. The instructional method did not use students' constructive activity.

In the second example, the teacher's instructional method used students' own way of thinking. The teacher helped students construct a better understanding by coordinating the learning processes into an investigation cycle which shifted back and forth from the developing concept to more experiences with objects. The instructional method actively followed students' mental constructions and was far richer than a simple discovery method.

Concept/process-based instruction organizes learning activities into cycles to help students relate their experiences to a conceptualization and to construct a deeper understanding. These constructive cycles help students move back and forth between what they see (their experiences with objects) and what they see with (their developing understanding).[22]

The teacher helps students to...



Learning or Problem-Solving Cycles

To change from transmission teaching to student construction means finding an instructional method which allows the teacher to coach rather than present material. The learning cycle is a method of coaching investigations and constructions conducted by students. The simplest form of learning cycle method might consist only of three very general steps such as *explore, invent,* and *discover.*[23]

In concept/process-based science, the problem-solving steps are the different uses or functions of students' activity. Studying what has been written[24] and having exemplary teachers describe their instructional methods reveals a rich variety of advanced forms of coaching students. Rather than simply giving students objects and haphazardly attempting to keep students busy by asking questions or giving activities, advanced teachers seem to follow a natural learning or problem solving cycle by students. They sense how students naturally shift their focus of attention and these teachers seem to become coaches by posing each step as a problem for learners to address. Here is an example:

1. **Generate Interest.** Problem solving investigations might begin with an exploratory activity which generates interest and motivation such as free exploration, demonstrations of unusual phenomena, interesting, or divergent group activities. Particularly rich are major societal problems derived from Science/Technology/Society (STS) materials such as the greenhouse effect, endangered species habitat, old growth, etc. or engineering problems derived from practical projects.[25] The teacher might have two purposes in posing a problem in this initial step of students' activity:

- *to explore a topic to develop an interest*
- *to display or test students' initial conceptions or limits to their understanding*

2. **Find a Problem.** Next the teacher might help students develop a more specific problem focus from

[22] See John W. Renner and Edmund A. Marek, *The Learning Cycle and Elementary School Science Teaching* (Portsmouth, NH: Heinemann, 1988). Steven J. Rakow decribes the learning cycle in a useful Phi Delta Kappan *Fastback* (#246) called "Teaching Science as Inquiry" (Bloomington, IN: Phi Delta Kappa Educational Foundation, 1986).

[23] For example, see the SCIS 3 elementary science program (Hudson, NH: Delta Education, Inc.).

[24] *Student as Worker, Teacher as Coach,* is a viewers guide for Re-Learning teleconferences (Morristown, NJ: Simon and Schuster School Group, 1989) from the Coalition of Essential Schools. It includes articles by Grant Wiggins describing authentic testing and coaching students through collaborative inquiry cycles.

[25] See Ray Hull, "Science, Technology and Society," Science Curriculum Paper #3 (Salem, OR: Oregon Department of Education, 1990) for STS resources. For an Oregon program in the early grades, see Susan Dunn and Rob Larson, *Design Technology: Children's Engineering* (New York: Falmer Press, 1990).

disagreements either from differing opinion or from an acknowledged lack of information. Often teachers display different points of view on the board or chart paper during a whole class discussion. Getting a display of their thought helps students see the limits of their understanding and the problems they face. The following might be the purposes for students' activity:

- *to clearly express a contradiction, disagreement, gap, or limit of their knowledge*
- *to clarify a specific problem (need for facts)*

3. **Formulate a Plan.** Once students clarify their problem focus, the teacher may be thinking about how to help students formulate a method for gathering data. The concept/process-based science teacher might ask, "How will you find out?" to help students propose a plan. At the primary level, rather than symbolic representations, students might use physical models such as ordering objects, for example, by temperature or weight, or by classifying organisms by similarities as methods for investigating or demonstrating something. During this step, activities might have these purposes:

- *to identify specific data gathering activities or experiences (e.g., library research, computer based research, questioning experts, experiments) which will answer their question or need for information*
- *to organize a new method or one previously used to generate the data or experience*

4. **Gather Data.** Carrying out a plan will involve experiences with objects or data sources in which students' hands-on activities will act on objects to transform them in some way through changing, modifying, grouping, comparing, or so on. Activities become much more individualized as all students will want to work with the objects for themselves. The purposes of this step might be:

- *to learn field and laboratory techniques to produce effects or changes in objects*
- *generate and organize data or experiences*

5. **Describe and Explain the Results.** After most hands-on experiences, teachers usually help students talk about the *language*; analyze and explain as much of their results as they can. The student purposes in this step seem to be:

- *to figure out whether the problem was solved or question was answered*
- *to resolve discrepancies between their initial predictions or conceptualizations and the new evidence they generated*

6. **Evaluate Progress.** At some point, teachers might help students return to their original position regarding a problem so students can re-evaluate the wisdom of their position in light of the increased understanding they have constructed. This evaluative return is especially important with a Science/Technology/Society (STS) focused investigation, but self-evaluation activities or peer feedback with ratings and supporting evidence can help students self-evaluate what was of value in anything they accomplish. Two purposes for students' activity appear important:

- *to close or shift a line of activity by comparing accomplishments with original problems*
- *to identify what is of value in what the students have produced*

7. **Represent Understanding.** Completed work leads naturally into representing that work in verbal, graphic, project, or model form. Young students may construct a model or drawing and use oral language to *present* their findings. Intermediate students may do simple written reports with graphic models such as diagrams, tables, maps, drawings or charts. Any projects including demonstrations, models, and video-tapes can be noted in portfolios, displayed, or simply noted on a student record. Teachers might help students to:

- *close a unit or re-open a new line of investigation*
- *provide formal self-evaluation to appreciate what of value they have constructed*

In complex investigations, teachers may repeat the learning cycle and use any degree of complexity or length depending on the depth of an issue. Learning cycles are driven by problem posing rather than assignment giving.

The teacher's task is to help students take ownership and responsibility for organizing their learning. The teaching problem is not one of determining what to teach or what is developmentally appropriate but how to use students' activity so students construct the valued knowledge. Rather than present concepts, rules, or information, the teacher asks, "How can I help the students put these ideas together or find this information on their own?" Concept/process-based science is helping students learn to learn.

D. Changes in Evaluation

In the textbook example, the activities do not in themselves reveal much about students' understanding, nor do the activities follow the thought processes of students. Only after all activities are completed does the textbook establish an evaluation activity. Evaluation is an add-on at the end of a series of activities, and it depends on right/wrong, single answer tests.

But evaluation of student growth is changing from single answer, add-on teacher directed tests to methods integrated into the problem solving cycle in which students display how they are actually constructing and understanding concepts.[26] In the concept/process-based science example, the teacher had a display of students' understanding in the very first activity and could immediately work with their particular conceptualizations of the situation. Because the learning activities worked with students' constructions of the temperature scale, no add-on evaluation activity was necessary. The scales which the students constructed and explained clearly showed each students' development of understanding of the concept of temperature and more generally, of measurement.

Concept/process-based science helps make evaluation a student-owned activity so students can identify and value what they have constructed, and evaluation helps students determine what next to tackle in a unit. Concept/process-based science transforms evaluation in two ways.

- First, it focuses on reasoning and understanding rather than single answers.
- Second, it uses the stages of construction of conceptual understanding as its scale.

[26] The NWREL provides excellent evaluation resources and bibliographies. See Judith A. Arter and Vicki Spandel, "NCME Instructional Module: Using Portfolios of Student Work in Instruction and Assessment," (*Educational Measurement: Issues and Practices* 10 (1), 1991): 37-45; Rick Stiggins, "NCME Instructional Module: Design and Development of Performance Assessment," *Educational Measurement: Issues and Practices* (Fall, 1987): 33-42; or the National Assessment of Educational Progress, *Learning by Doing. A Manual for Teaching and Assessing Higher-order Thinking in Science and Mathematics* (Princeton, NJ: National Assessment of Educational Progress, 1987).

III. School Support

A. Changes in School Support

School management and restructuring can provide essential support in the transformation of science programs toward concept/process-based science. Support for transforming the curriculum involves materials, supplies and equipment, and instructional time.

Program Materials

Schools can support the transformation to concept/process-based science by providing a wide variety of advanced programs, curriculum materials, computer networks, data bases, and learning technologies for students. These supports are not add-ons to textbooks, but integral, necessary components of concept/process-based science investigations by students.

Support

Schools can greatly encourage the change to concept/process-based science by providing teachers with the rich resources of supplies and science areas necessary to active hands-on experiences. Schools can provide support in several ways:

- **Science kits** — These provide all the objects, supplies, and instructional materials for a single unit of instruction. They are re-stocked and their distribution coordinated by a central office but they have not proven successful because science work space remains a problem.[27]

[27] Several successful centers are currently operating in Oregon (Multnomah County, Central School District of Monmouth-Independence, and the Corvallis, Medford, and Lincoln County School Districts). Schools and districts unable to provide or join such a service must address the need for supply replenishment and create a system which they are committed to sustaining. Release time or an extra paid day for a teacher to inventory, order and distribute materials could be successful with administrative encouragement.

- **Science rooms** — Very few schools are fortunate enough to have a separate science room or hall area. However, teachers can departmentalize so one can specialize and dedicate a room to science.
- **Science areas** — Many schools can provide science areas located on or very close to the school site. These can be a pond, garden, environment center, greenhouse, zoo area, weather station, etc.
- **Field laboratories** — Oregon is rich in field sites and instructional resources which can be developed into field labs in conjunction with trips. For example, science instruction can be developed to feature the ocean beach as a field site. Preparatory work in a learning cycle can lead up to a field trip in which time is used only for efficient and focused data and specimen observations and study. These data can then be used back in the classroom to complete one or more learning cycles.
- **Community resources** — Museums, businesses, libraries, government agencies also provide rich opportunities as data sources for investigations.[28]
- **ORNET** — The computer conferencing network linking the Oregon Cadre for Assistance to Teachers of Science (OCATS) science education staff development leaders in the 15 instructional regions of Oregon provides an opportunity for every school in the state to share information (e.g., teaching ideas, data, resources).[29]
- **Informal (non-traditional) science programs** — Programs like Hands-On-Science-Outreach (HOSO), Science Olympiad, Saturday Academy, Family Math and Family Science, Oregon Museum of Science and Industry (OMSI), and Science and Technology for Children can provide alternative engaging activities.

Time Allocation

Schools can make powerful statements about the value of science by insuring a large portion of elementary education is devoted to the development of basic intellectual capabilities and learning processes through active student learning such as concept/process-based science programs. Allotting time for science teaching is a problem for many elementary teachers but in-depth investigations can provide a practical foundation for thematic integration with other subjects and particularly whole language programs.[30] Teachers must have support for prioritizing instructional time, preferably through a building or grade level plan which is developed by the teachers with the input of parents. Although traditionally there have been recommended allotments of time[31] for science, schools which emphasize active, in-depth, integrated learning will devote most of the day to student investigatory activity as distinct boundaries among the content areas dissolve.

B. Changes in Staff Development

Staff development is the essential element for persuading teachers to "do" concept/process-based science.[32] Staff development involves both helping teachers to develop (1) a new *understanding* of concept/process development in students and (2) the skills of successful concept/process-based teaching *practices*.

Teachers' Understanding

For many teachers, concept/process-based science instruction involves fundamentally changing their basic conceptions of student learning. Without opportunities

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28 See the helpful OMSI "Science Education Resource Directory, 1986" (Portland, OR: 1986) for Oregon resources or contact the Science Education Specialist of the Oregon Department of Education.

29 The Oregon Department of Education ORNET system provides an intrastate computer conferencing network that is also linked to agencies and educators throughout the nation through PSInet, the national interstate computer conferencing network.

30 See "Linking Literature with Science" by Marlene Thier in *SuperScience*, October 1991.

31 These standards come from the Oregon Department of Education and the National Science Teachers Association.

32 Rodger W. Bybee provides an excellent overview of the changes in science teaching in "Contemporary Elementary School Science: The Evolution of Teachers and Teaching" in *Science Teaching: Making the System Work*, Audry B. Champagne, ed., (Washington, D.C.: American Association for the Advancement of Science, 1988).

for in-depth study of concept/process-based science and the new instructional methods, teachers may find it difficult to give up the traditional control they exert over students. To help teachers make changes, staff development programs themselves can be transformed from simple, one-shot training sessions, in-service, or coursework to extended, integrated, goal-based programs which involve teachers in active, long range, in-depth investigations into teaching and learning.[33]

Staff developers can support teachers by providing extended, in-depth programs for teachers such as year long coursework, regular teacher seminars, or action research. Staff development programs can be made more powerful by narrowing their focus to study of the teaching and learning of the key concepts and processes to be developed in students. In-depth, goal-based staff development allows teachers to become researchers, peer coaches, and leaders in changing science instruction.

As with students, five factors appear important in promoting teachers' ability to understand and promote the cognitive development of scientific understanding in students.

- The first *factor* is ***teachers' conceptual framework.*** Consultants and researchers can assist teachers by helping teachers examine their own frameworks and conceptions which shape how they view teaching and learning. Staff development methods which attempt to understand and work with qualitative differences among teachers can support each teacher's unique needs as well as common development.
- ***Research experiences*** are a second *factor* which contribute to teachers' development. Research experiences which clearly display students' misunderstandings of the concepts in the school curriculum and show how students construct new understandings can provide powerful support for concept/process-based instruction. Research on students' conceptions can come from teachers' own classrooms, laboratory classrooms designed to provide videotapes or direct demonstrations, transcripts, or video-tapes provided by resource personnel.
- A third *factor* promoting teacher development is teachers' access to the most ***advanced research literature and educational materials.*** Curriculum laboratories, presentations and conferences, professional libraries, and computer access to ERIC provide necessary help to teachers as they re-think learning and teaching.
- Teachers need time for a fourth *factor*, ***dialogue and discussion*** with colleagues. Having collegial support and a supportive ethic for professional dialogue including dialogue on computer conferencing networks makes the in-depth change and development easier and safer for teachers.
- ***Reflection*** is an essential *factor* because of its special place in allowing teachers to focus on understanding their own internal change. The first four factors may provide healthy stimulus and support but self-reflection encourages teachers to re-organize their thoughts and find a clearer sense of direction for their own development.

Teachers' Practices

Parallel in helping teachers develop a new way of understanding student growth, staff development programs can help teachers develop new teaching methods and skills.[34] Again, several factors appear important in helping teachers make significant instructional changes:

- Teachers must be able to observe and study clearly described and modeled concept/based-science management and instruction.[35]

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[33] For some basic references see D. A. Schon, The Reflective Practitioner, (Basic Books 1987); Georgia Mohlman Sparks-Langer and Amy Bernstein Colton, "Synthesis of Research on Teachers' Reflective Thinking" in *Educational Leadership* 48 (March, 1991): 37-45; and Judith Warren Little, "Norms of Collegiality and Experimentation: Workplace Conditions of School Success," American Educational Research Journal 19 (n. 3, 1982): 324-340.

[34] For programs directed to the development of teaching, see the *Texas Elementary Science Inservice Program (TESIP)* based on the AAAS Project 2061 and developed by James Barufaldi, P. Carnahan, and Steven Rakow, (Education for Economic Security Act Title II, Project #00690401-04, Austin, Texas: Texas Education Agency, 1991). It provides five modules and videotapes as an essential part of teacher development and is available from the Science Education Center-EDB340, U of Texas at Austin, TX 78712. British teacher developers also report the value of videotapes to teachers. The Holmes Group integrated staff development into *Tomorrow's Schools: Principles for the Design of Professional Development Schools*. (East Lansing, MI: The Holmes Group, 1990)

[35] Some recently developed programs include Insights, Newton Math, FOSS, Science for Life and Living, LifeLab, and Kids' Network

- Teachers must have available discussion, support, and coaching from other teachers.
- Teachers must have guidance and information from expert teachers which is specific to their grade level, topic, and materials.
- Teachers must have concept/process-based program materials and science objects available.
- Teachers must have opportunities to experiment and develop the new instructional methods.

Staff development services can support teacher development, but they cannot be responsible for it. Teachers themselves must control and evaluate instructional support services; the basic principles of concept/process-based science call for empowering teachers as well as students.

Elementary concept/process-based science presents a model of human growth and a framework for educational practices. Empowering students by helping them follow problem solving cycles of investigation helps students identify and develop the key conceptual tools and processes necessary in learning to learn. These same principles of active investigation and construction of professional understanding and techniques provide a staff development model for teachers.

By involving and empowering elementary students to take ownership for their learning, by helping elementary students focus on understanding basic concepts, and by featuring the constructive processes of inquiry, elementary teachers can promote in all learners the habits of success and the capability of powerful learning which are so necessary in our modern, changing society[36].

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36 Margaret S. Klein and F. James Rutherford. *Science Education in Global Perspective: Lessons from Five Countries* (Washington, DC: American Association for the Advancement of Science, 1985), and American Association for the Advancement of Science. "Science for All Americans: Summary," (Washington, DC: American Association for the Advancement of Science, 1989).

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Oregon Schools ...A Tradition of Excellence!

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