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AUTHOR Wilson, Brent; Cole, Peggy
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ABSTRACT

This paper offers a critique of elaboration theory (ET) based on recent cognitive research and offers suggestions for updating the model to reflect new knowledge. It begins by summarizing the basic strategies of this model for sequencing and organizing courses of instruction: (1) organizing structure; (2) simple-to-complex sequence; (3) sequencing guidelines; (4) summarizers; (5) synthesizers; (6) analogies; (7) cognitive strategy activators; and (8) learner control. It then discusses the notion of content structure and its epistemological assumptions, including the basic idea of content structure, how content is structured, content structure as organizing structure, and ill-structured domains. Discussions of sequencing issues address microworld design, functional context training, cognitive apprenticeships, cascaded problem sets, middle-out sequencing, sequencing for conceptual change, and internal reflection-in-action processes. Making content structure explicit is also discussed. The paper concludes with four recommendations: (1) deproceduralize the theory; (2) remove unnecessary design constraints; (3) base organization and sequencing decisions on learners' understandings as well as the logic of the subject matter; and (4) assume a more constructivist stance toward content structure and sequencing strategy. (89 references) (BBM)

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Authors:

Brent Wilson
Peggy Cole

A Critical Review of Elaboration Theory

Brent Wilson & Peggy Cole
University of Colorado at Denver

Elaboration theory (ET) is a model for sequencing and organizing courses of instruction. Developed by Charles Reigeluth and associates in the late 1970s (Reigeluth, Merrill, & Wilson, 1978; Reigeluth, Merrill, Wilson, & Spiller, 1979), ET drew heavily upon the cognitive research on instruction available at the time, in particular the work of Bruner, Ausubel, and Norman (Merrill, Wilson, & Kelety, 1981). Since then, Reigeluth has refined the theory by offering detailed procedures for the planning and design of conceptual (Reigeluth & Darwazeh, 1982), procedural (Reigeluth & Rodgers, 1980), and theoretical instruction (see Reigeluth and Stein, 1983 for an overview and Reigeluth, 1987 for a detailed example). ET has been one of the best-received theoretical innovations in instructional design (ID) in the last 15 years, and is heavily referred to and used by practitioners and researchers. At the same time, research in cognitive psychology has continued to shed light on relevant processes of learning and instruction. Just as models of learning change over time, ID models also undergo regular changes (Merrill, Kowallis, & Wilson, 1981; Rickards, 1978). The purpose of this paper is to offer a critique of ET based on recent cognitive research, and to offer suggestions for updating the model to reflect new knowledge. We believe ID models should undergo such revisions every few years to stay current with the growing knowledge base in learning, instruction, and other areas of research.

Elaboration Theory Basics

ET's basic strategies are briefly summarized below.

1. *Organizing structure.* Determine a single organizing structure for the course which reflects the course's primary focus. This organizing structure may be one of three types: conceptual, procedural, or theoretical. Reigeluth (1987) explains that "In all the work that has been done on sequencing, elaborations based on concepts, principles, and procedures are the only three we have found, although additional ones may be identified in the future" (p. 249). Reigeluth justifies the use of a single organizing structure by suggesting that "careful analysis has shown that virtually every course holds one of these three to be more important than the other two" (Reigeluth, 1987, p. 248). The other two types of content, plus rote facts, "are only introduced when they are highly relevant to the particular organizing content ideas that are being presented at each point in the course" (Reigeluth & Stein, 1983, p. 344).
2. *Simple-to-complex sequence.* Design the course proceeding through the identified structure in a simple to complex fashion, with supporting content added within lessons. Begin with a lesson containing "a few of the most fundamental and representative ideas [taught] at a concrete, application (or skill) level..." (Reigeluth, 1987, p. 248). This first lesson is termed the "epitome"; successive lessons add successive layers of complexity in accordance with the categories of the organizing structure.
3. *Sequencing guidelines.*
   —For conceptually organized instruction "present the easiest, most familiar organizing concepts first" (p. 251).
   —For procedures, "present the steps in order of their performance" (p. 251).

—For theoretically organized instruction, move from simple to complex.
- Place supporting content immediately after related organizing content.
- Adhere to learning prerequisite relationships in the content.[1]
- Present coordinate concepts simultaneously rather than serially.
- Teach the underlying principle before its associated procedure.

4. *Summarizers* are content reviews (presented in rule-example-practice format), at both lesson and unit levels.
5. *Synthesizers* are presentation devices—often in diagram form—designed to help the learner integrate content elements into a meaningful whole and assimilate them into prior knowledge. They help make content structure *explicit* to the student; examples include a concept hierarchy, a procedural flowchart or decision table, or a cause-effect model with nodes and arrows.
6. *Analogies* relate the content to learners' prior knowledge. Effective analogies will tend to bear strong resemblance to the content; weak analogies will contain more differences than similarities with the target content. Reigeluth and Stein (1983) suggest the use of multiple analogies, especially with a highly divergent group of learners.
7. *Cognitive strategy activators*. A variety of cues—pictures, diagrams, mnemonics, etc.—can trigger cognitive strategies needed for appropriate processing of material. Reigeluth and Stein (1983) note that these cues for strategy use may be *embedded*, such as pictures, diagrams, or mnemonics—indirectly "forcing" appropriate processing—or *detached*, such as directions to "create a mental 'image' of the process you just learned" (p. 362). Continued use of these activators can eventually lead students to understand when and where to apply various cognitive strategies spontaneously upon learning materials.
8. *Learner control*. Reigeluth and Stein (1983) believe that "instruction generally increases in effectiveness, efficiency, and appeal to the extent that it permits informed learner control by motivated learners (with a few minor exceptions)" (p. 362). Learners are encouraged to exercise control over both content and instructional strategy. Clear labeling and separation of strategy components facilitates effective learner control of those components. Regarding content, Reigeluth and Stein (1983) claim that "only a simple-to-complex sequence can allow the learner to make an informed decision about the selection of content" (p. 363), presumably because content choices will be meaningful at any given point.

KNOWLEDGE REPRESENTATION

Before turning to sequencing concerns, we discuss the notion of content structure and its epistemological assumptions.

WHAT IS CONTENT STRUCTURE?

The basic idea of content structure—the way content elements are interrelated—is a long-accepted notion in educational psychology (e.g., Bruner, 1966). However, the nature of content structure is ambiguous. Is content structure something different from people's cognitive structures? Is there an external body of knowledge with its own logic and form (Ford & Pugno, 1964; *Education and the structure of knowledge*, 1964), or can we only meaningfully speak of the structure of

[1]Wilson and Merrill (1980) argue that both learning hierarchy analysis and ET analysis result in simple-to-complex sequencing. If this is true, then searching for prerequisite relationships in ET-sequenced skills is a largely redundant exercise.

individual understandings? If the distinction between external and internal structures is sound, what is the relationship between the two? These questions are substantive because instructional-design theory has been challenged in the past because of its behavioristic focus on external tasks and lack of attention to mental structures and the cognitive mediation of learning.

Certainly, a variety of task analyses may be performed that emphasize different aspects of the task, many of which do not attempt to model cognitive structure (Jonassen, Hannum, & Tessmer, 1989). The same may be said of content structures. Content may be categorized, analyzed, and represented in different ways for different purposes, and need not relate directly to internal cognitive representations. While different positions may be taken, however, we believe that content/task analysis, as a basic ID procedure, is most useful when it *models* in external form the structure and process of people's knowledge and skills. Such a model of internal forms is important as a basis for planning sound instruction.[2] Typically, the most useful kind of "content structure" is a model of the way knowledge is thought to be structured in people's minds. Admittedly, an external model may be a poor approximation of people's knowledge, but it serves a useful purpose for planning and designing instruction.

HOW IS CONTENT STRUCTURED?

If we accept the notion of content structure as modeled cognitive structure, the next question becomes, what kinds of knowledge are there, and how are they structured; that is, how are content elements interrelated? Another way of asking the question is, how is human knowledge organized? As we might imagine, there are as many answers to this question as there are models of human thought and memory, ranging from simple chains of learned behaviors to complex networks to a refusal to explicitly model human knowledge on the grounds that it is *inherently* tacit and ineffable.

Anderson (1990) posits two basic kinds of knowledge: declarative and procedural knowledge. This distinction is also made by philosophers (Ryle, 1949) and is influential among educational psychologists (E. Gagne, 1985). The distinction is also popular with instructional designers (e.g., Gagne, Briggs, & Wager, 1988). Practicing teachers and designers make common reference to "knowledge" (declarative knowledge) and "skills" (procedural knowledge). Thus students may learn about computers, or they may learn how to operate them. The two forms of knowledge support each other. Some theorists add image encoding as a separate knowledge type (e.g., Kosslyn, 1980; Gagne, Yekovich, & Yekovich, in press), but instructional designers have not emphasized imagic knowledge as an independent learning outcome.

Several theorists add an integrative structure of some sort to accommodate these knowledge elements into a whole pattern, referred to variously as schema, script, frame, or mental model (Norman, Gentner, & Stevens, 1976; Johnson-Laird, 1982). Rumelhart and Norman (1981) propose that all knowledge is procedurally represented, "but that the system can sometimes interrogate this *knowledge how* to produce *knowledge that*," that is, declarative knowledge (p. 343). Simon (1980) holds a similar view. Tulving's (1985) research suggests at least three types of

[2]We are not naive to the controversy surrounding attempts to explicitly model human cognitive structure (e.g., Dreyfus & Dreyfus, 1986; Churchland, 1984). It seems clear that present methodologies are only partially successful at capturing human expertise. We are also sensitive to connectionist models of cognition that emphasize pattern matching over rule-following (Bereiter, 1991; Bechtel, 1991; Martindale, 1991). Nonetheless, modeling of content structure, whatever its limitations, remains a valuable component of the instructional design process.

memory: (1) procedural memory, with a specialized subset of (2) semantic memory, with a specialized subset of (3) episodic memory.

A number of psychologists have added the situation or context of use as part of what gets learned (Brown, Collins, & Duguid, 1989). Rather than thinking of expertise as the acquisition of a general schema, they claim that learning and expertise are always embedded in a particular physical, social, and cultural context. Learning is a matter of enculturation, that is, of becoming part of a community which jointly constructs meaning. Seen in this way, the context of use becomes part of the "content structure" in need of analysis and representation for the design of instruction.

As mentioned, there is even some resistance to the notion that human expertise can be defined by discrete concepts and rules. Dreyfus and Dreyfus (1986) argue that real knowledge cannot be separated from the person, and that reductionist attempts to model knowledge explicitly are doomed to failure. In a less radical but equally compelling position, Bereiter (1991) challenges the idea common in cognitive science that human thinking is rule-based; instead, he presents an argument for viewing thinking in connectionist terms as a pattern-matching, pattern-using activity.

> At least since Rousseau, there has been a strain of educational thought opposed to the classical, rule-based view of learning and cognition. It has often appealed to biological concepts of growth, emergence, and organicism or to social and cultural concepts and has emphasized imagination, spontaneity, feeling, and the wholistic character or understanding....This strain of thought has given rise to many worthwhile developments in education, such as the...currently popular whole language movement. (Bereiter, 1991, p. 15)

The connectionist model thus rejects the partitioning of knowledge into discrete structures (e.g., declarative and procedural), integrating cognitive, affective, and psychomotor aspects of performance. Bereiter contrasts this wholistic view of learning with a more rule-based approach:

> In contrast to the Rousseauistic tradition is a family of instructional theories in which rules, definitions, logical operations, explicit procedures, and the like are treated as central (Reigeluth, 1983). From a connectionist standpoint, this family of instructional theories has produced an abundance of technology on an illusory psychological foundation. (Bereiter, 1991, p. 15)

Connectionist theorists would clearly object to ET's discretely dividing knowledge into concepts, procedures, and theories. Bereiter concludes the article by suggesting that the "situated" and "embodied" cognitive approaches could provide a comprehensive alternative that would accommodate elements of both rule-based and connectionist perspectives appropriately. ET currently does not provide detailed prescriptions for making instructional sequences "authentic" or "situated" in a context similar to real-life problems.

The claim that not all people solve problems by following rules finds support in research by Papert (1988) and Gillian (1982). Papert explains the two ways bright 10- and 11-year-olds program computers. One way

> fits the model of "the logical." Faced with a problem, [the children] subdivide it, modularize it, deal with the parts one at a time, put them together and make a program that is clearly logically structured.
>
> But other children demonstrate a different style—one in which a program emerges...through something closer to the way in which a sculptor or painter makes a work of art—a process in which the plan of what is to be made emerges and is refined at the same time as the created object takes form. (p. 12)

Papert says the children who use the "negotiational style are performing at an intellectual level that is fully as excellent and of high quality as the other children" (p. 12).

CONTENT STRUCTURE AS ORGANIZING STRUCTURE

Recall that ET suggests using content structure as an organizing and sequencing device, with three main prescriptions offered. First, courses and lessons should be organized into components according to the content structure being taught. This prescription is fairly broad and benign. The second prescription is stronger: A course's organization should depend on the primary goals of instruction: conceptual, procedural, or theoretical. If you want learners to have a conceptual overview of a new subject, subdivide and organize the course's lessons according to a taxonomy. If your goals are procedural, begin with the simplest version of the procedure and progressively add more steps and decision points; and if your goals are theoretical, begin with the most important principles and add qualifying or extending principles in later lessons. The third prescription is also strong: Course units should all reflect the primary organizing structure. That is, a course with a conceptual structure as its primary organizing structure should be chunked into lessons of concepts within the original conceptual structure. A procedural course should be chunked into increasingly complex versions of the overall procedure. The rationale for the latter two prescriptions seems to be that if the organizing structure entirely reflects the primary course goals it will enhance meaningful encoding, retention and retrieval.

The first prescription—that course organization should basically reflect content structure—is consistent with text design studies of access structure. As a rule, students are aided when text structure somehow reflects underlying semantic structure (see, however, Mannes & Kintsch, 1987, discussed below). The second and third prescriptions, though, are much stronger versions of the idea. Again, such constraints on designer judgment provide ostensive gains in economy but questionable payoff. The rationale for a single organizing structure seems to be based on assumptions that the development of stable cognitive structures, a goal of ET (Reigeluth, 1983), is best achieved by presenting content in the framework of a single, top-down organizing structure. As we will illustrate below, there are many challenges to this assumption.

There seems to be little evidence to draw on in psychology literature to support such a constrained approach to course organization. Posner and Strike (1976; Strike & Posner, 1976) reviewed a variety of methods for organizing courses. In essence, they suggest that a course structure should have a certain "face validity" to the student; that is, it should have a logical and meaningful connection to students' prior understanding. The implication of their review is that courses need some kind of organizing device or logic; the precise kind of organization is much less important than that it make sense to the learner.

Posner and Rudnitsky (1986) present a somewhat eclectic approach to course design. Rather than three basic kinds of course structure, they suggest a variety of orientations: inquiry, application, problem, decision, skill, or personal growth. Laurel (1991) presents a strong case for organizing computer interactions based on a theatre metaphor, involving the learner in a stage-like structure. This longer, looser list seems to leave more room for accommodating different kinds of course and learning goals, as well as prior knowledge; moreover, following Posner and Rudnitsky, a course's orientation does not constrain its sequencing strategy.

We would argue for a revision of ET that relaxes the connection between course goals and overall content structure. First, course goals can be typed on a broader basis than the three goals listed by ET. Second, a variety of chunking strategies may be useful for subdividing lesson elements above and beyond a single type of content structure. Designers need to guard against rigid conceptions of the domain and encourage a more dynamic structure for students to access and learn at various points of instruction.

ILL-STRUCTURED DOMAINS

Another perspective on the structure of knowledge raises additional concerns about ET. Spiro and colleagues (Spiro, Feltovich, Coulson, & Anderson, 1989; Spiro & Jehng, 1990) became frustrated in their attempts to apply ID principles in teaching complex and ill-defined domains. This, according to Spiro, can partly be attributed to the fact that most ID principles are based on research using introductory subject matter. As expertise increases, however, the "content" becomes less easily defined, more conditional and problematic, and much more difficult to capture using traditional representational models. As a consequence Spiro and colleagues have proposed a dynamic view of knowledge, which they call *cognitive flexibility theory*. According to this theory, in complex and ill-defined domains, a person generally cannot retrieve an intact schema from memory; instead, schemas combine or recombine in response to the requirements of each particular situation. Spiro and colleagues have developed an instructional approach to facilitate knowledge acquisition in complex and ill-defined domains, criss-crossing the domain with mini-cases to provide multiple perspectives which can later be reassembled. They recommend the use of multiple analogies and cases to prevent the development of oversimplifications and misconceptions common among students (Spiro, Feltovich, Coulson, & Anderson, 1989).

A key feature of cognitive flexibility theory is its view of the subject matter. At least for advanced knowledge levels, content structure cannot simply be captured, analyzed, and used to organize courses. Advanced knowledge is variable, dynamic, and ill-defined; students in turn need a variety of perspectives and experiences to appreciate its complexity and subtlety. Students will tend to oversimplify and overgeneralize when presented single analogies or discrete procedures and rules. Moreover, students' misconceptions are fairly robust and resistant to change (Spiro et al., 1989, 1990). This dynamic view of the subject matter seems at odds with ET, which assumes that the designer will organize instruction based on a well-defined content structure.

ET's strong typing of knowledge categories—conceptual, procedural, and theoretical—is one of its most theory-laden prescriptions. Constraints on knowledge representation might be justified if there were some kind of consensual agreement among researchers, yet precisely the opposite is the case. According to one survey of educational literature in language and cognition, twenty-five distinct categories of knowledge were identified (Alexander, Schallert, & Hare, 1991). Philosophers and humanistic theorists have even more widely diverging views about the nature of knowledge and expertise (e.g., Schon, 1987; Dreyfus & Dreyfus, 1986; Winograd & Flores, 1986). This is a far cry from ET's three basic knowledge types! Indeed, the overwhelming finding concerning knowledge representation seems to be that *there is no single right way to represent knowledge*, even for a given context or instructional purpose. Even if a course were thought to be primarily "conceptual" in purpose, a number of diverse outcomes are associated with "conceptual" learning (Tessmer, Wilson, & Driscoll, 1990; Wilson & Tessmer, 1990). ET's use of conceptual, procedural, and theoretical structures achieves parsimony in its procedures, but at a high cost to validity and fidelity to current models of learning and knowledge.

SEQUENCING ISSUES

ET suggests that instruction proceed from highly simplified representations to gradually more complex content. While this prescription is perhaps amenable in well-structured domains, where expertise is clearly defined, it is problematic in ill-structured domains. For example, if the primary content structure is procedural, ET would identify the various paths through a given procedural network, then begin with the simplest version of the procedure; subsequent elaborations would merely add complexity to the basic procedure. But ET does not provide for the possibility, or even desirability, of two learners learning mutually exclusive procedures. Recall that Papert (1988) found that student programmers engage in mutually exclusive styles (logical vs. negotiational). Also, Resnick (1983) has shown that math students construct more sophisticated procedures than those taught in class. Thus an ID that depends entirely on a single representation of structure could possibly limit students' personal constructions of meaning from the content.

A number of theorists support the basic sequencing precepts of ET. Bunderson, Gibbons, Olsen, and Kearsley (1981) suggested that instruction be geared around a series of work models, each progressing in complexity. Learners then "work" and solve problems within a current level of work model until a mastery level of performance is reached; they are graduated to the next level, which builds upon the prior level. This is similar in some ways to White and Frederiksen's (1986) approach that builds instruction around a series of increasingly complex qualitative mental models. However, their approach begins with students' intuitive mental models, forcing students to confront their misconceptions and develop increasingly more sophisticated and correct mental models. White and Frederiksen have applied their simple-to-complex sequencing strategy to the design of intelligent tutoring systems, as well as more traditional computer-based simulations.

MICROWORLD DESIGN

Burton, Brown, and Fischer (1984), anticipating "situated cognition" (see discussion above) used skiing as a basis for studying the design of learning environments which they called "increasingly complex microworlds." Helping novice performers "debug" their skills is a key goal of microworlds: "The appropriate microworld can transform 'nonconstructive bugs' into 'constructive bugs,' ones that can be readily learned from" (Burton, Brown, & Fischer, 1984, p. 140).

Burton and colleagues point to three primary design variables of skill-based microworlds:

1. equipment and tools used in performing the skill;
2. the physical setting in which the skill is performed;
3. the specifications for correctly performing the task.

The authors' notion of microworld design shares one key design feature with ET, that of performing the simplified whole task whenever possible:

> Within each microworld that a beginning skier goes through, a particular aspect of the skill is focused on. But this skill is not executed in isolation. The student must still do simplified versions of many other skills required to ski. Simplifications of other interacting subskills let the student learn not only the particular subskill but also how it is used in the context of the entire skill. (p. 150).

However, they differ from ET in their emphasis on the means of simplification. Burton and colleagues encourage simplifications of all three design variables, but within real-world contexts. They simplify equipment by recommending the use of short skis rather than long ones. They recommend simplifying the physical setting by finding a downhill slope that feeds into an uphill slope so the learner can learn to glide without having to learn at the same time to stop. They also simplify the task itself by asking the novice to practice gliding rather than traversing. Thus a variety of means of task simplification are available that go beyond what we normally think of as content structure (see also Wilson, 1985).

FUNCTIONAL CONTEXT TRAINING

Montague (1988) provides evidence for the effectiveness of "functional context training," a spiraling method which begins with familiar objects about which learners have intuitive knowledge and moves to progressively more complicated but still familiar objects. For example, an introductory course for electronic technicians uses concrete and familiar objects for instruction, starting with a flashlight and proceeding to a table lamp, a curling iron, an AC adaptor, and a soldering iron. Instruction is situated in realistic settings; it integrates several domains of knowledge at once: problem solving, basic electricity/electronics knowledge, mental models of devices, language processing, and mathematics. The sequencing emphasis for the functional context approach is to move from simple-familiar toward more complex-familiar. This is similar to ET. The approach differs from ET in its emphasis on fidelity to job conditions and in-context training. Also, rather than elaborating upon a single epitome, they use a series of concrete cases or analogies, each drawing attention to different aspects of the subject area.

COGNITIVE APPRENTICESHIPS

Collins, Brown, and Newman (1989) have described their idea of the "cognitive apprenticeship." Like Montague (1988), they provide numerous recommendations for integrating instruction with realistic performance. Their specific recommendations for sequencing content, however, are similar to those of ET in many ways: (1) increasing complexity, (2) increasing diversity, and (3) global before local skills. The third recommendation requires a short explanation. Collins et al. suggest scaffolding as a way to support lower-level skills while the student thinks about larger problems. "In algebra, for example, students may be relieved of having to carry out low-level computations in which they lack skill to concentrate on the higher-order reasoning and strategies required to solve an interesting problem....The chief effect of this sequencing principle," they explain, "is to allow students to build a conceptual map, so to speak, before attending to the details of the terrain" (p. 485). This idea of supporting performance and helping students develop clear mental models is implicit in ET and certainly consistent with its principles (*cf.* Wilson, 1985, 1985–86).

Collins cites Schoenfeld's (1985) math research as a cognitive apprenticeship. He has developed an approach for teaching college-level math that employs a number of innovative instructional strategies. The method focuses on guiding students to use their current knowledge to approach and solve novel problems. The instructor models problem-solving heuristics, including the inevitable false starts and dead ends; the process of math problem solving is shown to require creativity and flexibility. It is noteworthy that Schoenfeld sequences lesson plans around carefully selected cases that build on each other in a simple-to-complex fashion. These cases are selected to bring out certain features to be learned; class discussions and problem-solving activities are flexible within the overall structure of the ordered cases.

CASCADED PROBLEM SETS

Schank and Jona (1991) present a sequencing approach they call *cascaded problem sets*, one of several possible teaching architectures they recommend, including case-based learning, incidental learning, simulation, and directed exploration. Cascaded problem sets rely on many assumptions similar to those of ET; however, instead of beginning with the simplest case, Schank *begins at the end and then works backward*. In essence, Schank is saying, "We don't presume to know just what a beginning student already knows; we prefer to give an overall picture of the final task by starting at the end, then work backwards to find a realistic starting place depending on the student's initial competency level."

> The idea is to build a problem space whereby each problem relates to each other problem with respect to the extra layer of complexity that it entails. In other words, "if you can't solve Problem A, you certainly can't solve Problem B" means that B is logically above A. Between A and B would be some information that B entails that A does not. Below A would be something simpler than A that perhaps does not entail the knowledge common to A and B. As students have trouble with one problem, they move *down* the cascade of problems by learning about the issues that one would need to know to solve the problem they were having trouble with. (Schank & Jona, 1991, pp. 20–21, italics added.)

Another difference with ET is that Schank considers task components as part of the cascaded problem set. "A problem must be broken down into its constituent parts. Each constituent would itself be a problem, and it too would have constituent parts....For example, at the bottom of a cascade of algebra problems would be basic arithmetic" (Schank & Jona, 1991, p. 20). This parts analysis seems more reminiscent of Gagne's learning hierarchies than ET's meaningful spiraling. In either case, the idea of cascaded problem sets is clearly derivative of well-established ID principles, including work on computer-adaptive testing, even though the authors do not cite previous work on the problem.

MIDDLE-OUT SEQUENCING

ET's conceptual structures are sequenced from the top down, that is, from the most general conceptual category down to the most detailed sub-category in a taxonomy. We have criticized this approach elsewhere (Wilson & Cole, in press a) for its failure to accommodate learners' prior knowledge. Our basic point is, why teach the concept 'vertebrate' before 'cow' to a small child, just because it happens to be higher in a conceptual hierarchy? Lakoff (1987) makes a similar point; he reviews a large body of literature suggesting that in normal settings, people tend to classify and think about objects at a "middle level," not too general and not too detailed. Rosch (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) gives the term 'basic categories' to this level of natural perception. For example, people tend to think in terms of dogs (basic level) rather than animals (superordinate level) or retrievers (subordinate level). Similarly, 'chair' is more psychologically basic than 'furniture' or 'rocker.' Rosch suggests that most of our knowledge about the world is organized at this level; most attributes pertaining to category membership are stored at this middle level. She also suggests that this basic level of category is:

- The highest level at which category members have similarly perceived overall shapes.
- The highest level at which a single mental image can reflect the entire category.
- The highest level at which a person uses similar motor actions for interacting with category members.
- The level at which subjects are fastest at identifying category members.
- The level with the most commonly used labels for category members.

- The first level named and understood by children. (Lakoff, 1987, p. 46)

If people organize their knowledge primarily around these basic-level categories, then it seems unreasonable to insist on proceeding in a strict general-to-detailed order down a taxonomy. A more defensible strategy would start from learners' prior schemas, then proceed both up and down the taxonomy into new territory, as increasingly difficult but authentic tasks require. Tessmer (1991) terms this a "middle-out" sequencing strategy, where instruction begins at a middle level of generality, gradually adding both superordinate and subordinate detail. This alternative sequencing strategy represents a significant revision of ET's design prescriptions.

SEQUENCING FOR CONCEPTUAL CHANGE

A line of cognitive research investigates instructional interventions that try to link up with learners' preconceptions and schemas about the world (e.g., Siegler, 1991); this body of research is sometimes referred to as conceptual change literature. Some researchers (e.g., Case & Bereiter, 1984; Resnick, 1983; White & Frederiksen, 1986) have directly challenged models that order instruction based on subject matter logic and neglect learners' existing conceptions. Preexisting conceptions may be a help or a hindrance to new learning; misconceptions and "buggy" procedures can often interfere with the assimilation of new skills and knowledge. Case (1978) developed an instructional model in which the teacher directly confronts learners' misconceptions; after learners see clearly the inadequacy of their existing conceptions, they become ready to acquire new models, and will tend to integrate the new knowledge more directly into their current structures. The general strategy for conceptual change is :

1. Learners must become dissatisfied with their existing conceptions.
2. Learners must achieve at least a minimal understanding of an alternate way of conceptualizing the issue.
3. The alternative view must appear plausible.
4. Learners must see how the new conceptualization is useful for understanding a variety of situations. (based on Bransford & Vye, 1989)

Whereas an ET-style lesson might proceed smoothly through a content structure, conceptual-change lessons proceed in fits and starts, working from student misconceptions, failing, trying again, beginning false starts, retreating from dead ends, each time elaborating upon students' schematic understandings (*cf.* also Schoenfeld, 1985). The "elaboration" is not on an external content structure, but rather on an internal representation.

Thus the conceptual change literature emphasizes the dynamic nature of learning. Two observations are particularly relevant here. First, learners' understandings result from the interplay of their prior/existing knowledge and the current instructional situation (e.g., Mayer, 1980). Second, we cannot anticipate students' emergent mental models; they may be riddled with "bugs" or more sophisticated than a course's terminal objective (e.g., Resnick, 1983). ID must accommodate this dynamic, often chaotic situation (e.g., Jonassen, 1990; Winn, 1990).

A number of conceptual-change researchers draw heavily on Vygotsky's notion of a "zone of proximal development," wherein children can perform tasks with the help of adult "scaffolding" and assistance (Wertsch, 1985). Vygotsky's approach would sequence tasks so as to keep learners engaged in tasks that stretch them to go beyond their present level of expertise, but which can be performed with social support and appropriate tools and information resources.

In line with Vygotsky's zone of proximal development, Newman, Griffin, and Cole (1989) think of tasks as something accomplished by groups of people. They contrast their approach with traditional ID. Following traditional ID,

> First, the tasks are ordered from simple or easy to complex or difficult. Second, early tasks make use of skills that are components of later tasks. Third, the learner typically masters each task before moving onto the next. This conception has little to say about teacher-child interaction since its premise is that tasks can be sufficiently broken down into component parts that any single step in the sequence can be achieved with a minimum of instruction. Teacherless computerized classrooms running "skill and drill" programs are coherent with this conception of change. (Newman, Griffin, & Cole, 1989, p. 153)

The authors contrast this task-analysis approach with a more teacher-based approach where simplicity is achieved by the social negotiation between teacher and learner:

> The teacher and child start out doing the task together. At first, the teacher is doing most of the task and the child is playing some minor role. Gradually, the child is able to do more and more until finally he can do the task on his own. The teacher's actions in these supportive interactions have often been called "scaffolding,"...suggesting a temporary support that is removed when no longer necessary....There is a sequence involved...but it is a sequence of different divisions of labor. The task—in the sense of the whole task as negotiated between the teacher and child—remains the same. (p. 153)

This sequencing method is less analytic and formal than ET, yet the end product of the social interaction is usually a simple-to-complex sequencing of "content." This approach, like the skiing example above, offers a more flexible view of content and ways of simplifying instruction.

INTERNAL REFLECTION-IN-ACTION PROCESSES

Schon's (1983, 1987) reflective practitioner model sees professionals—doctors, lawyers, architects, teachers, etc.—as embodying personal theories of practice. These personal theories are much more important than academic theories or representations of expertise. When professionals (or aspiring professionals) encounter a problem in everyday work, much of their response is routinized, but there is nonetheless an element of on-the-spot reflection and experimentation. Schon describes a typical learning sequence of reflection-in-action:

- First we bring routinized responses to situations. These responses are based on tacit knowledge and are "spontaneously delivered without conscious deliberation." The routines work as long as the situation fits within the normal range of familiar problems.
- At some point, the routine response results in a *surprise*—an unexpected outcome, positive or negative, that draws our attention.
- The surprise leads to reflection-in-action. We tacitly ask ourselves "What's going on here?" and "What was I thinking that led up to this?"
- Through immediate reflection, we re-examine assumptions or recast the problem in another way. We may quickly evaluate two or three new ways to frame the problem.
- We engage in an "on-the-spot experiment." We try out a new perspective or understanding of the situation, and carefully note its effects. The cycle of routine performance—surprise—interpretation—experiment is repeated as needed. (adapted from Schon, 1987, p. 28)

Schon rejects the validity of traditional academic formulations of expertise. The traditional discipline—its theories, concepts, models, etc.—simply does not capture the personal expertise needed to reason and evaluate in a professional capacity. By extension, we could argue that instructional designers simply cannot capture, represent, and teach the "content structure" really needed for expertise. That expertise lies embedded within the expert practitioner, and can only be acquired through extended opportunities of practice in authentic settings, with appropriate coaching, mentoring, and other guidance with feedback. The guidance is less in the form of general principles and rules, and more in the form of contextualized reasoning based on the specifics of a case. Because the domain is ill-structured, the practitioner cannot always routinely activate an intact schema; instead the practitioner must assemble a new schema, combining and recombining knowledge from many cases in memory.

Viewed differently, the reflective-practitioner model provides a convincing portrait of the way that general models of ID relate to the everyday practice of ID professionals. There is a growing indication that instructional designers do not apply formal models in a lock-step fashion. Indeed, ID models often fail to capture expert designers' knowledge and skill. This common problem between theory and practice is aggravated when the "prescriptive" ID models are represented in a highly technical and rigidly proceduralized fashion. We return to this point in the recommendation section below.

Putnum (1991) reports some interesting research in which he observed how consultants grew in their expertise in using Schon's reflective practitioner model with teachers. Putnum notes:

> Many of us who seek to engage people in significant learning experiences disparage formulas, rules, or recipes for action as superficial....Novices are likely to misuse rules and recipes; they have not developed the know-how to use them correctly.
>
> Yet well-intentioned learners do search for rules and recipes, especially early in a learning process. As one participant said after a workshop on promoting organizational learning, "If you could only give us a list of the eight things to say, that would be really helpful in getting started." This person was not naive; he understood that a handful of recipes was not a substitute for genuine mastery. The difficulty is that a new theory of practice cannot be acquired whole. Yet if it is acquired piecemeal, the pieces are likely to be used in ways that violate the whole. (p. 145)

Schon's model includes several techniques that Putnum calls "recipes." In a general sense, "a recipe is a formula, a set of instructions, for designing action" (Putnum, 1991, p. 147). In his research, Putnum studied a particular kind of recipe, a question fragment ("What prevents you from...?") used as a technique in consulting situations. Putnum reports that consultants seemed to progress through stages of competence in their use of these fragments:

1. Novices use recipes as "one-liners" or invariant procedures. "Lacking experience in the theory of practice from which the recipe was drawn, novices may get themselves in trouble they cannot get themselves out of. Nevertheless, they may feel a sense of success at having done what they are 'supposed to do,' what they believe an expert might have done. At the same time they may feel some discomfort or chagrin at imitating or 'being a parrot'" (Putnum, 1991, p. 160).
2. The novice gradually shifts orientation from the recipe itself to broader strategies and concepts. Still, "learners may remain caught in a kind of tunnel vision, concentrating intently on the mechanics of implementing the new strategy. It is therefore difficult to respond flexibly to the [dynamic feedback] of the situation" (p. 160).
3. Eventually, learners become able to "respond to surprising data by reframing the situation, stepping out of their original perspective to take account of another." Learners' attitudes about recipe-following also shift: "Rather than

feeling successful simply by using a recipe, they may consider whether that usage was pro forma or genuine" (p. 161).

Putnum points to three positive functions of recipes that serve to counterbalance the negative effects of their misuse by novices. First, they serve to elicit useful data in practice situations. That data can then serve as feedback to learners in improving their practice. Second, recipes tend to have memorable phrases which can serve as hooks or mnemonics to aid performance. Thus a recipe may act as a retrieval cue to activate an appropriate schema for a given situation. Third, the concrete, memorable nature of recipes also can aid problem encoding and reflection. Students often organize their reflective thoughts around preexisting recipes.

The reflective practitioner model is relevant to ET because it highlights how learners themselves construct and organize meaning in a basically simple-to-complex way. Novices take what they can from the content. Then, given authentic performance opportunities and appropriate coaching and reflection, surface-level imitation proceeds to a kind of problem solving based on deeper understanding of the situation. As Resnick (1983) stated, "Effective instruction must aim to place learners in situations where the constructions that they naturally and inevitably make as they make sense of their worlds are *correct* as well as sensible ones" (p. 31). Rather than being "presented" the content structure, learners construct the content for themselves through reflective processes. Thus a simple-to-complex progression may occur, even if the external "content" remains the same: the same recipe comes to mean something entirely different to an experienced practitioner.

MAKING CONTENT STRUCTURE EXPLICIT

ET suggests that content structure be made explicit to students through various synthesizers and organizers. This approach is in line with most research on text design (e.g., Jonassen, 1982, 1985). However, findings of Mannes and Kintsch (1987) and McDonald (1988), challenge the conventional wisdom about organizing devices and synthesizers. They found that presenting students an outline consistent with the text structure fostered memory-level encoding but impeded far transfer of the material to problem-solving tasks. This finding may be related to Smith and Wedman's (1988) comparison between instruction sequenced according to ET prescriptions and Gagne-style learning hierarchies. They found that students made more meaningful elaboration upon the learning hierarchy sequenced material, even though the ET materials were more meaningfully ordered and presented. It seems possible that highly structured and clearly ordered materials may allow superficial encoding precisely because of their easy access structure.

These possible negative effects of explicit teaching of structure may be related to the reported negative effects of constant knowledge-of-results feedback for motor learning tasks (Salmoni, Schmidt, & Walter, 1984): When the student has to do less work to make sense of things, less learning may occur. Salmoni et al. distinguish between immediate performance in instruction and delayed performance as a measure of learning. They suggest that certain instructional strategies may result in a performance decrement during practice, but that on a retention task, the strategies may result in learning gains. Thus the possibility may be entertained that ordering instruction in a too facile way could result in minimal dissonance and could ironically result in shallow processing of material by students (Wilson & Cole, 1991 b). Salomon and Sieber (1970) provide some evidence for this interpretation. They hypothesized "(a) that a randomly spliced film arouses states of uncertainty which in turn lead the learner to extract information concerning possible interpretations of [the] film, and (b) when the film is well organized, it provides a structure for remembering details" (Salomon, 1974, p. 394). This is an area that is threatening to key concepts in ID; there is an obvious need, however, for further research before strong claims can be supported.

Constructivism has recently gained prominence as a philosophy of cognitivism; ID theorists currently are exploring implications for practice (e.g., *Educational Technology*, May and September 1991). A constructivistic approach to instruction is reflected in Harel and Papert's (1990) teaching of fractions through Logo. Students' learning of fractions was reinforced by their designing computer lessons which taught something about fractions. Through the process of designing the lessons, students came to understand the procedures and concepts of fractions at a deeper level than a control group. Their knowledge of Logo programming, fractions, and problem-solving skills significantly exceeded those of both a Logo-programming group and a control group. (The design group, however, took proportionately longer on task.) The fractions study reflects a growing emphasis among cognitive researchers in design and composition activities as a method of learning new knowledge (Harel, 1991). An analogy might be the student journalist who learns a lot about both street crime and writing by doing a series of stories on the subject. Currently, ET does not directly address the issue of building instruction around design activities.

Constructivistic/connectionistic approaches also tend to stress coaching environments (Burton & Brown, 1979; Rossett, 1991) and inquiry-learning strategies (McDaniel & Schlager, 1990; Collins & Steven, 1983). The conditions of appropriate use of a variety of alternative sequencing strategies go beyond ET prescriptions and need to be more clearly articulated for instructional designers to be able to make appropriate design decisions.

RECOMMENDATIONS

As research in cognitive psychology continues to shed light on the process of learning, we are forced to reexamine the assumptions and prescriptions of various theories of ID, including ET. We have explained what we believe are some of the stronger challenges to ET. Following are some of the clear implications for change, which we believe may require a radical restructuring of ET, particularly if it is to serve the needs of instruction in complex and ill-defined domains:

1. *Deproceduralize the theory*. In its current form, ET is less a theory and more of a design procedure. Explicit steps are provided for designing and sequencing instruction. This procedural approach has two problems associated with it: (a) the procedural prescriptions often go far beyond our knowledge base about learning and instructional processes, and are often at odds with that knowledge; and (b) instructional designers tend to follow models in a principle-based, heuristic manner in spite of detailed procedural specifications (Taylor, 1991; Wedman & Tessmer, 1990; Nelson & Orey, 1991; Schon, 1983). ET should be reformulated into a set of guiding principles referenced more clearly to learning processes. A principle-based formulation will allow practicing designers to adapt the concepts to a greater variety of instructional situations.

   The key principles of a revised version of ET seem to be:

   - All subject matters have an underlying content structure, i.e., how people relate constructs together meaningfully. This structure, however, is personally idiosyncratic and dynamic, particularly in complex domains.

- The modeled structure of the content should be taken into account in organizing and sequencing courses and lessons. Overall sequence should generally proceed from simple to complex, allowing for the great variety of ways to move toward increasing complexity.
- The content structure should ultimately be made explicit to the student. The specific mechanisms (e.g., direct instruction versus inquiry methods) should be determined by the instructional situation (learner characteristics, goals, setting, need for efficiency, etc.).

2. *Remove unnecessary design constraints*. A number of ET prescriptions constrain designer options without a demonstrable return in the form of instructional effectiveness. Examples include
   - the use of three primary structures (conceptual, procedural, and theoretical),
   - tying together the primary course goal and primary organizing structure, and
   - using a single structure as a basis for organizing the entire course.

   These prescriptions make ET's application more standardized and parsimonious, but they also preclude a number of alternative organization schemes that follow the "spirit" of ET but not the "letter." Again, a principle-based formulation of ET could more easily accommodate variant schemes.
3. *Base organization and sequencing decisions on learners' understandings* as well as the logic of the subject matter. An assumption implicit in ET is that the simplest, most general concepts in a subject are also the closest to learners' prior understanding. We have shown this assumption to be unfounded. An alternative emphasis would be to add these heuristics:
   - Move from familiar to less familiar content.
   - Use content with high interest and perceived relevance (Hidi, 1990).
   - Create and then take advantage of the "teaching moment" (Bransford & Vye, 1989) when learners are receptive and prepared for new ways of looking at things. Induce cognitive conflict, e.g., by presenting an anomaly (Perkins, 1991), then help learners accommodate new information into their existing schemas.
   - Respond to emergent mental models, encouraging learners to confront their misconceptions.
   - Wherever possible, ground instruction in an authentic performance setting. Make heavy use of immediate, concrete situations, tools, problems, and forms of feedback.
4. *Assume a more constructivist stance* toward "content structure" and sequencing strategy. An objectivistic view of content is that it is "out there"; a constructivist view claims that content is in people's minds, generated through a process of social negotiation, and can only be loosely modeled externally (Cunningham, 1991). We can only hope to approximate an accurate representation of true expertise; much of an expert's knowledge is tacit and ineffable, resistant to reduction and analysis. On this view, a desig-ner's understanding of the content can guide selection of learning experiences, but cannot directly control learning outcomes in a direct, engineered way.

AUTHOR NOTES

Please send requests for reprints to Brent Wilson, University of Colorado at Denver, Campus Box 106, P.O. Box 173364, Denver CO 80217-3364.

REFERENCES

Alexander, P. A., Schallert, D. L., & Hare, V. C. (1991). Coming to terms: How researchers in learning and literacy talk about knowledge. *Review of Educational Research, 61 (3), 315–343.*

Ausburn, L. J., & Ausburn, F. B. (1978). Cognitive styles: Some information and implications for instructional design. *ECTJ, 26* (4), 337-354.

Bechtel, W. (1991). *Connectionism and the mind: An introduction to parallel processing*. Oxford: AIDC/Basil Blackwell.

Bereiter, C. (1991, April). Implications of connectionism for thinking about rules. *Educational Researcher*, 20 (3)10–16.

Bransford, J. D., & Vye, N. J. (1989). A perspective on cognitive research and its implications for instruction. In L. B. Resnick & L. E. Klopfer (Eds.), *Toward the thinking curriculum: Current cognitive research* (pp. 173–205). Alexandria VA: Asso...ation for Supervision and Curriculum Development.

Brown, J. S., Collins, A., & Duguid, P. (1989, January–February). Situated cognition and the culture of learning. *Educational Researcher*, 32–42.

Bruner, J. S. (1966). Toward a theory of instruction. Cambridge MA: The Belknap Press of Harvard University Press.

Bunderson, C. V., Gibbons, A. S., Olsen, J. B., & Kearsley, G. P. (1981). Work models: Beyond instructional objectives. *Instructional Science, 10*, 205–215.

Burton, R. R., & Brown, J. S. (1979). An investigation of computer coaching for in formal learning activities. *International Journal of Man-Machine Studies*, 11, 5–24.

Burton, R. R., Brown, J. S., & Fischer, G. (1984). Skiing as a model of instruction. In B. Rogoff & J. Lave (Eds.), Everyday cognition: Its development in social context (pp. 139-150). Cambridge MA: Harvard University Press.

Case, R., & Bereiter, C. (1984). From behaviourism to cognitive behaviourism to cognitive development: Steps in the evolution of instructional design. *Instructional Science, 13*, 141–158.

Case, R. (1978). A developmentally based theory and technology of instruction. Review of *Educational Research, 48*, 439–463.

Churchland, P. M. (1984). Matter and consciousness: A contemporary introduction to the *philosophy of mind*. Cambridge MA: MIT Press/Bradford Books.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale NJ: Erlbaum.

Collins, A., & Stevens, A. L. (1983). A cognitive theory of inquiry teaching. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: An overview of their current status* (pp. 247–278). Hillsdale NJ: Erlbaum.

Cunningham, D. J. (1991, May). Assessing constructions and constructing assessments: A dialogue. *Educational Technology*, 13–17.

Dreyfus, H. L., & Dreyfus, S. E. (1986). *Mind over machine: The power of human intuition and expertise in the era of the computer*. New York: The Free Press.

Education and the structure of knowledge. (1964). Fifth annual Phi Delta Kappa Symposium. Chicago: Rand McNally.

Ford, G. W., & Pugno, L. (Eds.). (1964). *The structure of knowledge and the curriculum*. Chicago: Rand McNally.

Gagne, E. (1985). *The cognitive psychology of school learning*. Chicago: Scott Foresman.

Gagne, E., D., Yekovich, C. W., & Yekovich, F. R. (in press). *The cognitive psychology of school learning* (2nd ed.). New York: Harper Collins.

Gagne, R. M., Briggs, L. J., & Wager, W. W. (1988). Principles of instructional design (3rd ed.). New York: Holt, Rinehart and Winston.

Gillian, C. (1982). *In a different voice: Psychological theory and women's development*. Cambridge MA: Harvard University Press.

Harel, I. (1991, April). *When mathematical ideas, programming knowledge, instructional design, and playful learning are intertwined: The Instructional Software Design Project*. Paper presented at the meeting of the American Educational Research Association, Chicago.

Harel, I, & Papert, S. (1990). Software design as a learning environment. Interactive Learning *Environments*, 1(1), 1–32.

Hidi, S. (1990). Interest and its contribution as a mental resource for learning. *Review of Educational Research*, *60* (4), 549–571.
Johnson-Laird, P. N. (1982). *Mental models*. Cambridge MA: Harvard University Press.
Jonassen, D. H. (Ed.). (1982). *The technology of text: Principles for structuring, designing, and displaying text*. Englewood Cliffs NJ: Educational Technology Publications.
Jonassen, D. H. (Ed.). (1985). *The technology of text volume two: Principles for structuring, designing, and displaying text*. Englewood Cliffs NJ: Educational Technology Publications.
Jonassen, D. H. (1990, February). Chaos in instructional design. *Educational Technology*, *30* (2) 32-34.
Jonassen, D. H., Hannum, W. H., & Tessmer, M. (1989). *Handbook of task analysis procedures*. New York: Praeger.
Kosslyn, S. M. (1980). *Image and mind*. Cambridge MA: Harvard University Press.
Lakoff, G. (1987). *Women, fire, and dangerous things*. Chicago: University of Chicago Press.
Laurel, B. (1991). *Computers as theatre*. Reading MA: Addison-Wesley.
Mannes, S. M., & Kintsch, W. (1987). Knowledge organization and text organization. *Cognition and Instruction*, *4*, 91–115.
Martindale, C. (1991). *Cognitive psychology: A neural-network approach*. Pacific Grove CA: Brooks/Cole.
Mayer, R. E. (1980). Elaboration techniques that increase the meaningfulness of technical text: An experimental test of the learning strategy hypothesis. *Journal of Educational Psychology*, *72* (6), 770-784.
McDonald, D. (1988). *Drawing inferences from expository text*. Unpublished doctoral dissertation, New Mexico State University, Las Cruces.
McDaniel, M. A., & Schlager, M. S. (1990). Discovery learning and transfer of problem-solving skills. *Cognition and Instruction*, 7(2), 129–159.
Merrill, M. D., Kowallis, T., & Wilson, B. G. (1981). Instructional design in transition. In F. Farley & N. Gordon (Eds.), *Psychology and education: The state of the union*. Chicago: McCutcheon.
Montague, W. E. (1988). Promoting cognitive processing and learning by designing the learning environment. In D. Jonassen (Ed.) *Instructional designs for microcomputer courseware* (pp. 125-149). Hillsdale NJ: Erlbaum.
Nelson, W., A., & Orey, M. A. (1991, April). *Reconceptualizing the instructional design process: Lessons learned from cognitive science*. Paper presented at the annual meeting of the American Educational Research Association, Chicago.
Newman, D., Griffin, P., & Cole, M. (1989). *The construction zone: Working for cognitive change in school*. Cambridge: Cambridge University Press.
Norman, D., Gentner, D., & Stevens, A. (1976). Comments on learning schemata and memory representation. In D. Klahr (Ed.), *Cognition and instruction* (pp. 177-196). Hillsdale NJ: Erlbaum.
Papert, S. (1988). The conservation of Piaget: The computer as grist to the constructivist mill. In G. Forman, & P. B. Pufall (Eds.), *Constructivism in the computer age* (pp. 3-13). Hillsdale NJ: Erlbaum.
Perkins, D. A. (1991, September). What constructivism demands of the learner. *Educational Technology*, 19–21.
Posner, G. J., & Strike, K. A. (1976). A categorization scheme for principles of sequencing content. *Review of Educational Research*, 46, 665–690.
Putnum, R. W. (1991). Recipes and reflective learning: "What would prevent you from saying it that way?" In D. A. Schon (Ed.), *The reflective turn: Case studies in and on reflective practice* (pp. 145–163). New York: Teacher College Press.
Reigeluth, C. M. (Ed.). (1983). *Instructional-design theories and models: An overview of their current status*. Hillsdale NJ: Erlbaum.
Reigeluth, C. M. (1987). Lesson blueprints based on the elaboration theory of instruction. In C. M. Reigeluth (Ed.), *Instructional theories in action: Lessons illustrating selected theories and models* (pp. 245–288). Hillsdale NJ: Erlbaum.
Reigeluth, C. M., & Darwazeh, A. N. (1982). The elaboration theory's procedure for designing instruction: A conceptual approach. *Journal of Instructional Development*, *5*, 22–32.
Reigeluth, C. M., Merrill, M. D., & Wilson, B. G. (1979). *The structural strategy diagnostics profile project: Final report*. Provo, UT: David O. McKay Institute, Brigham Young University.

Reigeluth, C. M., Merrill, M. D., Wilson, B. G., & Spiller, R. T. (1978, July). *Final report on the structural strategy diagnostic profile project.* A final report submitted to the Navy Personnel Research and Development Center, San Diego.

Reigeluth, C. M., & Rodgers, C. A. (1980). The elaboration theory of instruction: Prescriptions for task analysis and design. *NSPI Journal, 19*, 16–26.

Reigeluth, C. M., & Stein, R. (1983). Elaboration theory. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: An overview of their current status.* Hillsdale NJ: Erlbaum.

Resnick, L. B. (1983). Toward a cognitive theory of instruction. In S. G. Paris, G. M. Olson, & H. W. Stevenson (Eds.), *Learning and motivation in the classroom* (pp. 5-38). Hillsdale NJ: Erlbaum.

Rickards, J. P. (1978). Instructional psychology: From a behavioristic to a cognitive orientation. *Improving Human Performance Quarterly*, 7 (4) 256–266.

Rosch, E., Mervis, C., Gray, W., Johnson, D., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8*, 382–349.

Rossett (1991, February). *Coaching successful performance.* Paper presented at the meeting of the Association for Educational Communications and Technology, Orlando.

Rumelhart, D. E., & Norman, D. A. (1981). Analogical processes in learning. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 335-359). Hillsdale N.J.: Lawrence Erlbaum Associates.

Salomon, G. (1974). What is learned and how it is taught: The interaction between media, message, task and learner. In D. R. Olson (Ed.), *Media and symbols: The forms of expression, communication, and education (73rd Yearbook of NSSE)* (pp. 383 - 406). Chicago: University of Chicago Press.

Salomon, G. Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher, 20* (3), 2-9.

Salomon G., & Sieber, J. E. (1970). Relevant subjective response uncertainty as a function of stimulus-task interaction. *American Educational Research Journal*, 7, 337-350.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95*(3), 355–386.

Schank, R. C., & Jona, M. Y. (1991). Empowering the student: New perspectives on the design of teaching systems. *The Journal of the Learning Sciences, 1*(1), 7–35.

Schoenfeld, A. H. (1985). *Mathematical problem solving.* New York: Academic Press.

Schon, D. (1983). *The reflective practitioner.* New York: Basic Books.

Schon, D. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions.* San Francisco: Jossey-Bass.

Siegler, R. S. (1991). *Children's thinking* (2nd ed.). Englewood Cliffs NJ: Prentice-Hall.

Simon, H. (1980). Problem solving and education. In D. T. Tuma & F. Reif (Eds.), *Problem solving and education: Issues in teaching and research* (pp. 81–96). Hillsdale NJ: Erlbaum.

Smith, P. L., & Wedman, J. F. (1988). The effects of organization of instruction on cognitive processing. In M. Simonson (Ed.), *Selected research papers.* Washington D. C.: Association for Educational Communications and Technology.

Spiro, R. J., Feltovich, P. J., Coulson, R. L., & Anderson, D. K. (1989). Multiple analogies for complex concepts: antidotes for analogy-induced misconception in advanced knowledge acquisition. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 498-531). Cambridge UK: Cambridge University Press.

Spiro, R. J., & Jehng, J-C. (1990). Cognitive flexibility and hypertext: Theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix & R. J. Spiro (Eds.), *Cognition, education, and multimedia: Exploring ideas in high technology* (pp. 163-205). Hillsdale NJ: Erlbaum.

Strike, K. A., & Posner, G. J. (1976). Epistemological perspectives on conceptions of curriculums organization and learning. *Review of Research in Education, 4*, 106–141.

Taylor, R. (1991, Spring). NSPI president challenges instructional design profs. *ITED Newsletter*, 1, 4–5.

Tessmer, M. (1991, April). Personal communication.

Tulving, E. (1985). How many memory systems are there? *American Psychologist, 40*(4), 385 - 398.

Wedman, J. F., & Smith, P. L. (1989). An examination of two approaches to organizing instruction. *International Journal of Instructional Media, 16*(4).

Wedman, J., & Tessmer, M. (1990). Adapting instructional design to project circumstance: The layers of necessity model. *Educational Technology*, 48–52.

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind*. Cambridge MA: Harvard University Press.

White, B. Y., & Frederiksen, J. R. (1986). *Progressions of quantitative models as a foundation for intelligent learning environments. Technical Report # 6277*, BBN.

Wilson, B. G. (1985). Techniques for teaching procedures. *Journal of Instructional Development*, *8* (2) 42 - 51.

Wilson, B. G. (1985–86). Using content structure for course design. *Journal of Educational Technology Systems*, *14* (2), 137–147.

Wilson, B. G., & Cole, P. (in press a). An instructional-design review of cognitive teaching models emerging from cognitive psychology. *Educational Technology Research & Development Journal*.

Wilson, B., & Cole, P. (in press b). Cognitive dissonance as an instructional variable. *Ohio Media Spectrum*.

Wilson, B. G., & Merrill, M. D. (1980). General-to-detailed sequencing of concepts in a taxonomy is in general agreement with learning hierarchy analysis. *Performance and Instruction*, 1980, *19*, 11 - 14.

Wilson, B. G., & Tessmer, M. (1990). Adults' perceptions of concept learning outcomes: An initial study and discussion. In M. Simonson (Ed.), *Proceedings of selected research presentations*. Washington, D. C.: Association for Educational Communications and Technology, Research and Theory Division.

Winn, W. (1990). Some implications of cognitive theory for instructional design. *Instructional Science*, 19, 53-69.

Winograd, T., & Flores, F. (1986). *Understanding computers and cognition: A new foundation for design*. Norwood NJ: Ablex.