DOCUMENT RESUME

ED 326 421 SE 051 780

TITLE Concept/Process-Based Science. Science Curriculum Concept Paper #4.
INSTITUTION Oregon State Dept. of Education, Salem.
PUB DATE Sep 90
NOTE 13p.; For a related document, see SE 051 781.
AVAILABLE FROM Oregon Dept. of Education, 700 Pringle Parkway, SE, Salem, OR 97310-0290 (Free while supply lasts).
PUB TYPE Information Analyses (070)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Cognitive Development; *Concept Formation; *Educational Trends; *Elementary School Science; Elementary Secondary Education; Experiential Learning; Literature Reviews; Misconceptions; Personal Autonomy; *Problem Solving; Science and Society; *Science Curriculum; Science Education; Scientific Concepts; *Secondary School Science; Values Education
IDENTIFIERS *Constructivism

ABSTRACT

Major efforts are underway to identify and define a science of science education which will reverse the relationship between research and program development. This trend is toward using research on how learners grow and develop prior to program development and the organization of instructional techniques. Clear scientific explanations of how students learn will be of great practical value in assisting teachers to more directly work with and promote students' learning activities. Therefore, in order to define concept/process-based science education, this paper begins by summarizing the relevant research trends. The research, which leads to a definition of concept/process-based science, has been summarized in five main areas which include: (1) the instructional methods teachers use; (2) the curriculum that is identified as important to student growth; (3) the learning activities in which students are asked to participate; (4) the evaluation of student growth; and (5) placing science in a broader, interdisciplinary context which relates it to societal values. Each section discusses the problem, the trend, and the implication for science education. The paper concludes with a definition of Oregon's concept/process-based science. (KR)

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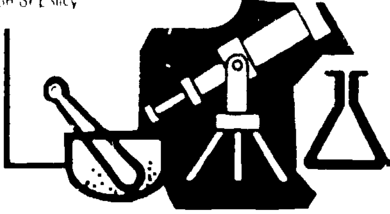

Concept/Process-Based Science

Science Curriculum Concept Paper #4

I. Introduction

Major efforts are underway to identify and define a science of science education which will reverse the relationship between research and program development (Resnick, 1986; Shulman, 1987). This trend is toward using research on how learners grow and develop *prior* to program development and the organization of instructional techniques. The trend is a movement away from basing programs on a pre-established philosophy or using research techniques merely to test for program effects *after* a program has been formulated. Clear scientific explanations of how students learn will be of great practical value in assisting teachers to more directly work with and promote students' learning activities. It is the advancement of scientific understanding which informs, makes possible, and, in general, promotes humans' practical activity. Therefore, in order to define concept/process-based science education, this paper begins by summarizing the relevant research trends.

The research which leads to a definition of concept/process-based science can be summarized in four, main areas which suggest and substantiate qualitative changes for Oregon science education. These include:

- the instructional methods teachers use,
- the curriculum that is identified as important to student growth,
- the learning activities in which students are asked to participate,
- and the evaluation of student growth.

An additional, fifth component also provides guiding principles for concept/process-based science and particularly Science, Technology, and Society education (STS):

- placing science in a broader, interdisciplinary context which relates it to societal values.

II. Trends from Research

While individual research findings do not directly tell educators what to do, trends in research have important implications for educational practice. Increasingly, these trends are toward:

- explaining how knowledge is not transmitted but develops as a human mental activity,
- showing how concepts and scientific knowledge can be described and specified,
- describing the students' constructive activities of conceptualization,
- explaining how students' systems of mental activity or 'naive conceptions' reorganize themselves as students' use them and develop an understanding of a concept—in other words, explaining the stages of conceptualization, and
- understanding science as playing a necessary and valuable role in illuminating practical problems of human adaptation to the world and not just as a body of knowledge studied for its own sake.

The research trends, indicating that researchers are reorganizing their fundamental conceptions of how students learn science, are producing qualitative changes in science education (NSTA, 1987; Linn, 1987; NASBE, 1988; and see Shymansky and Kyle, 1988; and the Blosser and Helgeson series of summaries). The awareness of these qualitative changes clarify how concept/

process-based science programs differ from traditional science programs in each of the five areas discussed above. From these differences comes emerging responsibilities and directions for change by support personnel and science teachers.

Each of the following sections discusses the research trends by (1) posing a fundamental problem of science education, (2) discussing a trend emerging from advances in research, and (3) drawing the implications from the scientific basis for concept/process-based science. Each ends with a summary chart.

1. Instructional Methods

Problem: In attempting to educationally promote the development of scientific knowledge in students, can knowledge be *directly presented and transmitted to students* such as through language or in experience with objects? Or, is knowledge *an internal or mental, constructive activity* which is simply stimulated and triggered by external sources such as teaching? Is it possible to have the learner directly study completed knowledge? Or, can instruction only assist the learner in putting together knowledge such as through problem solving cycles?

The Trend: Instructional methods have primarily been based on perceptions, typologies, and procedural guidelines such as *Models of Teaching* (Joyce & Weil, 1986) or ITIP (Hunter & Russell, 1981). These methods usually have the intent of carefully organizing and directly presenting or demonstrating completed concepts to students for them to learn. Increasingly, however, instructional methods are being derived from research into the problem solving cycles and natural processes students must go through in the construction of concepts and understanding (Cate & Grzybowski, 1987; Pizzini, Shepardson, & Abell, 1989; Lockhead and Clement, 1979; Renner and Marek, 1988).

- The trend is toward basing instruction on methods which work directly with the dynamic constructive and problem-solving activities of the learner rather than on static models of presenting or showing completed concepts, and teacher organized learning activities and 'labs'.

Implication for Science Education: Rather than using the activity of students to practice or apply knowledge, the trend is toward assisting them to construct knowledge through the the activity itself. This means that rather than simply presenting and covering the material to be learned, instructional methods are being based on learning cycles which follow and facilitate the developing mental abilities of the student.

As the constructive nature of students' mental and physical activities is better understood, instruction will increasingly focus on first, helping students to generate concrete or practical activities and second, helping them abstract and conceptualize the concepts within the activities. These instructional cycles eventually and naturally lead the student to the abstract representations of concepts (such as mathematical and scientific formulas). Instruction, then, helps the learner reconstruct or 'conceptualize' previous mental and physical activity first using verbal and then mathematical forms. Commonly, these final, abstract formulas are the place where instruction begins. (See Chart I.)

2. Curriculum

Problem: In specifying what is to be developed in the learner, should knowledge be considered as *a body of information* to which increasingly complex information is added (that is, something which can be comprehended directly in completed form and which exists outside of the learner)? Or, should knowledge be considered fundamentally as *systems of mental activity* necessarily organized and initiated by the learner? In other words, should the curriculum specify knowledge as something to be presented ready made to the learner in static, completed form? Or, should curriculum essentially be viewed as an activity by the learner?

Chart I: Instructional Methods

A Traditional Science Program	A Concept/Process-Based Science Program
• Features clear organization and presentation of information either from teacher or text, or uses objects to show information (teacher centered). • Puts activity of learner after teaching and uses it to reinforce, apply, or practice what has been learned from teacher or text. • Features emphasis on testing of learner to insure control of learning through correct reception and recall. • Confuses method with how to present or expose knowledge to learner. • Assumes all learners 'ready' at same time.	• Features clear problem posing as initial beginning of activity with objects. • Makes organization and conceptualization of knowledge the responsibility of learner. • Works with and through learners' activities. • Is based on shifting learner activities through problem posing and solving cycles which follow natural construction and stages of conceptualization. • Constantly attempts to 'decontrol' learner to push learner toward independence. • Accommodates wide range of learners.

And, is that activity essentially a mental one or an observable, behavioral one?

The Trend: In a "call for fundamental reform" of the curriculum, the National Association of State Boards of Education (NASBE, 1988) called for K-12 curricula which address central concepts and thinking skills. These objectives address the need to develop fundamental intellectual capabilities which lead to understanding rather than superficial knowledge that covers many topics and is easily testable. Theodore Sizer's Coalition of Essential Schools features essential, intellectual capabilities by stressing that "less is more" (Wiggins, 1987).

Curriculum reformers (but not most teachers and publishers) are moving away from specification of a number of courses, coverage of texts, or hours of science instruction, to identification of fundamental concepts and understandings (e.g., AAAS, 1989), deeper mental processes of reasoning, investigation, and problem solving (Costa, 1985; Chi, Geltovitch, & Glaser, 1980), identification of the relations among concepts, and specification of the development of concepts (Lawson, 1988; Driver and Easley, 1978).

Rather than speculation and armchair task analysis of concepts, the mental complexity of the construction of understanding of various scientific concepts is increasingly being derived from research (Gardner, 1985) such as that reported in the *Proceedings of the 2nd International Seminar: Misconceptions and Educational Strategies* (Novak, 1987) and *Published Articles in Science Education: Alternative Conceptions and Cognitive Development* (Dykstra & Schroeder, 1987).

Chart II: Curriculum

A Traditional Science Program	A Concept/Process-Based Science Program
• Tends to be based on topics, information to be covered, or written materials to be used. • Has fragmented notion of educational objectives, often a listing of skills and content. • Specifies knowledge specified as behaviors, performances, or uses. • Based on static 'body' of information which can be transmitted and learned; division into content and process skills.	• Abstracts and identifies important capabilities or systems of understanding making up an area of study. • Concepts and processes seen as two integrated aspects of any understanding. • Focuses on mental rather than observable activity. • Based on knowledge not static body but internal activities which depend on what and how learner initiates and organizes.

These research findings are the beginnings of a scientific basis for specification of the science curriculum.

- The trend is to see and define the concepts of the science curriculum as mental *activities* whose *development* forms different perspectives and misconceptions leading up to the most current valid scientific conceptions. The trend is away from seeing the science curriculum as a static content or a body of knowledge to be covered.

Implication for Science Education: The trend to understand knowledge as mental activity means to understand: (1) concepts as organized systems of thought and not as simple accumulations of learning, (2) knowledge as *mental* activity and not as behavioral activity or as specific performances, and (3) concept development as the formation of perspectives, wholes, or *systems,* and not merely as the accumulation of facts and isolated experiences. (See Chart II.)

Once these underlying systems of thought are better understood and their stability and shaping influence is studied (as Piaget and others have already done with many scientific concepts), they will become increasingly important as teachers use them to develop scientific competence in their students.

3. Learning Activities

Problem: Is learning a *reception of information* which the learner must then understand through activity such as practice or application? Or, is learning essentially *mental activity initiated and organized by the learner* which shapes what the learner sees and experiences? Can a learning experience be presented to the learner? Or, must it be constructed by the learner? The problem rests in whether the learner's activity is thought to be formative of knowledge and the source of understanding or whether the learner's activities are merely products or outputs used to receive, practice, store, and display something delivered by instruction.

The Trend: Science education research is moving toward identifying the essential importance of the learner's activity and involvement in putting together scientific knowledge (Bredderman, 1983; Shymansky, Kyle, and Alport, 1983). Intimately bound up with the increasing emphasis on constructive learning activities are active interpersonal exchanges among students in cooperative learning (Johnson & Johnson, 1986; Slavin, 1988). Essential to the notion of active learning is the principle that this student activity is directed to objects and not to abstract verbal concepts and processes. Student organized activity always provides the necessary and essential beginning point for students' mental constructions. Active learning does not mean the use of manipulatives to present information or to have learners practice presented information.

- The trend is toward seeing learning as an activity organized by the student and directed to the world (that is, an active assimilation of objects and phenomena), rather than as a passive, verbal reception from teacher or text, or as a passive recording of experience.

Implication for Science Education: The trend is to see learners as actively involved in construct-

Chart III: Learning Activities

A Traditional Science Program	A Concept/Process-Based Science Program
• Consists of application or practice of previously presented material.	• Uses and develops students' conceptual framework rather than "correct," completed understanding.
• Is preorganized by the teacher or text ('canned' labs, filling in tables or graphs, worksheets, etc.)	• Builds and reorganizes by examining previous learning and conceptual framework of students.
• Features premature 'closure', fragmentation, and topic hopping rather than building on previous learning.	• Shifts between learners' conceptual framework (logic) and testing it on real objects (experience).
• Directs learners' attention to completed knowledge to be learned rather than on objects, or activities are done for activities sake.	• Focus students' activities on objects to be understood rather than on already formed knowledge.
• Uses passive textbook-based survey type learning with interactions featuring short 'right answer' responses.	• Integrates experiential/lab activity with learners' organization of activity and data organization (table, graph, etc.).

ing their experiences rather than as passive receivers of information and experience who only act after the fact to make sense out of a received experience. The activity initiated and organized by the learner is therefore increasingly coming to be understood as the fundamental constructive factor in students' understanding of the world. Process and content are not two distinct things but simply the two aspects (logic and experience) which make up every instance of thought and knowledge. (See Chart III.)

4. Assessment of Student Growth

Problem: In understanding learner growth, should learning be considered as providing the development in the learner? Or, does learning depend on development which provides the capabilities to learn? In describing the growth of knowledge in students, is quantitative measurement of learned performances most important and objective? Or, is the growth of the learner more objectively described by qualitative measurements of specific mental abilities which themselves provide the conceptualizations necessary for learning and performance?

The Trend: The scientific study of learning is slowly discarding the old model of learning as an effect of a treatment (instruction) measured by achievement and performance tests. The trend is toward identifying the exact series of conceptual frameworks the learner goes through in constructing various scientific concepts (Driver & Easley, 1978; Gentner and Gentner, 1983; for examples see Mestre & Touger, 1989, and McDermott, 1984, for physics; Mintzes, 1984, for biology; Clement, 1983, for astronomy; Smith, 1989, for genetics).

Chart IV: Evaluation of Student Growth

A Traditional Science Program	A Concept/Process-Based Science Program
• Quantitatively measures sample of many learnings.	• Qualitatively measures level of understanding of major idea using developmental stages.
• Focuses on right/wrong answers.	• Focuses on explanations and reasoning.
• Sees growth as accumulation information from learning experiences.	• Sees growth as reorganization and extension of thought.
• Tests to determine retention, transfer, and application to problems of material previously taught.	• Uses assessment which triggers a display of current level of understanding.
• Separates evaluation from learning and places it after learning.	• Integrates evaluation with students' activities for constant self-regulation and redirection by learner.

Reporting learners' growth increasingly depends on tracing the development of these cognitive frameworks with the use of specific, qualitative stage scales which replace the quantitative measures of simple right/wrong performance (Ridgeway, 1988; Finley, 1986; Byron and Clement, 1980; Posner, 1982).

- The trend is toward measuring and explaining more fundamental aspects of learner growth by describing the qualitative development of underlying conceptual frameworks. The trend is to move away from quantitative measures and short term learning effects.

Implication for Science Education: Rather than a focus on observable performances as measures of learning, the trend is toward assessing the developments of the fundamental internal conceptual frameworks which produce the specific answers and performances of students. This trend of moving from assessing learning to assessing the development of understanding in learners means teachers will increasingly be asked to distinguish between short term learning effects and the long term development of understanding, and to shift from quantitative, single answer type tests to qualitative assessments of learning products such as portfolios and projects which provide displays of students' understanding.

5. Value of Science Education

Problem: Is science a unique field having its own intrinsic value? Or, does its role fundamentally grow out of human activity and human adaptation to reality? Is science a special domain with its own unique processes? Or, are there processes fundamental to human development which the scientist as well as young children employ? Do students study *about* the science which scientists do produce, or do students actually *do* science and derive its value implications?

The Trend: If science is a body of already completed knowledge which is studied by the student, then science exists in and of itself as a distinct subject having its own value. But scientific knowledge is increasingly seen to be fundamentally a constructive activity involving both the investigator's active mental construction and facts and experiences from external sources made possible by those constructions. Scientific knowledge is thus essentially an increasingly objective human activity.

STS (science, technology, and society) is the attempt to understand and make use of the fundamental utility of scientific investigation in human problem solving and adaptation (Bybee, 1986; Roy, 1985; Singleton, 1988).

- The trend is to see scientific understanding as the active and necessary solution of fundamental problems of human adaptation encountered in even the most mundane of projects, and not to view science as an end in itself whose esoteric intricacies are pursued only by advanced students.

Implication for Science Education: This trend is toward seeing problem solving and investigation as fundamentally a human processes. It suggests that science teachers will be increasingly asked to facilitate science understanding by basing students' science experiences on activities of practical scientific understanding and then extending them into human problems and implications (STS) rather than simply teaching science as a distinct body of knowledge produced by scientists.

Concept/process-based science attempts to recognize the trend to place the world in the hands of students and have them actively organize and study it rather than have it presented to them as a completed, static body of knowledge. The fundamental need and value of science grows out of directly confronting the real world in all its complexity, and the need to understand the world is raised by problems of human activity in the physical and living environment. (See Chart V.)

Chart V: Values in Science

A Traditional Science Program	A Concept/Process-Based ScienceProgram
Sees:	**Sees:**
• science as fun, isolated activities.	• scientific investigation as interesting.
• science important to taking next science course or getting high test scores.	• science as thoughtful investigation and understanding of the world.
• science a body of valued information about the world which can be applied.	• science as awareness and thoughtful reflection of human activity directed to changing the world.
• science distinct from 'practical', everyday activity.	• science as informing human activity and anticipating reasons for success or failure.
• science as isolated from the real, practical world.	

III. Definition of Oregon's Concept/ Process-Based Science

The movement toward a science of science education means educators must look deeply into their programs to determine what model of the learner their program is based on and whether that model is based on research or derived from personal opinion and preference. Concept/process-based science education is not a particular program but a general direction for continual program refinement and renewal. General trends from research lead to the five features defining Oregon's approach:

- Concept/process-based science education is the movement in science education toward **identifying and basing science education on those fundamental ideas necessary for students to objectively understand the world.** It is a movement away from topical or textbook-controlled coverage of information which lacks underlying, integrating goals of conceptual development.

- Concept/process-based science education is the movement toward instructional methods which are based on and follow **the constructive process of students' developing mental activity in putting together the fundamental ideas of science.** It is a movement away from teaching methods which are based on attempts to directly present or transmit completed concepts and understandings to students.

- Concept/process-based science education is the movement toward learning activities in which **students study real objects and phenomena so as to conceptualize them** by describing and classifying them, by seeing relationships in their changes, and finally, by providing explanations for causal changes. It is a movement away from having students study completed science concepts and knowledge through careful, teacher-organized canned labs, learning experiences, or demonstrations.

- Concept/process-based science education is the movement toward **objectively describing and evaluating the degree of development and quality of students' understanding** as they construct scientific knowledge through the learning activities. It is a movement away from simple quantitative measures of right and wrong answers, increased testing to control the focus of students' learning, or closed book tests disconnected from the learning products students produce.

- Concept/process-based science education is the movement toward placing science instruction in **an interdisciplinary context which promotes the intellectual development of students and their responsible engagement in practical, societal values.** It is a movement away from compartmentalizing science as an end in itself or isolating it from important ethical responsibilities of citizenship and stewardship.

The general directions for program development defined by concept/process-based science education provides help to teachers and their colleagues so they may identify specific changes in local programs. Concept/process-based science education works through local processes of curriculum and instructional review to identify and promote changes in curriculum goals, and instructional methods. Thus, concept/process-based science education is not to be seen as a program but as the result of changed thinking regarding the role and responsibilities of science educators in understanding and promoting student growth.

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September 1990

The original draft of this free-lancepaper was prepared by a science education researcher. Educators who served as reactors or editors of this paper include: Candy Armstrong (Region 11 OCATS staff development specialist), Pat Blosser (Science Education, Ohio State University), Wallace Cassel (Region 7 OCATS staff development specialist), Marvin Druger (Biology and Science Education, Syracuse University), Jerry Fenton (Region 4 OCATS staff development specialist), Dorothy Gabel (Science Education, Indiana University), Dale Rosene (Science teacher Marshall Middle School, Marshall, MI), Susan Smoyer (Project Manager, Science Curriculum and Assessment Project, Northwest Evaluation Association), Ardith Stensland (Region 1 OCATS, co-director), David Stronck (Science Education, California State University-Hayward).

Particular thanks are extended to Richard Meinhard, director, Institute for Developmental Sciences, for extensive assistance in organizing and editing additional comments from Oregon educators and the reviewers

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