COGNITIVE PROCESS INSTRUCTION: NEW APPROACHES TO LEARNING IN SCIENCE

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The purpose of cognitive process instruction is to apply the techniques and insights on high-order human cognitive processes to problems in education in order to develop instructional programs that teach students how to think. Advocates of cognitive process instruction approach learning from a constructivist perspective. They reject the behavioristic influence on education which they feel has resulted in undue emphasis on product and neglect of process. They consider cognitive process instruction an applied science anchored in observation, and borrow techniques from biology, specifically, ethology or naturalistic observation. These investigators and advocates do not come from the mainstream of educational research; rather, they tend to be scientists, especially physical scientists and mathematicians, and their work has been done primarily with college students.

Essentially, the cognitive process instruction investigators are concerned with developing "good habits of mind." That notion obviously brings to mind "faculty psychology." Cognitive process instruction is like faculty psychology in that it does deal with the idea that disciplined and logical analysis can be taught. It is different primarily in the level of specificity possible. Logical thought is no longer conveyed through Latin; instead, more specific cognitive skills may be isloated and taught. Further the conception of learning is different—in cognitive process instruction the structure is not presented, the teacher is not the giver of knowledge. Instead the teacher is a tutor/coach who helps students develop their own knowledge systems—in other words, the constructivist perspective (Lochhead, 1979a).

Those people who are developing cognitive process instruction are well grounded in the traditional quantitative sciences and realize the limitation of quantitative approaches. Their methods stress naturalistic observation and contextual validity in realistic educational situations. They acknowledge it as a "messy science" on which to base tentative hypotheses, not firm conclusions.

In his discussion of approaches to cognitive process instruction research, Lin (1979) points out that cognitive process instruction is primarily clinical with the purpose of illuminating processes underlying behavior in complex intellectual domains. Therefore, it is concerned almost entirely with complex problems characteristic of higher education; i.e., those involved in solving a physics or math problem, composing an essay, or even understanding a complex text. The major tools are introspection and protocal analysis through "thinking aloud" or interaction with an interviewer with a concern for looking at "why" and "how" a student does what he does. A major goal is to make expert skills explicit, including not just content, but also the nonfactual and nonpropositional knowledge—procedures, heuristics, organization strategies, and values (Lin, 1979).

Most cognitive process instruction educators and researchers work from a descriptive perspective with an emphasis on educational engineering. Lin identifies four basic descriptive model-building frameworks that characterize the work related to cognitive process instruction. They are: (1) a developmental framework, (2) a micro-analytic framework, (3) a diagnostic framework, (4) an instructional or prescriptive framework. Obviously, since the aim of cognitive process instruction is instructional, specific models do not necessarily fit purely into only one framework. Models build on developmental, micro-analytical, or diagnostic frameworks usually have instructional implications, if not complementary prescriptive models.

The Developmental Framework

A model based on the developmental framework provides a developmental scale along one or more intellectual dimensions onto which judges may map a student. One developmental model is Perry's work on the intellectual and moral development of college students (Perry, 1970). Perry traces the development of college students' views of knowledge along a continuum of dualism—relativism—commitment. Perry's model is interesting both in methodology and content.

First, Perry's work is an excellent example of the validation or verification process used by descriptive research. Secondly, Perry and his colleagues observed that the impetus that moved students along the continuum from dualism to relativisim to commitment was not so much the formal college experience; i.e., the coursework: it was rather the interaction, especially discussion, with their fellow students with diverse backgrounds and divergent viewpoints (Perry, 1970). This is consistent with Vygotsky's view of the facilitating effect of collaborative learning (Vygotsky, 1978).

Perry draws no specific instructional prescriptions from his model.

The second developmental model which has received extensive attention in the literature of science teaching is the work of Piaget on the growth of logical thought. Science educators believe that a large majority of the science concepts taught at the secondary and college levels require formal thinking. However, their research indicates that large numbers of adolescents do not appear to be at the formal level of intellectual development. One review of the literature (Chiappetta, 1976) estimates that number to be 85%. Research done specifically with college freshmen reports from 25% to 40% reasoning at the formal level (Killian, 1979).

Much of this work may be criticized on methodological issues, if not theoretical ones, but it is extensive and consistent enough to convince science educators to develop instructional models and techniques based on its conclusions and the assumption that operations of the formal stage can be taught, and/or that transition from the concrete to formal reasoning can be fostered.

DeCarcer, Gable, and Staver (1978) review a number of studies that seem to provide evidence that operations of the formal stage (i.e., controlling variables, proportional reasoning, etc.) can be taught if students have the necessary maturation level. There is not much evidence, however, for maintenance, generalization, or transfer of training.

Two common factors that appear in successful training studies attempting to promote transition from concrete to formal thought are physical manipulation and peer interaction (Ward & Herron, 1980). One teaching approach utilizing these factors is Karplus' Learning Cycles Model. It is a three stage model: Exploration, Concept Introduction, Concept Application. Students work together as they advance through the stages, manipulating the material and devising a system for organizing it (Karplus, 1974). Treatment studies using the Learning Cycles Model have shown positive results when the treatment is extended to at least a semester (Ward & Herron, 1980).

It isn't surprising that science educators have been so enthusiastic about Piagetian theory and its applications since most of the task Piaget used were logio-scientific. There is some question, though, as to the reasonableness and practicality of such a direct application of Piagetian theory to education. Briggs (1980) cites research that shows that the responses of college students on a variety of tasks in physics and other disciplines may jump from concrete to formal or drop from formal to concrete, in a simple test-retest situation. Further, changing the way a question was asked, increasing response time, providing strong motivation, or providing specific instruction in content can dramatically affect the level of responses.

Biggs argues that the Piagetian stages refer to *personalogical* characteristics while educators are concerned with *response* characteristics. He suggests that we must distinguish between the developmental base level from which a student is operating and the structure of the outcome of his learning a particular content task. In his opinion, educators can do virtually nothing about the first. They can influence some determinates of the latter (Biggs, 1980).

In fairness to cognitive process instruction investigators, they are obviously more concerned with learning outcomes that with the hypothetical cognitive structure, although some of them tend to cite the data about Piagetian levels as a way of demonstrating the need to instruct differently.

The Micro-Analytic Framework

Those who work with the micro-analytic frameworks are good examples of the focus on learning outcomes. The micro-analytic framework provides a way of modeling cognitive structure. Micro-analytic models specify the manner in which knowledge is organized, the causal mechanisms responsible for processing that knowledge, and the mechanism by which the structure evolves in time. In this group, we can include Larkin's qualitative models of an expert and a novice solving standard physics textbook problems (Larkin, 1976). Another example is Clement's analysis (1979) of a beginning student's conception of momentum and force.

Clement's purpose was to evaluate the student's knowledge structure and reasoning processes relevant to causal conception in mechanics in order to take common preconceptions and misconceptions into account during instruction. Clement recorded the student's thinking aloud as he worked on the problem, and then this protocol was analyzed to produce a map of the conceptions that underlie the student's responses. The student did not come up with the "correct" answer, but Clements was able to analyze the student's level of concept development, his ability to identify and manipulate variables, his use of analogies and quantitative functions, and other reasoning processes. From the protocol analysis of this student and other beginnign physics students, Clements began to derive a list of common preconceptions that could prove a valuable aid to teachers (Clements, 1979).

Lochhead (1979b) uses a microanalytic approach in a paper which consists primarily of the dialogue between two beginning physics students as they solve the problem of determining a mathematical equation that describes the equilibrium state of a balance beam. The striking characteristic of the dialogue is repetition—as the students repeat and rephrase each other's statements and as they oscillate between understanding and confusion. Lochhead explains these oscillations as being "associated with the learner's need to construct multiple representations of new knowlege and test these representation against each other" (Lochhead, 1979b, p. 149). As the students view the problem with increasing sophistication, their descriptions become more precise. The students themselves detect and correct inappropriate uses of terminology spontaneously once they discover the need. Lochhead observes that: "the correct use of terminology is a natural consequence of understanding, but understanding does not result from skill in the correct use of terminology" (Lochhead, 1979b, p. 177). In summary, Lochhead sees meaningful learning as a slow and repetitive process which can be hindered with too much intrusion by the teacher. Instead teachers need to be able to distinguish superficial knowledge from well-developed conceptions and design tasks that force students to recognize where their knowledge is incomplete (Lochhead, 1979b).

The Diagnostic Framework

Both developmental and most micro-analytic models deal with behavior over time. They are, in essence, *movies* of the subject. Models in the diagnostic framework might better be compared to snapshots of a subject's behavior. They provide descriptors which are used to diagnose behavior of a particular subject in a given situation. Perhaps, for this reason, they seem to be used less frequently by cognitive process instruction researchers. The classic examples that are drawn upon by the field are Bloom and Broder's (1950) study of the problem-solving behavior of college students and Polya's (1973) work on mathematical heuristics.

Finally, let's look at what cognitive process instruction proponents have written about instruction and at several instructional models that have been evolved.

The Instructional Framework

di Sessa (1979) calls for a program of research and development for education material, especially in physics and mathematics, which will both "do justice to the powerful logical structure of the subject, but at the same time mesh properly with the cognitive reality of human beings" (di Sessa, 1979, p. 239). She uses the computational metaphor to emphasize the difference between *material* knowledge (directed externally on physical events or abstract relationships) and *control* knowledge (directed internally toward personal functioning and thinking itself). She points out that the way an expert uses a concept; i.e., the control structure, is as much a part of his understanding as the formal structure of the idea, in much the same way that the control structure of a computer program makes a significant difference in its functioning. Further, process itself can be an effective knowledge carrier.

di Sessa warns against the overuse of the logical formalist metaphor in education—that is, the overuse of axiomatics and the assumption that science is deductive. She calls for a curriculum that takes into account intuition, control knowledge, and experiential support. Thus she recommends that pedagogical material— (1) provide a discovery-rich environment; (2) discuss and develop "higher-level" organization skills; i.e., control knowledge; and (3) be active and constructive rather than perscriptive or descriptive with process as its large scale unifying form (di Sessa, 1979).

D'Amour (1979), on the other hand, takes to task the inductive view of the scientific method as a model for science teaching because it reduces the student to the passive role of merely observing and making the "correct" inferences, and because it assumes that observations can be made independent of theory. Citing Karl Popper's critical fallibilist view, he concludes that the best approach for the scientist and the science student is by initiating a hypothesis and seeking evidence of its untruth. In such a situation what the student comes to accept as scientific knowledge rests on his own effort to disprove it. Science teaching methods must involve the student in actively reflecting on his own thought process while seeking to learn, and hypothesis generation and critical testing. D'Amour says that traditional lab activities are as educationally faulty as the lecture method because the emphasis is on adhering to an ideal model and finding the right answer.

D'Amour recommends the Guided Design methodology developed by Wales and Stager (1978). In the Guided Design, students are presented with an ascending order of well-designed, open-ended problems which they work through in small groups. Critical features of Guided Design are the instructional/feedback pages with leading questions, the group discussion, and the role of the instructor as model/consultant. Solutions to the problems require familiarity with a subject matter unit which is read independently outside of class as part of the background information. "Expert" answers to each question are provided as additional informed opinion, not as the "right answer." This approach helps students shift from seeing knowledge as acquisition of facts to an understanding that useful knowledge is the result of certain thoughtful modes of activity.

Finally, Whimbey and Lochhead (1980) have devised a program for teaching analytic reasoning that has been demonstrated to have positive effects on the math, science, and reading comprehension scores of disadvantaged college students (Whimbey, 1979; Whimbey, et al, 1980). It is an adaptation of Bloom and Broder's method which explicitly presents and teaches the characteristics of good problem solvers. A key to its effectiveness appears to be the method of "loud thinking"—students are forced to verbalize their thoughts, and bad habits, like jumping to conclusions, or misinterpretations or omission of important steps or information become vividly apparent. Students work in pairs, thinking aloud and monitoring one another's processes, as they solve progressively more difficult problems.

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