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9 How Much and What Type of Guidance is Optimal for Learning from Instruction?*

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This chapter summarizes evidence relevant to the debate about the amount and type of instructional guidance that is most effective and efficient for learning, performance, and transfer. Arguments about the disputed benefits of "constructivist" versus "instructivist" or "objectivist" approaches (e.g., Duffy & Jonassen, 1992; Jonassen, 1991; Kirschner, Sweller, & Clark, 2006) or "problem-based learning" versus "transmission models" (e.g., Schwartz & Bransford, 1998; Sweller, 2006) focus primarily on different views about how much and what type of guidance needs to be offered when and to whom with what impact. All of the participants in the debate seem to agree about many of the forms of instructional support that must be offered to most students in most educational environments. The disagreement that fuels the debate stems from different views about the necessity and consequences of forcing specific procedural guidance in situations where learners may be able to discover solutions to unfamiliar problems and tasks. It will be argued that all evidence supporting the discovery elements of constructivist theory is based on studies that failed to vary the type and amount of guidance provided. It is also argued that the debate can be resolved by reference to research that systematically varies the type, amount, and beneficiaries of instructional guidance needed to solve problems or perform tasks.

Any attempt to explicate a construct such as "guidance" or "discovery" is hampered by the fact that advocates of different instructional theories and models tend to define and operationalize instructional support in very different ways. These different theories often spring from different models of learning and sometimes different belief systems, inquiry methods, and philosophies (Cronbach & Snow, 1977; Jonassen, 1991; Merrill, 2002; Romiszowski, 2006). To some extent, these differences reflect the increased specialization and fragmentation in educational research and theory over the past half-century (Winthrop, 1963; Ravitch & Viteretti, 2001) and a growing fragmentation among various sub-specializations in educational research. One result of this phenomenon is that researchers who favor a specific theory or point of view tend to isolate them-

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selves and limit their research, reading, and collaboration to the journals and professional associations or divisions of associations that emphasize their perspective. Attempts to encourage dialogues between the diverse groups who are concerned with instruction and learning will help bridge the gaps and resolve important disagreements.

This chapter begins with the assumption that those participating in this discussion want to improve instruction in the educational system we have inherited rather than to change our approach to guidance in order to impose ideological changes on our educational system. With this exception in mind, the discussion turns next to a description of the types of instructional support that many of the parties to the debate seem to accept as valid and those that have caused disagreement.

Guidance and Discovery in Learning from Instruction

In the past century the instructional support provided during learning has been referred to by terms such as instructional methods (Cronbach & Snow, 1977; Tobias, 1982; Clark, 1982), instructional strategies or teaching strategies (e.g., Merrill, 2002; Weston & Cranton, 1986), direct instruction (Klahr and Nigam, 2004), and scaffolding (e.g., Pea, 2004). Salomon (1994), in a very engaging discussion of the way that instructional methods influence learning, hypothesized that instructional support either activated or supplanted cognitive processes necessary for performance. Yet a large number of operationally different treatments have been offered as examples of each of these types of support. The variability in definition has made it nearly impossible to develop a coherent system for understanding instructional treatments. Three decades ago, Cronbach and Snow (1977) complained that "taxonomies of instructional treatments ... are almost totally lacking ... we [need] to identify the significant underlying dimensions along which complex treatments vary" (pp. 164–165). Three decades later, we continue to lack a systematic way to describe differences between the varieties of instructional support activities examined in research and used in practice. This lack of a system for describing instructional treatments does not imply that those concerned with instruction disagree about all activities that are required to support instruction. For example, many of the participants on both sides in the debate about constructivism would agree in general about the usefulness of some of the types of support that Pea (2004) characterized as aspects of instructional "scaffolding."

Contrasting Scaffolding and Guidance

Pea (2004) and others have adopted the term "scaffolding" to describe one approach to instructional support. Scaffolding is an engineering term that refers to an external frame placed to support a building during the early stages of construction and gradually withdrawn or "faded" as the building becomes stronger. In an educational context, scaffolding provides learning support that is faded as student learning becomes stronger. Pea describes scaffolding as "modeling more advanced solutions to the task – [and] reducing the degrees of freedom for the task ... by recruiting and focusing the attention of the learner by marking relevant task features" (p. 432). Further, he characterizes scaffolded situations as "those in which the learner gets assistance or support to perform a task beyond his or her own reach if pursued independently when *unassisted* ... [and gradually] fading [support] as the learner becomes more proficient" (pp. 430, 431; emphasis in the original text).

These descriptions are general and so open the door to discussions about the specific types of measures employed to gauge learning progress or exactly when, how, and how much support should be faded without cognitively overloading "unassisted" learners—and exactly how we should model solutions or focus attention most effectively and efficiently. Yet there is wide agreement about the benefits of fading, modeling, and directing attention. The devil is in the details in arguments about these general categories of support. A critical detail for the debate about guidance concerns whether unassisted learners should be required to construct or discover their own solutions to problems or ways to accomplish a task or whether they should be required to use procedures that are demonstrated for them. Pea (2004) suggests that a scaffolding theory must demonstrate that scaffolding is only provided when we have "independent evidence that the learner cannot do the task or goal unaided" (p. 443). Guidance advocates suggest that learners must be provided with a complete demonstration of how to perform all aspects of a task that they have not learned and automated previously. So even if a learner could solve a problem with adequate mental effort, guidance advocates provide evidence that it is more effective and efficient to provide a complete description of "when and how" (Kirschner, Sweller, & Clark, 2006; Sweller, Kirschner, & Clark, 2007). This is the key issue that separates many of the participants in this debate.

Contrasting Problem-Based Learning and Guidance Theories

Similarly, many of those who disagree with some aspects of the constructivist approach can agree with advocates of problem-based or inquiry learning (PBL) who recommend providing learners with a description of an "authentic" problem or task during instruction (e.g., Barrows, 1986; Savery and Duffy, 2001). Problems are presented in advance of instruction in order to motivate learners, focus their attention and help connect with their prior relevant experience, and again when learners are learning to solve a class of problems. For example, when teaching a history lesson, problem-based learning advocates would have us describe history problems that represent "the use of history in ways that ... a good citizen would [use their knowledge of history]" (Savery & Duffy, 2001, p. 4). The agreement about problem or task authenticity extends also to the measures that are used to validate learning. In most PBL courses, outcome measures test students' ability to apply what they have learned to solving problems in realistic settings rather than memorizing arbitrary facts or procedural steps (e.g., Merrill, 1983, 2002).

Yet some of us part company with problem-based learning advocates when they require learners to invest effort in order to construct a solution to an authentic problem when an effective solution is available. Savery and Duffy (2001) want students to "engage in the construction of history" in order to learn historical analysis and when learning science, "we do not want the learner to [learn to] ... execute scientific procedure as dictated – but rather to engage in scientific problem solving [designed for the developmental level of the learner]" (p. 4). They suggest, "The teacher's role should be to challenge the learner's thinking – not to dictate or attempt to proceduralize that thinking" (p. 5). The key issue is whether learners will be required (forced, dictated) to discover or invent any part of their own learning support or the curriculum they are learning. This issue is subtle but vital in understanding what Mayer (2004) and Kirschner, Sweller, and Clark (2007) believe to be the reason why many instructional treatments in the past have failed to show adequate benefits. It is also the issue that dominated discussions about the design of experiments offered as evidence in rejoinders by Hmelo-Silver, Duncan, and Chinn (2007) and Schmidt, Loyens, van Gog, and Paas (2007) and a reply to the rejoinders by Sweller, Kirschner, and Clark (2007).

What is Guidance and Why Is It Preferable to Discovery During Learning?

Instructional "guidance" is defined as providing students with accurate and complete procedural information (and related declarative knowledge) that they have not yet learned in a demonstration about how to perform the necessary sequence of actions and make the necessary decisions to accomplish a learning task and/or solve a problem. Guidance also forces students to practice by applying the demonstrated procedure to solve problems or accomplish tasks that represent the performance expected in an application environment and receive supportive and corrective feedback during their practice.

This approach to guidance is based on three defining criteria:

1. Guidance must provide an accurate and complete demonstration of how (decisions and actions) and when (conditions) to perform a task or solve a class of problems;
2. When adaptive transfer is required, guidance must also provide the varied practice and declarative knowledge that permits learners to adapt a procedure to handle a novel situation;
3. Guidance requires forced individual application practice of procedures accompanied by immediate corrective feedback on part- and whole-task versions of problems and tasks that represent those to be encountered in the transfer environment.

The evidence and theoretical rationale for each of these three criteria are discussed next.

1 Guidance Must Provide an Accurate and Complete Demonstration of How (Decisions and Actions) and When (Conditions) to Perform a Task or Solve a Class of Problems

Mayer (2004) and Kirschner, Sweller, and Clark (2006); Sweller, Kirschner, and Clark (2007) have reviewed a combination of laboratory and field-based studies of the effects of variations in guidance on learning. Mayer (2004) offered evidence that this finding has been clearly evident in research that stretches back at least a half-century. Merrill (2002, 2006) provides a description of the way a number of evidence-based contemporary instructional design systems implement guidance. These research reviews conclude that the most effective instructional guidance provided complete information in the form of a demonstration that depicted how to perform a task or solve a class of problems. Effective treatments also provided an opportunity for application practice accompanied by corrective feedback

In order to describe why procedural instruction is more effective than requiring students to discover or construct a procedure, and why it has been difficult to provide both accurate and complete demonstrations of how to accomplish complex tasks, the discussion turns next to a brief review of research on the impact of knowledge types in learning and the way that automated expertise affects the development and delivery of instruction.

Declarative and Procedural Knowledge

Schneider and Shiffrin (1977) and others (Anderson, 1983, 1996; Newell, 1990; Schneider & Chein, 2003) have provided a theoretical rationale for strong guidance with evidence that two types of knowledge are involved in the performance of a complex task: controlled knowledge (often called declarative) and automated (also called procedural, implicit, or production) knowledge.

Complex learning (Clark & Elen, 2006) requires that these two types of knowledge interact in ways that we seldom acknowledge in either instructional research or practice. Understanding the way that knowledge types interact during learning and performance is critical to advancing our understanding of instruction. Anderson's (1983, 1996; Anderson & Lebiere, 1998) ACT-R (Adaptive Control of Thought-Revised) theory is an example of a systematic body of research on the learning and cognitive operation of these two types of knowledge and is based on cognitive information-processing theories of cognition. He and his colleagues present evidence that all learning and performance is supported by a combination of declarative knowledge—which is an abstract representation of facts, concepts, processes, and principles in episodic or semantic form—and procedural knowledge in the form of mental "productions" which consist of goal statements and the overt actions and cognitive operations that will achieve the goals under specified conditions. Each type of knowledge is stored in separate long-term memory systems.

Research based on ACT-R provides evidence that performance on complex tasks such as advanced mathematics problem solving requires productions in the form of procedures that accomplish goals and that declarative knowledge is sometimes useful to fill in the missing steps of already-learned productions. ACT-R also suggests that with use over time, productions become automated and unconscious but declarative knowledge is processed in working memory where activity is consciously recognized. ACT-R specifies that whenever we recognize the conditions that reflect a performance goal, performance is initiated that draws on available productions. When the goal is to learn or solve a problem, we apply the goal-directed productions we have available and if available productions are incomplete or inadequate we use declarative knowledge to fill in the missing steps. If instruction provides the necessary steps to fill the gap, learning occurs faster and more effectively (e.g., with fewer performance errors) than if we must fill in the gaps using declarative knowledge (Velmahos et al., 2004; Clark & Elen, 2006). Yet our awareness of performance is limited to the declarative knowledge we have processed in working memory because productions are automated and unconscious so that they circumvent the limits on working memory (see, for example, an engaging discussion of this process in a chapter on consciousness by Kihlstrom, 1987, and in Sweller's 2006 description of Cognitive Load Theory).

Self-awareness is, in part, the capacity to observe our thinking about and remembering declarative knowledge. Yet we are only indirectly aware of our constant use of automated, unconscious procedural knowledge, which we can observe only by noticing the consequences of its operation. For example, most adults, when asked for the product of 6×108 will respond "648" without an awareness of how they solved the problem. Only the unautomated portions of the solving procedure are conscious and therefore open to conscious inspection. Some readers may have multiplied 100 by 6 and added the automated product of 6 times 8 to get the solution; others may have immediately realized the answer "648." Those who performed the operation in two conscious steps are more likely to be aware of their cognitive processing than those who have automated the entire solution process for this type of problem.

Important to this discussion is recent evidence that the declarative components of learning or problem solving may only be the "tip of the iceberg." It is likely that the teaching and learning of most tasks and the solving of complex problems require an understanding of a large number of task-specific automated processes that support the handling of the conscious components of tasks. These unconscious components may be unknown and/or ignored by instructional researchers, teachers, or trainers. Because of the severe limits on our working memory, it is likely that most mental processes supporting problem solving and learning are automated and unconscious (Cowen, 2001; Clark & Elen, 2006; Sweller, 2006; Feldon, 2007). One way to interpret the evidence from the past half-century of research on discovery learning (Mayer, 2004) is that the type of learning that most effectively supports performance on complex tasks is almost completely procedural and that experts are largely unaware of how they perform tasks and solve problems because expertise is largely automated and unconscious (Clark & Elen, 2006; Clark, Feldon, van Merriënboer, Yates, & Early, 2007).

Experts Are Largely Unaware of How They Perform—The 70% Principle

One component of instruction is a curriculum, which is, in part, a description of the knowledge required to accomplish a set of tasks. Experts who most often have both practical experience and a formal education in the field to be taught prepare curricula. When experts develop instructional materials they attempt to share what they know about the tasks students must learn. Yet there is evidence that while most experts are successful at solving even very complex problems within their area of expertise, they are largely unaware of the operation of their own expertise (Besnard, 2000). For example, Feldon (2004) studied the self-awareness of personal research design strategies used by a number of well-published psychologists who teach research design. He found that these experts who serve as mentors for young researchers were approximately 70% unaware of the primary analytical strategies they were using when designing experiments.

Additional evidence for the hypothesis that expertise is largely automated and unconscious comes from studies of task analysis and other self-report protocols conducted with experts. For example, Chao and Salvendy (1994) studied the errors made by a number of top programming experts during systematic task-analysis interviews. The steps suggested by the experts to solve and debug specific programs were collected and used to develop a master protocol. Their analysis suggested that the debugging strategies suggested by each expert were only approximately 31% accurate. These experts could debug programs but were not aware of about 70% of the steps they used. Besnard (2000), Clark et al. (2007), and Hoffman, Crandall, and Shadbolt (1998) have described other studies that report similar data.

Teachers and Trainers May Often Provide Wrong or Incomplete Information

The evidence for our lack of awareness of our own automated procedural knowledge sheds doubt on many of our most closely held assumptions about instruction and learning. Teachers are selected for their expertise at all educational levels from early schooling to the most advanced doctoral programs. Cognitive apprenticeships (Brown, Collins, & Duguid, 1989) and communities of practice (Brown & Duguid, 1991) are both popular strategies for teaching complex knowledge. Teachers, mentors, and collaborative colleagues are expected to "teach what they know." If experts who teach are an average of 70% unaware of their procedural knowledge, what might be the consequence for their students or collaborators? For the past half-century, studies examining the interaction between student aptitudes and different forms of instructional treatments (most often called aptitude x treatment or ATI studies) have consistently reported that students with lower ability levels and/or less prior knowledge and/or lower motivation are more vulnerable to learning difficulties when instruction is incomplete, unstructured, or gives inaccurate information (e.g., Cronbach & Snow, 1977; Kyllonen & Lajoie, 2003).

Guidance in Poorly Defined or Ill-Structured Domains of Knowledge

Some instructional researchers and developers argue that accurate and complete guidance is not possible for many tasks required in modern curricula that come from ill-structured domains of knowledge (Jonassen, 1997; Spiro, Feltovich, Jacobson, & Coulson, 1992). Poorly structured problems are those that "possess multiple solutions, solution paths, fewer parameters which are less manipulable, and contain uncertainty about which concepts, rules, and principles are necessary for the solution or how they are organized and which solution is best" (Jonassen, 1997, p. 65). Examples include medical diagnosis, historical analysis, leadership or organizational management and counseling psychology. It is also argued that the research tasks used to demonstrate the benefits of procedural instruction, such as Anderson's ACT-R theory, tends to be drawn from more structured domains such as mathematics, and therefore may not generalize to poorly structured domains.

Describing a domain as "ill structured" most often means that either domain experts do not agree or that there are no solutions to some problems. Nearly all problems contain "multiple solution paths," many of which achieve an acceptable resolution to a problem. In this case, the best option is to teach the most direct and simple solution path to novices. In general, when experts fail to consistently solve complex problems we can hardly expect students to discover solutions during instruction. In the case where students are expected to invent a solution, the preferable instructional approach is to provide expert-based procedures for inventing solutions to problems in the domain. In this case the focus of the instruction shifts from students discovering solutions to students learning a procedure for discovering solutions. The important issue for those designing problem-solving instruction is whether there are experts in a knowledge domain who consistently succeed at solving problems or performing tasks in that domain. Expert solutions to problems can be captured using cognitive task analysis and taught to novices.

Cognitive Task Analysis for Capturing Expertise

Research on the use of cognitive task analysis (CTA) to capture and identify the automated knowledge used by experts has grown in recent years (Clark & Estes, 1996; Schraagen, Chipman, & Shalin, 2000; Clark et al., 2007). As evidence of the instructional value of using CTA to identify automated and unconscious expert knowledge, Lee (2004) performed a meta-analytic study of the effectiveness of CTA-based training and performance-improvement studies in a variety of organizations and focused on different types of tasks. She reported an overall median percentage of post-training performance gain effect size of 1.72 (an average increase of 44% on outcome performance measures) for CTA-based instruction when compared to more traditional instructional design using behavioral task analysis. Most of the outcome measures reviewed emphasized application of learning rather than recall or recognition tasks.

Velmahos et al. (2004) studied the expertise of emergency medicine experts who teach in a medical school. In a controlled study, half of a randomly assigned group of 24 medical students were taught a routine emergency procedure in a traditional modeling and practice strategy by expert emergency physicians who teach. The established teaching strategy employed is called "see one – do one –teach one." The student first watches a procedure performed by an expert who explains it in a "think aloud" fashion, and then practices the procedure while getting feedback from the same expert. Finally the student teaches another student to perform the procedure while the expert observes. While this instructional method has served medicine for decades, recent concerns about medical mistakes have refocused interest on the way medical students are trained and have encouraged attempts to close the gaps identified in the way complex procedures are taught (Starfield, 2000). The "see-do-teach" students' post-training performance was compared with the other half of the medical students who were trained with information gathered in a "cognitive task analysis" or CTA (Clark & Estes, 1996; Schraagen et al., 2000; Clark et al., 2007) on the same emergency procedure. The CTA interview is designed to expose automated decisions made by experts and make them available for training. The CTA-trained students were required to use the procedures they saw demonstrated. The emergency medicine experts who were interviewed with CTA also served as the instructors for the see-do-teach condition. All students received both memory and performance tests. It was clear from the analysis that the information provided to the see-do-teach students contained significant omissions and errors.

After training, whenever the medical students performed the routines with patients in the following year, they were observed and evaluated with checklists by judges who were unfamiliar with the instructional method they had experienced. The experimental group who received training based on cognitive task analysis outperformed the expert-taught control group on all analytical (diagnostic) and many performance items by over 50% during the year following training. Velmahos (personal communication) also reported that the traditionally trained doctors caused three serious medical emergencies applying the medical protocol with patients (average for new physicians) and those with CTA training made no life-threatening mistakes.

Research Suggestions

Disputes about variations in guidance can best be determined by reference to evidence from "randomized, controlled tests of competing instructional procedures [where] altering one [relevant] variable at a time is an essential feature of a properly controlled experiment" (Sweller, Kirschner, & Clark, 2007, p. 115). In addition, the hypothesized operation of the strategies selected for examination should be drawn from an evidence-based view of human cognitive architecture. A balanced review of existing studies will indicate that most of the disputes about guidance may stem from different strategies for designing guidance experiments. Design issues appear to be the root of the disagreements with Kirschner, Sweller, and Clark's (2006) argument about the "failure" of constructivism, discovery and problem-based learning. Rejoinders to this review (for example, Hmelo-Silver et al., 2007; Schmidt et al., 2007) pointed to evidence from studies where lower or mid-level guidance conditions typically found in problem-based learning experiments were compared with no guidance or very minimal levels of guidance. Research protocols that examine the amount and type of guidance required for application learning must systematically vary the completeness of steps in instructional demonstrations and whether students are required to learn and apply procedures for completing tasks and solving problems. All models or demonstrations of problem solving and "worked examples" of ways to perform tasks are not equally complete or accurate (Clark et al., 2007; Velmahos et al., 2004). There is considerable evidence that incomplete demonstrations, models, or worked examples place unnecessary and sometimes overwhelming amounts of irrelevant cognitive load on learners (Mayer, 2004; Sweller, 2006). Yet all researchers must validate claims that the cognitive load imposed by requiring students to construct missing steps or sections of procedures or complete routines for solving problems are beneficial, harmful, or inconsequential. DeLeeuw and Mayer (2008) have examined various approaches to measuring different types of cognitive load and have provided evidence that different types of cognitive load imposed during instruction are sensitive to different types of measures.

We must clearly describe the operations, decision rules, and psychological reasoning used to construct treatments where guidance is varied. Critics and consumers of research on guidance must go beyond labels such as scaffolding, problem-based, or direct instruction and instead look carefully at the operations used to design and implement treatments.

Yet demonstrations are not the only type of support required for guidance. The discussion turns next to elements of guidance that are included to support the transfer of learning to novel contexts after instruction.

2 When Adaptive Transfer is Required, Guidance Must Also Provide the Varied Practice and Declarative Knowledge that Permits Learners to Adapt a Procedure to Handle a Novel Situation

There is considerable disagreement about whether people can be taught to become adaptable (see for example, Anderson, Reder, & Simon, 1996; Singley & Anderson, 1989) and yet most educators view adaptability as a desirable goal of education. Procedural knowledge is considered by some to be bound to the context where it was learned and thus some researchers reject the notion of adaptability entirely (Anderson et al., 1997). This section of the discussion begins with a brief description of the evidence for adaptable expertise and then considers the disagreements about the types of instructional support that foster adaptable expertise.

Different instructional theories propose different ways to achieve adaptable expertise. Foremost among those differences is the question of whether forced compliance with a specific procedure for solving problems or accomplishing tasks supports or inhibits adaptable performance. This concern is one of the main reasons why Pea (2004) stipulated that scaffolding provided learning support only until the problem or task was "beyond his or her own reach if pursued independently when *unassisted*" (p. 430) and required that instructional designers and teachers have "independent evidence that the learner cannot do the task or goal unaided" (p. 443). It is also part of the reason why Savery and Duffy (2001) were concerned that teachers do not "dictate or attempt to proceduralize ... thinking" (p. 5) but instead that learners be required to "engage in ... construction ... we do not want the learner to ... execute scientific procedure as dictated" (p. 4). Those who recommend the teaching of procedures argue that adaptable expertise results when procedures are demonstrated in conjunction with varied practice.

Does Forced Procedural Knowledge Inhibit Adaptability?

A large body of empirical research on expertise and transfer supports the conclusion that procedures do not inhibit (but instead support) adaptability. Hatano and Inagaki (1986, 2000), Besnard and Bastien-Toniazzo (1999), Bereiter and Scardamalia (1993), Gott, Hall, Pokorny, Dibble, and Glaser (1993), Perkins and Grotzer (1997), De Corte (2003), Masui and De Corte (1999), and Klahr and Nigam (2004), among others, have offered evidence that more flexible experts acquire and apply both procedural and conceptual knowledge differently than less flexible experts. In a recent review of research on the development of advanced expertise, Feldon (2007) tackles the flexibility question and states:

> careful empirical studies of acquisition and transfer for automated skills demonstrate that limited transfer of automated procedures to novel cues and circumstances can occur ... Further, because complex skills are inherently compilations of many distinct subskills, any particular performance may represent one of three possible paths. These paths are (1) fully automated processes, (2) serial execution of automated and consciously mediated subskills, or (3) simultaneous execution of both automatic and conscious elements.
>
> (p. 97)

Feldon goes on to suggest that when experts learn and automate procedures, they are able to apply them without "thinking" while using their conscious, conceptual knowledge to adjust "sub-skills" (chunks of larger procedures) to solve novel problems by enlarging and varying the conditions under which they apply a procedure. Without automated procedures, the complexity involved in handling the novelty involved in enlarging the application conditions for a procedure has been found to cause "cognitive overload" and defeat performance (Clark, 2001; Sweller, 2006).

Declarative and Procedural Knowledge Interactions

Anderson's ACT-R theory is supported by many years of studies that demonstrate the role of conscious, declarative knowledge in the development of productions (procedures) that support performance (Anderson & Lebiere, 1998). ACT-R hypothesizes that when existing automated knowledge (in the form of condition-action sequences) is not adequate to achieve a goal, learners rely on declarative knowledge to construct new steps and extend the conditions under which prior knowledge is applied to achieve a goal. While the construction process is not well understood, it is reasonable to assume that declarative knowledge is often involved in the construction process. Anderson and Lebiere (1998) claim, "production rules specify how to retrieve and use ... declarative knowledge to solve problems" (p. 5). And "productions are created from declarative chunks in a process called production compilation" (p. 11). In Anderson's ACT-R "flow of information" figure (Figure 9.1), he notes that declarative knowledge can modify a production but all performance is based on productions.

During instruction it is simply not possible to provide practice exercises that represent the entire range of transfer situations where knowledge will need to be applied. Identifying the declarative knowledge needed for transfer to novel situations is challenging because we have no widely shared approach to categorizing declarative knowledge in a way that relates the categories to the development of procedural steps.

Clark and Elen (2006) have described one possible system drawn from Merrill's (1983) taxonomy of declarative knowledge that has since been used by many instructional designers and researchers. His system proposes three types of declarative knowledge, each of which supports a different kind of procedure. For example, learning "concepts" (any term with a definition and at least one example) supports the development of classification procedures that permit people to identify common, culturally appropriate examples of a concept. For example, a classification procedure for anger would include steps where people

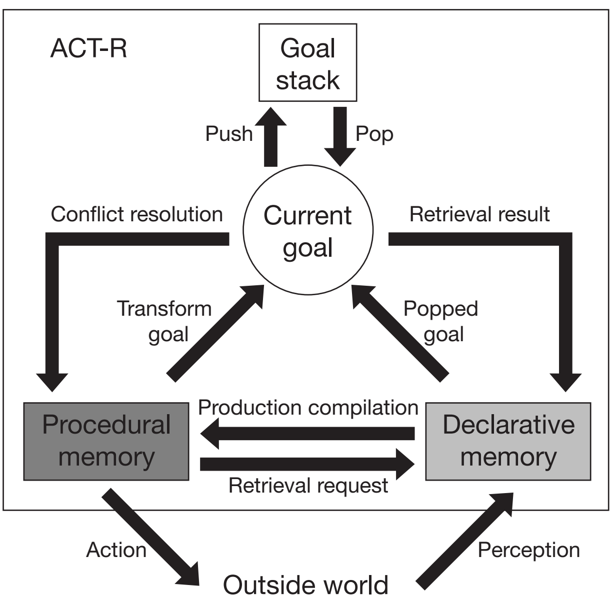

Figure 9.1 Flow of information among the components of ACT-R (source: taken from Anderson & Lebiere, 2004).

are asked to determine whether the defining attributes of anger are present in a typical situation. Relevant declarative knowledge in this situation might be to offer a psychological definition of "anger" which should permit someone to identify anger expressed in novel ways (such as a very angry person from a culture where anger is expressed with smiles or laughter). They would presumably construct steps that allow them to identify anger even when it is expressed in novel ways and settings. Providing declarative principles (cause-and-effect relationships) permit people to develop steps that enable them to change something in order to achieve a goal. If we describe anger as a principle (e.g., by describing factors that have been found to increase and decrease anger responses in most people) it is hypothesized that students should be able to develop steps that permit them to modify anger responses when interacting with others in a novel situation.

One additional type of support called "varied practice" has been found to increase adaptability and the discussion turns next to a brief description.

Varied Practice and Adaptability

In order to foster adaptable performance during instruction,

> it is important that all learning tasks differ from each other on all dimensions that also differ in the real world, such as the context or situation in which the task is performed, the way in which the task is presented, the saliency of the defining characteristics, and so forth. This allows the learners to abstract more general information from the details of each single task.
>
> (van Merriënboer & Kirschner, 2007, p. 19)

Requiring students to apply what they are learning to increasingly novel contexts or situations has been found to increase their adaptability, even to post-instructional transfer situations that do not mirror the actual contexts that were practiced (Cohen, Bloomberg, & Mulavara, 2005; Salomon & Perkins, 1989). Varied (or variable) practice is presumed to broaden the transfer conditions where students are able to apply the new procedure being learned (Salomon & Perkins, 1989).

Research Suggestions

It is possible to point to considerable evidence that forced procedures are more effective than constructed routines at supporting adaptable performance when procedures are accompanied by relevant declarative knowledge and varied practice. It is also possible to point to evidence that, for example, students in a collaborative learning setting who are required to construct a solution to a problem at the start of instruction may learn more and become more adaptable than those who receive only forced procedures (e.g., Schwartz, Bransford, & Sears, 2005; Sears, 2006). Yet it is possible that the Sears and Schwartz studies only examined "problem first" conditions which are considered to be a motivational treatment (e.g., Pintrich & Schunk, 2002) and did not test hypotheses concerning the impact of increasing amounts of varied practice or declarative knowledge. Additional research on these two variables would be valuable if they were systematically varied in future studies.

Varied practice must also be accompanied by corrective and supportive feedback so that students do not acquire misconceptions that must be unlearned later.

3 Guidance Requires Forced Individual Application Practice of Procedures Accompanied by Immediate Corrective Feedback on Part- and Whole-Task Versions of Problems and Tasks that Represent Those to be Encountered in the Transfer Environment

Guidance advocates suggest that effective instruction must provide the opportunity for students to apply the procedures they have seen demonstrated in forced and guided practice exercises where they receive immediate corrective feedback on their performance. Clark and Blake (1997) and Feldon (2007) argue that adaptability can be taught in a way that facilitates the solution of novel and challenging problems. De Corte (2003); Druckman and Swets (1988); Masui and De Corte (1999); Merrill (2002); Perkins and Grotzer (1997); Rosenshine and Meister (1997); Slavin (2006). Rosenshine and Meister (1997) and Rosenshine and Stevens (1986) have described the research base supporting guided practice with feedback and have provided guidelines for constructing demonstration and practice exercises in classroom settings.

The problems and tasks provided during practice exercises must be representative of the population of problems and tasks they will be expected to tackle after instruction. Since most transfer environments require task performance rather than the recall of facts, practice must follow a demonstration or worked example of a forced procedure and require the application of the procedure in order to complete a task and/or solve a problem. Corrective feedback must be frequent enough so that students do not learn errors. In addition, a meta-analysis of feedback studies conducted in many nations by Kluger and DiNisi (1998) indicated that the most feedback must be focused on the effectiveness of the strategy being used by a student during practice and not comment on whether a student is "wrong."

Constructivist Views on Practice and Feedback

Constructivist approaches to learning environments support practice and feedback but in a more limited form, often depending on the type of learning task. In their description of constructivism, Savery and Duffy (2001) suggest that the use of practice and feedback depend on the goal of a learning experience:

> Thus if domain-specific problem solving is the skill to be learned then a simulation which confronts the learner with problem situations within that domain might be appropriate. If proficient typing is required for some larger

> context, certainly a drill and practice program is one option that might be present.
>
> (p. 6)

Shabo (1997) describes a series of constructivist hypermedia projects where teachers found it necessary to increase the feedback provided to students because "The problem was that learners received little feedback to guide them on how to use the non-linear structure, and not all could acquire important skills and knowledge of the subject matter" (p. 231). Goodman, Wood, and Hendrickx (2004) present evidence from a large study where the prior knowledge of students was assessed and many different types of outcome measures were employed. They conclude that "increasing the specificity of feedback positively affected practice performance" (p. 248), but noted that feedback had to be accompanied by varied practice in order to promote transfer of learning.

The difference between constructivist and guidance advocates appears to be about whether practice and feedback is task-specific and at what point practice and feedback should be faded or eliminated as expertise develops. The suggestion that only certain types of learning tasks require practice and feedback requires more systematic research. Both constructivist and guidance advocates agree that as students gain more prior knowledge they sometimes require a gradual fading of practice and feedback, but the research and measurement technology available to support fading makes clear prescriptions difficult.

Fading Guidance and the Measurement of Prior Knowledge and Expertise

Many instructional theories recommend the fading of guidance and scaffolding as expertise increases. These same theories recommend against providing procedural guidance including practice and feedback to learners who have already achieved advanced expertise on the class or domain of tasks and problems that characterize new skills to be learned. Since the 1920s we have had evidence that guidance interacts with prior knowledge (Shulman & Keisler, 1966). In a comprehensive review of studies where aptitudes interact with instructional methods, Cronbach and Snow (1977) and Gustafsson and Undheim (1996) described many studies where the amount of "structure" in instruction interacted with prior knowledge and general ability. In fact, after reviewing hundreds of studies spanning a half-century, they concluded that the most robust interactions occurred between prior knowledge and general ability on the one hand, and prior knowledge and instructional structure on the other. According to Gustafsson and Undheim (1996),

> Treatments with a high degree of structure exercise a high level of external control of the learning activities through control of the sequence of pacing, feedback and reinforcement ... tasks are broken down into small units and presentations are concrete and explicit. Instructional methods characterized as expository, direct instruction, teacher controlled or drill-and-practice are instances of high structure.
>
> (p. 227)

This definition of the term "structure" is similar to the definition of guidance used in this discussion. Some of these "aptitude-treatment interactions" were disordinal which suggests that in some instances, as the amount of guidance increased, students with higher levels of prior knowledge experienced a gradual decrease in learning. Both Cronbach and Snow (1977) and Gustafsson and Undheim (1996) suggest that more structured treatments tend to interfere with automated routines that had been developed by learners with higher levels of general ability and/or more task experience. This finding clearly indicates that under some conditions, instructional guidance might also have negative effects.

Possible Negative Effects of Forced Practice

Kayluga, Ayres, Chandler, and Sweller (2003) describe a number of studies where instructional media and methods cause cognitive overload for novices but are either neutral or beneficial for more experienced students. They also describe studies where strong guidance in the form of forced practice and feedback on specific procedures or worked examples during learning led to less learning for students with higher levels of prior knowledge. Their findings about the interaction between prior knowledge and forced practice mirror those described earlier by Cronbach and Snow (1977) and by Gustafsson and Undheim (1996). One way to summarize these studies is to suggest that more experienced students are sometimes helped, sometimes neither helped nor hurt, and sometimes their learning is harmed by forced practice. One of the difficulties encountered by researchers in this area is that our technology for measuring prior knowledge is inadequate and tends to focus more on declarative than on procedural knowledge. Since we have defined prior knowledge ~~previously~~ as declarative and do not yet have an adequate technology for measuring the extent of automation of task-relevant procedural knowledge, the evidence about interactions between prior knowledge and guidance is suspect. Yet we have evidence (e.g., Kayluga et al., 2003) that some students with higher levels of prior knowledge apparently learned less from complete guidance in the form of worked examples. In the "direct instruction" studies by Klahr and Nigam (2004), about 10–15% of subjects who received lower levels of guidance outperformed students who received very complete guidance. It is possible that these findings will make more sense when better measures of automated, task-relevant knowledge are available. An interesting exception is a promising strategy for measuring application knowledge suggested by Kayluga and Sweller (2004).

Other uncontrolled factors might also be influencing the outcome of these studies. In a meta-analysis of instructional ATI research, Whitener (1989) noted that

> Results are consistent with the interpretation that there are greater differences in learning achievement between Ss with high prior achievement and Ss with low prior achievement when structuring and organizing support are provided and smaller differences between these Ss when instruction is self-paced.
>
> (Whitener, 1989, p. 65)

Her results suggest that when instruction provides forced procedures and specific feedback, learner control over pacing reduces (but does not eliminate) the benefits of prior knowledge. Other reviews of this issue (e.g., Clark, 1982, 1989) have found similar results. Self-pacing apparently allows lower-prior-knowledge students to avoid cognitive overload caused by the speed of processing demanded when pacing is externally controlled.

Conclusion

Advocates for various forms of constructivism and guidance appear to agree about the utility of many forms of instructional support. For example, both groups recommend the "modeling of more advanced solutions of the task" and "focusing the attention of the learner by marking relevant task features" (Pea, 2004, p. 432), as well as providing students with authentic problems that represent those found in the setting where we expect students to use the knowledge they have learned (e.g., Savery & Duffy, 2001) and using outcome measures that require students to apply what they have learned (not simply memorize facts). We seem also to agree about the benefits of varied practice and the teaching of declarative knowledge when performance requires that students adapt the skills being learned to handle novel contexts or problems (e.g., Jonassen, 1997; van Merriënboer & Kirschner, 2007) and providing supportive and corrective feedback during part- and whole-task practice exercises on some (not all) learning tasks (e.g., Savery & Duffy, 2001). Finally, there appears to be widespread agreement that all instructional support should be gradually faded when students' expertise reaches the level where additional support damages learning (Kayluga et al., 2003; Kayluga & Sweller, 2004).

Disagreement

The main source of disagreement between constructivist and guidance advocates appears to be focused primarily on one issue—whether students who are able to construct a procedure for performing a task or solving a problem (but have not yet done so) should be directed to apply an "advanced solution" presented in a demonstration or worked example and engage in forced part- and whole-task practice while receiving corrective and supportive feedback.

Guidance advocates (e.g., Mayer, 2004; Kirschner, Sweller, & Clark, 2006; Sweller, Kirschner, & Clark, 2007) argue that cognitive architecture places severe restrictions on working-memory capacity and so forced guidance allows students to allocate limited cognitive capacity to learning a successful performance routine without limiting transfer. They present consistent evidence from the past half-century where guidance results in significantly more learning than constructing solutions to problems and tasks.

Constructivism advocates believe that "the teachers role is to challenge the learners thinking ... and not to dictate or attempt to proceduralize that thinking" (Savery & Duffy, 2001, p. 5) and require that instructional support not be provided "unless we have independent evidence that the learner cannot do the task or goal unaided" (Pea, 2004, p. 443). Constructivism advocates point to studies where students who construct solutions to problems and tasks achieve not only immediate learning but also longer-term transfer benefits (e.g., Hmelo-Silver et al., 2007).

Resolution

A balanced view of the evidence offered on both sides of the debate would conclude that at this point, support for the guidance position appears to be stronger than for the constructivist position—but some of the constructivist evidence is promising nonetheless. It is clear that many advocates of the constructivist position have moved far beyond the radical views advocating total discovery suggested in the past and that considerable agreement exists between the parties to this debate. Yet current studies used to support both sides tend to examine gross comparisons between forced guidance and no guidance rather than situations where students are able to construct solutions but have not yet done so. Future research studies must systematically explore clearly operationalized variations in guidance that reflect the disagreements. Outcome measures must examine the short- and longer-term learning of declarative and application knowledge. In addition, adequate tests of existing hypotheses about fading instruction and the negative effects of guidance on farther transfer and adaptability require the development of improved measures of automated prior knowledge that include both declarative and procedural forms. We must be able to distinguish between how much and what kind of declarative and procedural knowledge students bring to instruction as well as an adequate technology for tracking their learning in real time during and after instruction. Equally important for the resolution of this and other disagreements is a commitment to increased communication and collaboration between those who advocate very different kinds of instructional support. We must collaborate to produce a clear taxonomy of instructional support that specifies the appropriateness of each type for different learning goals, tasks, and learners. In order to achieve any of those goals, we must be willing to give up the comfortable isolation of like-minded groups and welcome disagreements that can be solved by collaborative, evidence-based inquiry.

Question: Jonassen. *Direct instruction, including worked examples, is clearly effective for supporting learning how to solve well-structured problems. However, ill-structured problems, by definition, are not amenable to direct instruction. How can you design direct instruction to support learning how to solve emergent, interdisciplinary problems with multiple solutions, solution criteria, and solution paths, or no solutions at all? Should we ignore ill-structured problems because direct instruction, other than general heuristics, cannot be used to teach learners how to solve them?*

Reply: Clark. This question touches on one of the most important issues that separate constructivists from guidance advocates. The issue of structure in knowledge domains stems from a concern that strong guidance may not be possible in emergent or established domains where experts disagree about what students need to learn (e.g., counseling psychology, history). I want to suggest a different view of this issue and propose that the problem described in the question can be handled with direct instruction provided it is accompanied by cognitive task analysis. When attempting to design instruction for "ill-structured" domains we are most often in one of two situations—either domain experts can reliably solve emergent or long-standing problems but do not agree about how they do it, or experts have not yet succeeded in solving problems or accomplishing complex tasks. For solvable problems and complex tasks that experts succeed in performing, the goal is to identify and capture the simplest and most effective solutions and then employ procedurally guided instruction to teach those solutions to novices. The goal is to use cognitive task analysis interviews with experts and the literature of the domain to identify the most robust and simplest solution path and teach it to students. In some instances different solution paths indicate important variations in the problems being solved. Often, variations in the initial conditions or values assigned to different variables in a problem will lead to different solution paths.

The second alternative occurs when domain experts have not succeeded in inventing effective solutions that can be demonstrated to students. In this instance, it seems unrealistic to expect that even the most intelligent and motivated students would be able to discover minimally acceptable solutions during instruction. In the case where students are expected to invent a solution, the preferable instructional approach is to provide expert-based, domain-specific procedures for inventing solutions to problems through procedurally guided instruction. In this case the focus of the instruction shifts from students discovering solutions to students learning a protocol for discovering solutions in a domain. In this case, it is also necessary to teach the important conceptual knowledge in a domain (facts, concepts, processes, and principles) so that students will be able to use knowledge-invention procedures effectively. For example, if students want to learn how to develop solutions to counseling psychology problems that have not yet been solved, they need to be able to implement theory-development and research-design procedures that are appropriate to that area and they must be able to apply current concepts and principles as they plan and conduct research. The bottom line in this approach is that there are no "ill-structured domains" if we use cognitive task analysis and/or "how to solve this type of problem" as a basis for guided instruction.

Question: Jonassen. *Experts organize their knowledge around cases, rather than declarative knowledge, and they reason using forward chaining. Experts rarely agree, and they have difficulty unpacking what they know. How can you justify using experts in cognitive task analysis for the purpose of designing instruction for novice learners?*

Reply: Clark. We probably agree that novice reasoning and problem-solving strategies change as expertise develops. Without adequate learning support, novices initially start reasoning backward based on the surface characteristics of problems to choose a solution strategy and then reason forward as they use trial and error to check successive solutions to solve problems. This approach is very inefficient and not very effective for most performance objectives. Experts instantly classify problems into principled categories and reason forward as they implement effective and efficient solution strategies connected to the categories. If some novices can learn to solve problems like experts, why not accelerate this process for all novices by showing them how experts solve domain problems and give them the necessary declarative and procedural knowledge to imitate expert protocols? I appreciate the opportunity to make clear what I only implied in my chapter—that fully guided instruction based on newer cognitive task analysis (CTA) strategies is intended to teach novices to reason like domain experts.

Question: Wise and O'Neill. *Constructivists propose that simplifying a complex domain for the purpose of teaching may encourage learners to take inappropriately simple approaches to complex problems. True domain experts are aware of the limits of the knowledge they work with; is this not a facet of expertise that should be represented in instruction?*

Reply: Clark. You ask two questions—one about inappropriate simplification and another about domain experts. I respect your concern about inappropriate simplification of complex problems. No one wants to make the mistake you describe. I changed my mind slowly about this issue by looking at evidence from the systematic programs of inquiry by instructional researchers such as John Anderson. Anderson's ACT-R model includes the cognitive and neural mechanisms that support learning from instruction and he has applied it to the teaching of math, language, problem-solving, reasoning, and visual perception. His model has been translated into instructional programs that successfully support student learning and transfer of some of the most complex instructional tasks and problems.

Anderson's view is that all complex learning is a product of the gradual accumulation or "scaling" of simple learning into more complex assemblies of knowledge. For example, Lee and Anderson (2001) re-analyzed learning data collected from the very complex Kanfer–Ackerman Air Traffic Controller Task (Ackerman, 1988; Ackerman & Kanfer, 1994) and demonstrated convincingly that the learning in this complex task reflects the gradual build-up of small, procedural-knowledge chunks starting at the keystroke level. They also demonstrated that a large portion of the learning at the keystroke level reflected learning at an even lower, attentional level. The overall execution speed of the necessary complex cognitive skills increased according to Anderson's power law of practice. What was most interesting in this (and many of Anderson's other studies) is that the process by which trainees first learned and then assembled the individual subskills explained more of the variance in whole-task performance than fitting any single subtask to the overall task. So the sequential learning and gradual automating and interconnecting of larger sets of component attention and cognitive subskills was a necessary and sufficient condition for optimal performance at a highly complex task.

Assembling procedural components of complex cognitive routines is a function of sequencing rules, accurate problem-solving procedures including those used to make decisions, and "hands on" practice. In my chapter I stressed the need for "whole-task practice" following "part-task" practice instruction—and the need to introduce increasingly novel features in authentic practice problems to promote "varied practice." I have also become an advocate for training using multimedia immersive simulations and serious games as vehicles for whole-task practice since varied practice and knowledge automation is a gradual process that requires many hours of exercises.

Your second question proposes that "true domain experts are aware of the limits of the knowledge they work with" and ask whether that awareness should be included in instruction. I don't think that anyone has addressed this issue systematically. Over the past 20 years I've conducted cognitive task analysis interviews with many experts in different domains. My experience is that the majority of experts seem equally overconfident about their knowledge of areas both inside and outside their area of expertise. Yet if the issue you raise is intended to suggest that we should clearly describe to students the application limits of the knowledge being taught, I certainly agree. It seems that the difficulty for all of us is not our inclination to specify application limits but a lack of agreement about how to define those limits and what pedagogical approaches achieve different application limits.

Question: Wise and O'Neill. *We appreciate your effort to define instructional guidance from your perspective and agree that a clear definition around which to converse has been lacking in the recent dialogue. However, we are unclear how guidance, as you define it, relates to other commonly used terms such as scaffolding and instructional support. For example, are guidance and scaffolding two kinds of instructional support, useful in different situations? Or are demonstrations and feedback two kinds of instructional support that combine to become guidance? This is a question of more than just semantics, since you seem to critique Pea's (2004) discussion of scaffolding as referring to guidance or instructional support more generally, when we believe his intent was to set scaffolding (in its Vygotskian sense) apart from related guidance practices.*

Reply: Clark. Apparently I could have done a better job communicating my acceptance of nearly all of Pea's descriptions of the elements of scaffolding as shared elements of guidance—except for the requirement that learners discover or invent any part of the solutions to problems or steps necessary to perform a task. Nearly all of the elements of scaffolding, except for discovery, have a long and positive history in instructional research and practice.

Question: Wise and O'Neill. *We value your observation that instructionists and constructivists have largely kept to their corners, working with like-minded researchers for some time. However, there are clearly points of intersection between these camps in the literature. For example, like us, you reference the literature on intelligent-tutoring systems (ITS) to support your argument. Because of this, we were* *surprised to see you insist on the importance of immediate feedback in your definition of instructional guidance. In the ITS literature there appears to be some debate around the merits of immediate feedback (see Mathan & Koedinger, 2003 and the discussion in our chapter). How do you view this debate, and do you think it needs to be factored into your definition of instructional guidance somehow?*

Reply: Clark. Evidence about feedback has not been the exclusive domain of ITS researchers. It extends back at least a century and has been reconceptualized by many researchers over the years. Mathan and Koedinger clearly state that delayed feedback can sometimes result in the learning of incorrect information. They also describe a study where delayed feedback produced greater conceptual understanding and farther transfer but caution that the design of effective delayed feedback is difficult. Their conclusion was similar to the advice provided by Druckman and Bjork (1994) in their review. Applying the conflicting evidence about the timing of feedback is risky and so I believe that the most secure prescription is that well-designed immediate feedback prevents the learning of incorrect knowledge that must later be corrected. I've seen little evidence that delayed feedback typically enhances conceptual learning or farther transfer or that it is the only way to support adaptable learning—but I'm open to new evidence.

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