Argumentation, Critical Reasoning, and Problem Solving

J. Michael Spector and S. Won Park

Human cognition is wonderfully complex and multifaceted. Memory of past events, misremembering past events, recognizing friends, mistaking one person for another, planning a vacation, deciding what course of action to pursue, shopping for a gift, and solving a puzzle all involve cognitive processes that are generally taken for granted. Not surprisingly, it is when we discover a memory error or learn that we have mistaken one person for another that we are inclined to pay attention to our cognitive abilities. “Why did I misremember that event?” “Why did I think that person was someone else?”

Such questions, which seem to be associated with a natural desire to be correct and accurate, might lead one to an investigation of how knowledge is developed, which in turn could lead one to investigate the nature of reasoning. Philosophers have investigated such questions for many centuries. More recently, psychologists have turned an investigative eye to the nature of cognition, including reasoning and problem solving. More fundamentally, most people come to think about their own reasoning processes from time to time. The focus in this chapter is on a combination of these traditions with regard to reasoning and problem solving. Of particular interest is a naturalistic approach (Spector, 2010) that looks at how individuals reason through challenging problems and develop expertise in the broad area of critical reasoning. A naturalistic approach takes into consideration noncognitive aspects of reasoning and problem solving that occur in actual cases. Of course, it is well established that different kinds of problems require different kinds of reasoning (Jonassen, 2004), but a more general view of reasoning and problem solving will provide a perspective that can inform more specific support for reasoning and problem solving.

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Engineers, instructional designers, planners, and many others work with problems that are complex and ill structured. What makes a problem complex is partly based on the nature of the problem (e.g., many factors influencing the problem situation, factors that interact in nonlinear ways, delayed effects of actions and decisions, and ill-defined aspects of the problem) and partly on the nature of the problem solver (e.g., an experienced person may regard a problem as relatively straightforward and simple whereas an inexperienced person may be puzzled by the very same problem situation).

Examples of potentially complex problems include (a) the design of a bridge to span a particular body of water, (b) the development of an economic policy to resolve a persistent budget deficit, (c) determining how best to treat a patient suffering from multiple chronic illnesses, (d) finding the fault or faults in an electronic circuit that fails intermittently, and (e) planning a large social event. In short, complex problems occur in nearly every aspect of life and in nearly every subject domain.

Jonassen and Hung (2008) pointed out that complexity of problems can be determined by four aspects: (a) the breadth of knowledge, (b) the difficulty level of the major concepts in a problem, (c) the intricacy of problem-solution procedures, and (d) relational complexity among major concepts in a problem. Complex problems embody many different sets of knowledge and often involve various constraints and alternatives. Complex problems are often ill structured and dynamic in nature, requiring regular monitoring and adjustment as the situation evolves and new information is revealed (Dörner & Wearing, 1995; Funke, 1991; Funke & Frensch, 1995). There are no single decisive solutions to complex, ill-defined problems; in other words, there are multiple paths to solutions. Effective problem solvers should not only possess the capability to manage a huge knowledge set but also have the ability to execute higher-order, critical thinking skills. How do these effective problem solvers develop this vast knowledge base and advance their critical reasoning skills?

To motivate the discussion, first consider a representative problem-solving situation that many persons have experienced—planning a trip. Here is the scenario:

> George and Grace recently received an invitation from their close friends, Julio and Julietta, to meet them in LA (Lower Alabama) to spend a week in a beach house on the Gulf coast renewing their friendship. They have not seen each other for more than 2 years. Upon receiving the invitation, George and Grace look at their respective schedules to see if the proposed dates will work, and they do. Then they look at their savings to see if they can afford such a trip, and, as it happens, they do have adequate funds for the trip. Next they begin to reminisce about old times with the other couple. They need to give an answer to Julio and Julietta soon, so they then begin planning details, keeping in mind their schedules and budgets, to see if they can indeed follow their initial inclination to commit to the trip. Questions they might ask each other include what to pack, how best to get there, what gifts they might bring to their friends, would another location be preferable, and so on.

The point of this scenario is to emphasize that (a) there are both cognitive and noncognitive aspects to many problems (e.g., facts about schedules and finances as well as feelings about friendship and the location), (b) some aspects of the situation are related and likely influence each other (e.g., the location and their budget), (c) previous experience with similar problems are relevant (e.g., prior trips to LA and maintaining relationships with other friends), and (d) alternative solutions may exist that would satisfy their desire to renew the friendship while keeping savings intact.

These four kinds of considerations can be found in many different problem-solving situations and are likely to influence one's reasoning about the solution. Addressing such considerations often requires some reflection on the nature of the problem and some deliberation about alternative means to resolve the situation.

In summary, reasoning is a critical element of problem solving. What is the nature of reason and of being a rational individual? A traditional definition of being rational (Friedman, 2002) includes such things as:

- Being goal oriented—having an identifiable goal or purpose that one wants to attain for whatever reason.
- Conducting an analysis of the current state of affairs and the desired state of affairs—this involves being able to specify both the goal and the current situation, which will then lay the foundation for identifying alternative means of achieving the goal and then analyzing which means might be more feasible or optimal in attaining the goal according to one or more criteria.

Goals arise frequently in every aspect of life. Some are short-term—"I want to have fish for dinner" or "I want to renew our friendship"—and some are longer-term—"When I grow up I want to be a teacher" or "I want to maintain a lifelong friendship." The second characteristic (conducting means–ends analysis) is often more challenging than the first. An analysis of alternatives implies (a) that one can identify multiple ways of reaching the goal, (b) that one can determine both desirable and undesirable aspects among the alternatives, (c) that one can prioritize the alternatives in some way, and (d) that one can then select the most desirable alternative according to relevant criteria (Spector, 2001). The second characteristic of rationality may also include an examination of assumptions that apply to the goal sought as well as an examination of the consequences and implications of pursuing one course of action rather than another.

In short, the second characteristic of rationality implies a process of deliberation. One might characterize this kind of deliberation on assumptions and implications as a reflective process—reflecting on the quality of one's reasoning. Some might even call such reflection a form of metacognition since it is directed at one's own reasoning processes (Kuhn, 1999). Being rational implies that a person engages in deliberative, reflective thinking. In any case, deliberation and reflection seem desirable, but they require one's time and conscious effort. This kind of reasoning is not so easy or natural as simply deciding to act out of habit and grab some already prepared fish and chips at the closest fast-food provider.

Reasoning

The landscape of reasoning has been discussed in a number of ways by both philosophers and psychologists (Braine, 1990; Rips, 1984; Schauble, 1996). There are several traditional distinctions to consider. One is between formal and informal reasoning. A second is between deductive and inductive (nondeductive) reasoning, which is often associated with logic. The word "logic" is derived from the Greek word “logos” which is used alternatively for “word,” “plan,” or “reason.” Logic has come to be used in a number of ways in modern times. In everyday use, being logical is considered roughly equivalent with being rational. Within the professional community of logicians, the domain of logic is comprised of arguments.

An argument can be defined as a collection of statements, some of which are offered in support of another (Halpern, 1989; Toulmin, 1958). Those supporting statements are called premises and the statement being supported is called the conclusion. So the landscape of logic is comprised of arguments, each of which consists of statements offered in support of another statement. It seems that argument or argumentation skills do not naturally develop. Kuhn (1991, 1993) studied 160 people at different ages and found that only a few of them could consistently develop quality arguments. Other studies also indicated difficulties and weaknesses of adolescents and young adults in constructing arguments and developing argumentation (Brem & Rips, 2000; Klaczynski, 2000).

One concern is on determining the quality of arguments—distinguishing good arguments from bad arguments, or sound reasoning from unsound reasoning. Like other enterprises involving quality determinations, standards or criteria are needed to sort out the good ones from the bad ones. Since the nature of an argument is to offer statements intended to support another, one place to start is to determine the kinds of support that might be offered. Two kinds come to mind immediately: conclusive support and nonconclusive (suggestive) support. The nice thing about this distinction is that it is all-inclusive and the two categories are mutually exclusive. Moreover, such a distinction allows for correction of the type of support offered—that is to say that the person presenting the argument may believe that he or she is offering conclusive support when only suggestive support has been provided.

Before evaluating the adequacy of the support actually offered, one ought to be sure the argument is located in the proper category since the evaluation standards are different. An example of this problem can be found at the end of a correlation study in which the researcher claims that the study proves a certain point. Proof is a strong notion that is best reserved for the strongest types of argument, which are generally considered to be of the conclusive variety (deductive arguments). Correlation studies may suggest or show something, but they do not establish conclusions with certainty. Even rigorous controlled experimental studies aimed at establishing causality do not establish conclusions with certainty; rather they may establish conclusions with high degrees of probability. Mathematical proofs are familiar examples of the deductive variety. Statistical studies are familiar examples of the inductive or nondeductive variety. It would be wrongheaded to hold both kinds of arguments to the same standard. Next comes a short discussion about these two types of arguments.

Deductive Arguments

In assessing the adequacy of the premises of a deductive argument in supporting the conclusion with certainty, another distinction should be considered—that between form and content. As it happens, all that is needed to guarantee the truth of the

Table 1 Logical connectors

	P	Q	P and Q	P or Q	Not P	If P, then Q
1	True	True	True	True	False	True
2	False	True	False	True	True	True
3	True	False	False	True	False	False
4	False	False	False	False	True	True

conclusion based on the truth of the premises in a deductive argument is to consider the form of the argument—valid deductive argument forms are exactly those which are guaranteed to preserve truth—that is to say that in a valid deductive argument, if the premises are true, the conclusion must be true.

In determining the quality of a deductive argument, the focus is not on the content of the argument—validity has nothing to do with the actual truth or falsity of the statements that comprise the argument. Rather, validity is totally determined by the form of the argument. To determine validity one strips away the content and leaves behind just the logical form of the statements involved. This process is worth illustrating. Consider this argument implied in many discussions about American presidential elections:

If a Republican is elected President, then a Democrat will not be elected President.
A Republican will not be elected President.
Therefore, a Democrat will be elected President.

For the sake of this illustration, ignore the difference in tense ("is elected" and "will be elected" are considered synonymous). Is this a valid argument? It seems reasonable, and one might be inclined to simply accept the argument as reasonable and proceed on one's merry way.

It is customary to adopt the convention of representing discrete, simple assertions embedded in a compound statement by different letters. It is also customary to use a set of statement connectors based on familiar English usage, such as: and, or, not, and if-then. The commonly accepted definitions of these familiar connectors in a two-valued logic are based on a truth table (Table 1).

What does this truth table mean? It means that a conjunction of the form *P and Q* is true in just one situation—namely when both P and Q are true (see row 1 and column 3 in Table 1). Likewise, a disjunction of the form *P or Q* is false in just one situation—namely when both P and Q are false (row 4, column 4). Such usage generally conforms to the ordinary use of these connectors. The one case where the truth table definition may be different from common usage is with regard to IF-THEN statements when the antecedent (the statement following *IF*) happens to be false. These statements are called counterfactuals (rows 2 and 4 and column 6) and are treated as true in a two-valued logic since no evidence is produced to demonstrate that the entire compound IF-THEN statement is false—the person who knowingly utters a counterfactual admits no evidence can be produced to show that the statement is false; the only IF-THEN statements that take a risk are rows 1 and 3 in Table 1, which is the case with the antecedent being true. A person making a counterfactual claim (rows 2 and 4 and column 6), in an important sense, takes no risk, and there is nothing at stake. So the two cases with an admittedly false antecedent are considered true. Beware people who utter counterfactuals—they (both the statements and the people who utter them) are vacuous (as in devoid of meaningful content).

What then is the logical form of the argument involving Republican and Democratic candidates? Let "R" stand for "a Republican is elected" and "D" stand for "a Democrat is elected." The logical form can then be represented as follows:

If R, then not D.
Not R.
Therefore, D.

Does this logical form preserve truth? Can there be a case where the premises of such an argument would be true but the conclusion false? It is possible to build a complex truth table for this very complex statement: "[If (If R, then not D) and (not R)] then D"—that would be the case representing true antecedent and a false consequent in an IF-THEN statement (row 3 in Table 1). Building such a table seems like hard work. Here is an alternative to reason through the determination of validity. When could both premises of this argument be true? Well, when "R" is false, the second premise is true, since the NOT operator simply reverses the true value of the statement negated. But, when "R" is false, the first statement represents a counterfactual—one of those vacuous claims made by vacuous people—and it would be true regardless of the truth value of "D." Imagine that. "D" could be false and the first premise would be true when the antecedent is false (when "R" is false). So, the row in a truth table that has "R" false and "D" false would be a case that makes both premises true but the conclusion false.

However, some would say that the argument still makes sense since a person can only belong to one political party at any point it time and that only one person will be elected President in any particular election in the USA, which has only two active political parties. It would be wrong to say that the argument as represented makes sense, though. Fallacious arguments can be easily constructed with the same logical form. Consider the following example:

If a rich person is elected, then there will not be a decline in taxes for the poor.
But a rich person is not elected.
Therefore, there will be a decline in the taxes for the poor.

This argument has the same form as the previous argument. Is it a convincing argument? Should anyone be persuaded? If not, why should one be persuaded by the prior argument? In fact, both arguments fail the test of validity and should convince no one. Nevertheless, those who have accepted the first argument might have unconsciously added an additional premise: "A Democrat or a Republican will be elected"—"D or R." That simple additional premise rules out the one case that invalidates the simpler argument. So there is some value in examining one's assumptions—especially in making those assumptions explicit. Here is a revised and valid argument form:

If R, then not D.
Not R.
D or R.
Therefore, D.

Table 2 Toulmin's argument structure

1. Claim	Standpoint that people hold
2. Data	Statements that serve as evidence to support the claim
3. Warrant	Statements that justify the relationship of the data to the claim
4. Backing	Underlying assumptions of the claim that are often implicit
5. Qualifier	Conditions under which the claim holds true, which add the degree of force from data to claim
6. Rebuttal	Assertions that contradicts the claim or represent exceptions to the claim

In this argument, it turns out the first premise is not needed at all. The truth of the second and third premises is sufficient to establish the truth of the conclusion—this is called a disjunctive syllogism for those taking notes. An important lesson to be learned in this excursion into deductive logic is that identifying unstated assumptions is a critical aspect of critical reasoning.

Inductive Arguments

There are far too many variations of inductive arguments to treat at the same level of detail just provided for deductive reasoning. However, the same general concerns and kinds of tests apply. First, one examines the form of the inductive argument. If the form is acceptable, then one can investigate whether or not the premises are *probably* true. The kinds of evidence that are involved in supporting probable truth are far more complex and involve a variety of statistical inferencing methodologies. As already mentioned, the tests for an acceptable inductive argument form are more complex than those for a valid deductive argument form. It should be noted that this discussion of inductive arguments intentionally ignores matters of rhetorical style and persuasiveness, as those issues have nothing to do with validity. Unfortunately, many people count on rhetoric and persuasive techniques rather than on the validity and soundness of the reasoning involved.

Toulmin's (1958) model of argument analysis is most frequently used to develop criteria for evaluating the quality of an inductive argument in the literature. Toulmin identified six elements that a sound argument may comprise: (a) claim, (b) data, (c) warrant, (d) backing, (e) qualifier, and (f) rebuttal (see Table 2). According to Toulmin, arguments can be analyzed with these categories and those containing six components are considered strong although some of them need not necessarily to be explicit.

While Toulmin's model focuses on the structure of arguments, more recent studies on argumentation have started emphasizing a dialectical aspect of argumentation. The contemporary argumentation theorists acknowledge that argumentation should be regarded as a discourse that involves the social process between two or more individuals (Kuhn & Udell, 2003; Nussbaum, 2008, 2011); this happens to be true for both deductive and inductive arguments. Arguments (collections of statements offered in support of another statement) can be viewed as the products of dialogical argumentation and discourse (O'Keefe, 1982). Revealing hidden assumptions (as illustrated above) and identifying the implications of accepting the conclusion often occur in a dialogical or discursive context. This more comprehensive view of arguments has raised discussion about constraints in the Toulmin's model of arguments as an evaluative tool. That is, Toulmin's model fails to consider argumentation as a social process that involves two sides (van Eemeren & Grootendorst, 1999). Several alternative frameworks of argumentation have been proposed, including van Eemeren and Grootendorst's (1999) model of a critical discussion, Walton's (2000) dialogue theory, and the Bayesian model of everyday arguments (Andriessen, 2006; Nussbaum, 2011). These alternative models are more practical for evaluating the content of arguments as they take into account the dialectical process of generating arguments.

Reasoning Going Forward

To conclude this section on reasoning, it is worth noting that other forms of reasoning and logic have been proposed by philosophers and psychologists, including abduction, multivalued logic, and so on. What is worth carrying forward for the purpose of this discussion is that when reflecting on one's own reasoning that understanding the kind of reasoning involved and especially the form of that reasoning is important. Moreover, when deliberating on the quality of one's reasoning, a critical factor is in determining whether or not adequate evidence has been developed to support the conclusion or decision to be taken. Reflection, deliberation and consideration of alternatives are important aspects of reasoning regardless of the kind of reasoning involved. Critical reasoning involves examining assumptions as well as implications and this process is likely to occur in a dialogical or discursive context. Consequently, argumentation and critical reasoning can be as regarded in a naturalistic way as social processes involving others.

Mental Models and Schemas

The quality of an argument can be viewed as a product of sound reasoning. Arguments are an external representation of one's reasoning. What mental processes are involved in developing valid arguments? The internal representations of an individual's reasoning can be grouped together using the term "mental models" (Johnson-Laird, 1983, 1989; Norman, 1983). The internal cognitive processes of deliberation and reflection are hidden in the sense that they are not viewed directly and immediately. People make inferences about those processes based on external representations and observable entities and events, such as things that people say or write, diagrams that people create, actions that people take, and solutions to problems that people solve.

Cognitive psychologists are in general agreement that people have the ability to process a variety of different kinds of information and act appropriately in many different situations. These abilities include perception, pattern recognition, storing and retrieving different kinds of information, and acting on previously gained experience (Anderson, 1983; Atkinson & Shiffrin, 1968; Schunk, 2008). Pattern matching is an ability at which humans excel (Rumelhart, Smolensky, McClelland, & Hinton, 1986). Humans can quickly recognize an object, as shown by the ability of most people to recognize a familiar face in a group of people. Pattern recognition is a critical cognitive process that involves perceiving, remembering, and comprehending, which are all essential in many decision-making and problem-solving situations.

Pattern matching and recognition are generally believed to be based on schema, which are well-established in memory based on past experiences (Gagné, Yekovich, & Yecovich, 1993; Schraw, 2006). Moreover, it is not simply patterns of familiar objects that people can recognize and match with prior experience to help select appropriate actions. People also recognize more general situations that call for particular kinds of responses, such as the way that a restaurant is organized with a host or maitre-de who will seat you, with a different person taking your order, and possibly with others bringing you drinks and clearing the table when you are finished. Because such a situation has been experienced many times, you generally know what to do in a restaurant even though it may be your first visit to that particular restaurant. Schank and Abelson (1977) and others refer to the ability to recognize such general situations and respond appropriately as scripts rather than as schemas. In what follows, the term “schema” will be used to refer to specific cases involving previous experience in that situation as well as general cases involving unfamiliar objects set in a familiar kind of situation. Schemas involve somewhat complex but well-established internal representations that enable a person to respond immediately without any thought in a particular situation. It is often the case that a person may have difficulty in explaining why he or she acted automatically in a certain way in a particular situation, which is evidence that the internal representation is so well established and so automated that little or no conscious thought is devoted to retrieving and activating the schema. With regard to identifying and reflecting on one’s assumptions in reasoning through a particular problem, when schemas are involved it is sometimes a challenge to bring all relevant assumptions into consideration. It should be obvious that a schema necessarily involves a simplification of the actual situation in which it is invoked. Only a few key aspects of the situation are needed to activate a schema, such as a host or hostess at the front of the restaurant for seating or a receipt left inside a holder on a tray for payment.

Many problems do not lend themselves to resolution based solely on retrieving and activating schemas (well established prior experience). According to cognitive psychologists (Greeno, 1989; Johnson-Laird, 1983, 1989), humans have another way to resolve unfamiliar and puzzling problems. We naturally create internal models of the situation and use those internal representations to think through an unfamiliar problem. These models are created just when needed and are typically called mental models (Johnson-Laird, 1983, 1989). Mental models are generated to represent the perceived structure of the external world or puzzling phenomenon. These mental models are not and could not be replicas of the world. Like a schema, a mental model is necessarily a simplification. Such simplifications are useful in helping a person understand an unfamiliar situation or puzzling phenomenon. Including relevant aspects of the problematic situation are critical for the development of useful mental models; this will be taken up again in a subsequent section involving the implications of internal representations for the design of effective learning and problem-solving support.

Mental models and schemas are related and interact in many problem-solving situations. A person confronts a problem or situation and creates one or more internal representations to respond to the situation. Domain-specific knowledge previously learned, established schemas and newly created mental models may be brought to bear in this process of understanding the problem at hand. The main purpose of this process is to create a causal explanation of the puzzling problem or phenomenon like building an argument. As Kant noted in The Critique of Pure Reason, it is natural and unavoidable for people to think in terms of cause and effect, just as space and time are added to our experience of the world. The reasoning process of invoking schemas and integrating newly constructed mental models fits well with Piaget's (1985) epistemology. When a schema is invoked and a newly constructed mental model can be fit easily within that schema, one might say that assimilation has occurred. When no existing schema is found to help resolve the situation, a newly constructed mental model might be said to lead to a process of accommodation, which involves a refinement of an existing schema. One might also introduce the notion of an internal cognitive structure, which is akin to a repository of schemas (Gentner, 1983; Schraw, 2006). Humans are generally very good at modeling their experiences. We can anticipate new states of affairs and predict likely outcomes of existing states of affairs with relative ease, thanks to our ability to create and manipulate internal representations (mental models and schemas). Figure 1 suggests that over time, mental models are constructed and become associated with other mental models and eventually with schemas, which may be modified in order to take into account what has been learned from activation of the mental models and schemas.

It is possible to distinguish two different kinds of mental models: perceptual models and thought models (Stachowiak, 1973). Glaser, Lesgold, and Lajoie (1987) and Johnson-Laird (1983) consider perceptual models to be appearance or structural models that are used to represent an external reality. This kind of model serves to mediate between internal visual images and external representations in the form of statements, whereas thought models also include qualitative processes and inductions that support the construction of artifacts to represent complexity and causal relationships. In any case, the point here is that there is an interaction between the construction of internal models and external representations of those models. The construction of internal models serves as a basis for critical reasoning and associated external representations such as argumentation; in turn, critical reasoning and argumentation can advance and proliferate mental models, which as a whole facilitates better problem solving.

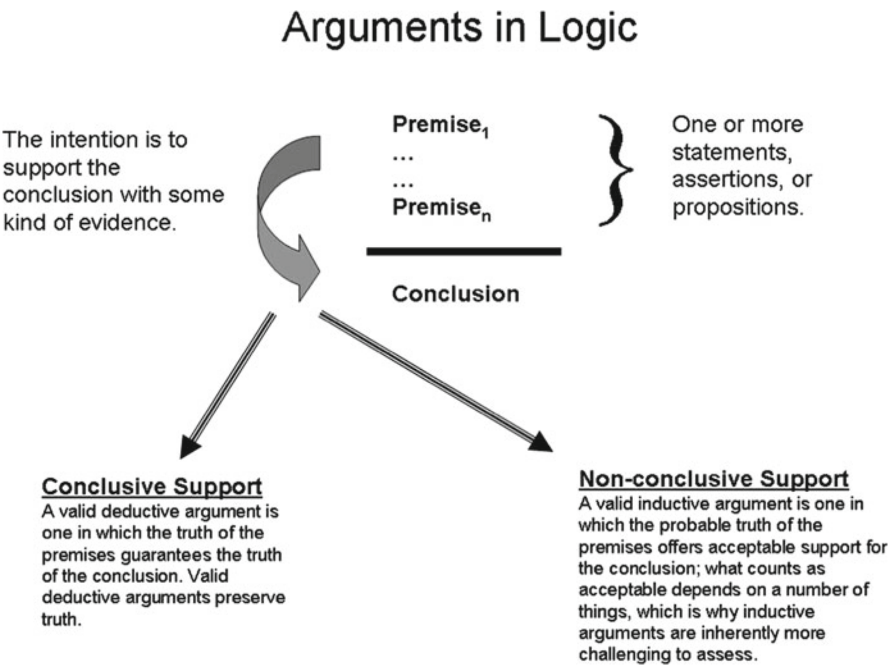

Fig. 1 Mental models, schemas, and the development of expertise

Implications for Learning and Instruction

Researchers are typically familiar with and concerned about ecological validity, which is the degree to which an experimental situation reflects a naturally occurring, real-world situation. Instructional designers have a related principle that suggests that primary instruction and practice should involve problems and situations that closely resemble problems and situations that are likely to be encountered subsequent to instruction. Instruction itself as well as research designs should have a high degree of ecological validity. With regard to instruction, understanding how people process information and reason about problems is a critical aspect of instructional ecological validity. Instruction that ignores how people process information and reason about problems is less likely to be effective (Farnham-Diggory, 1972; Reigeluth, 1999). Many examples can be cited to support this basic instructional design principle. The limitations of working memory are well established. When an instructional system or learning environment violates those limitations by presenting too much information all at once with too little learning support, cognitive overload results, learning outcomes become suboptimal, and many learners become frustrated (Hambrick & Engle, 2003; Sweller, 1988). The major implication from the previous discussion for learning and instruction, therefore, is that mental models and schemas should be taken into account when designing instruction and implementing support for learning and performance (Seel, Al-Diban, & Blumschein, 2000).

While this implication for designing learning support may seem obvious to many, there is the subsequent challenge to be more specific about all that is implied in such a principle. How can learning designs take into account the hidden processes of constructing mental models, activating schemas, and developing ever more useful and productive internal representations? If one is only concerned about performance and learning outcomes, then perhaps such questions are not a pressing concern. However, if one believes that the development of robust and flexible internal representations is critical for the development of competence and expertise, then such questions become a foundation concern for instructional design, which is what is being proposed in this chapter.

When learners are in an instructional situation, they will naturally be engaged in activating schemas and constructing mental models, based on the earlier discussion. Another way to think about the implications for the design of effective instruction is through the lens of cognitive efficiency, which can be defined as the optimal effort required to solve a problem correctly or perform a task in a satisfactory manner (Hoffman & Schraw, 2010). The notion of cognitive efficiency involves a tradeoff between time and resources and desired outcomes. There are three primary measures of cognitive efficiency: (a) instructional efficiency, (b) processing efficiency, and (c) outcomes efficiency (Hoffman & Schraw, 2010). The first and third are already familiar to most instructional designers who are concerned that learners achieve acceptable performance in a reasonable amount of time. Processing efficiency is most directly related to the reasoning processes discussed previously and clearly influences both instructional and outcomes efficiency. Measures of cognitive efficiency and the means to enhance it are well known to instructional designers. There are two factors that have yet to be fully explored in the research literature on cognitive efficiency and instructional design research: (1) individual differences that impact internal cognitive processes, and (2) how cognitive efficiency improvements and other instructional design principles can be effectively applied to situations involving complex and ill-structured problem-solving tasks. These considerations are likely to be important challenges for future research (see the last section of this chapter).

While there is much that is unknown and difficult to determine with regard to how individuals process information, solve problems, and develop competence in reasoning about challenging situations, some initial steps have been taken. First, it is now well established that instruction should be centered around meaningful and realistic problems (Lave & Wenger, 1990; Merrill, 2002). Second, when analyzing problems and tasks to be learned, it is also well established that there are different kinds of problems requiring different kinds of learning support (Jonassen, 2000). Third, representations of internal mental models and schemas are now being used explicitly to support learning (Spector, 2010, 2011).

Before presenting a general framework to support model-based reasoning, a discussion of the different kinds of models that might be used in alignment with internal models is relevant. Just as there are different kinds of internal representations, there are a variety of different kinds of external representations or models. External models come in many forms. Some are mathematical in nature, such as a regression model. Some are graphical, such as a schematic drawing. Some are in the form of arguments

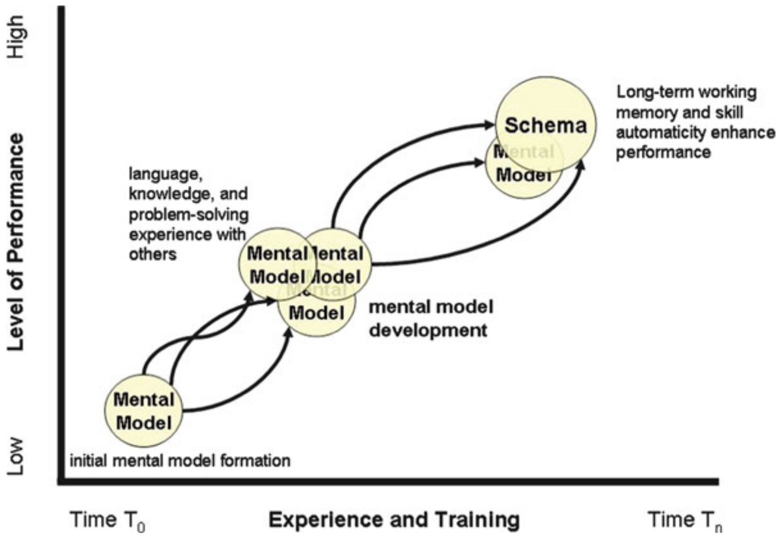

Fig. 2 Arguments involved in reasoning

with premises and a conclusion. Some models involve video or animation depicting how a device works. Some involve a combination of different forms of representation. Figure 2 can be considered an external representation of a mental model about the nature of arguments; others might represent their mental model of arguments quite differently. Table 1 can be considered an external representation of the definition of ordinary conjunctions in English; others would surely represent their understanding of those connectors differently. The equation $e=mc^2$ might be considered an external representation of Einstein's mental model of the relationship between energy and mass.

Which external representations are effective when, for whom, and why? One temptation is to think at the level of learning styles and preferences based on a belief that those individual differences are key factors in learning effectiveness. Certainly learning styles and preferences are often relevant, but they do not reach a level that aligns easily with how a person processes information. Some learners may say that they are visual learners, for example. They may even have some evidence for such a claim. However, this does not resolve the issue of which visual models will be easily aligned with a particular learner's internal representations and, as a consequence, be likely to help that learner.

Another approach is to have a general sense of common problems encountered when confronted with different kinds of challenging tasks. A cognitive task analysis can be a start along these lines, and cognitive task analysis has proven useful for the design of instruction (Clark, 2008). Those who have implemented intelligent tutoring systems have developed libraries of commonly encountered mistakes and misunderstandings that can be used to inform an instructional decision such as selecting an appropriate learning activity or providing targeted feedback (see van Lehn, 1988, for example). Dörner (1996) reported that those confronting complex and ill-structured problems experience common challenges and difficulties, including: (a) a failure to grasp the full breadth of a problem situation with a tendency to focus on just one component or familiar aspect of the problem, (b) the inability to reason effectively about nonlinear relationships among different aspects of the problem, and (c) difficulty in understanding and predicting delayed effects and the accumulation of effects over time.

A third approach to taking into account internal cognitive processes that has recently been explored is to elicit from a learner representations of that learner's internal mental models and schemas and use those in the course of instruction (Seel, 2003; Seel, Al-Diban, & Blumschein, 2000).

The question of whether and how we can influence model-building activities through instruction has long been at the core of various educational approaches (see, for example, Karplus, 1969), and in the field of research on mental models we can also find a strong pedagogical impetus from the very beginning. According to Johnson-Laird (1989) and other authors we can distinguish between several sources for the construction of mental models: (1) the learner's ability to construct models in an inductive manner, either from a set of basic components of world knowledge or from analogous models that the learner already possesses; (2) everyday observations of the outside world combined with the adaptation of cultural models; and (3) other people's explanations and their adaptation. Among these sources, the third one seems to be especially relevant for instruction.

According to Carlson (1991), it is possible in principle to design instruction to involve the learner in a process of inquiry in which facts are gathered from data sources, similarities and differences among facts noted, and concepts developed. In this process, the instructional program serves as a facilitator of learning for students who are working to develop their own answers to questions. On the other hand, instructional programs can present clearly defined concepts followed by clear examples. A designed conceptual model may be presented ahead of the learning tasks in order to direct the learner's comprehension of the learning material. More generally, we can distinguish between different paradigms of model-oriented instruction depending on whether they aim at (a) self-organized discovery and exploratory learning, (b) guided discovery learning, or (c) learning oriented toward the imitation of an expert's behavior or the adaptation of teachers' explanations.

In the next section, a framework that integrates aspects of all three of these approaches into a general framework will be presented. This framework should be considered provisional at best. Research to explore this and other possibilities will conclude the discussion.

A Framework for Integrating Models in Learning and Instruction

A well-established instructional design framework that has wide applicability is cognitive apprenticeship (Collins, Brown, & Newman, 1989). The cognitive apprenticeship model involves six different methods and the notion that learners new to a domain require more support than more experienced learners. The six methods are: (a) modeling (e.g., show how an experience person solves the problem), (b) coaching (e.g., observe performance and provide timely and constructive feedback), (c) scaffolding (e.g., implementing explicit support to facilitate learners' problem solving), (d) articulation (e.g., getting learners to talk about how they are thinking about solving a problem), (e) reflection (e.g., encouraging learners to compare their solution with that of others), and (f) exploration (e.g., allowing learners to investigate new problems and problem approaches on their own with little or no guidance).

The cognitive apprenticeship model is consistent with Gagné's (1985) nine events of instruction (a claim that many will find to be quite controversial) as well as with Merrill's (2002) first principles of instruction, just as the relative new notion of cognitive efficiency is consistent with a great deal of traditional instructional design. Essentially, cognitive apprenticeship can be characterized as a significant and explicit cognitive extensive of earlier instructional design models. What is really new and only recently emerging is the recognition that it is important to take into account how individuals think about complex problems and process information in the course of solving problems. In any case, there is a great deal of evidence that cognitive apprenticeship is a useful instructional design model (Palincsar & Brown, 1984; Roth & Bowen, 1995; Schoenfeld, 1994; Shuell, 1996). The next step is to refine that model to explicitly account for internal reasoning processes.

Model-facilitated learning (MFL) is an instructional design approach aimed explicitly at promoting model-based reasoning. MFL builds on cognitive apprenticeship (Collins et al., 1989) and Merrill's (2002) first principles. MFL is centered around and facilitated by models in the form of expert and student representations of a problem or problem space, a solution approach, and/or a solution. The models may or may not be created by learners, but learner interaction with models is generally an integral aspect of learning activities just as interacting with models is an integral aspect of living and learning in general.

The particular area for which model facilitated learning was designed involves complex and challenging learning tasks and problem-solving situations. Complex learning tasks tend to have many interacting components, some of which may be incompletely defined, and with some nonlinear relationships and delayed interactions among the various components (see Dörner, 1996; Sterman, 1994). Such problems occur in economic forecasting, engineering design, environmental planning, management decision making and in many other every day problem-solving situations. Using models of complex phenomena to help learners gain a holistic and meaningful sense of the problem is one aspect of model facilitated learning. Having learners engage in modeling activities to gain insight into the complexity of a problem situation is a second aspect of MFL. MFL assumes three stages of learning development and has associated instructional guidelines for each stage (Milrad, Spector, & Davidsen, 2003). The first stage is problem orientation in which problems or related sets of problems are presented to learners and learners are asked to solve relatively simple versions. The second stage of learner development involves inquiry exploration in which learners are challenged to explore a complex task domain and asked to identify and elaborate the relationships among the various components of the problem. The third stage of learner development involves policy development in which learners are asked to reason in a more global and holistic with regard to rules and heuristics to guide decision making with regard to various problem situations that may arise in that task domain. Principles to guide the elaboration of learning activities and instructional sequences within these stages include such notions as (a) situating the learning experience in the context of meaningful and realistic problems (Merrill, 2002), (b) presenting problems of increasing complexity, involving learners in a sequence of related tasks involving the initial problem scenario (van Merriënboer & Kirschner, 2007), (c) involving learning in an increasingly set of complex inquiries and explorations with regard to the problem situation, and (d) challenging learners to develop rules and guidelines to guide decision making in anticipated problematic situations.

The foundations for model facilitated learning are derived from system dynamics (see, for example, Sterman, 1994), educational and learning psychology (see, for example, Lave & Wenger, 1990; Spiro, Coulson, Feltovich, & Anderson 1988), and from instructional design (see, for example, Merrill, 2002). In addition, MFL adopts the principle of graduated complexity (Milrad, Spector, & Davidsen, 2003) in the form of guidance for the elaboration of instructional sequences. Graduated complexity in MFL is implemented consistent with cognitive apprenticeship methods (Collins et al., 1989). According to the principle of graduated complexity, instructional sequences should challenge learners to:

1. Characterize the representative behavior of a complex system, indicating how it behaves over time; this is similar to the first method in cognitive apprenticeship but is specifically elaborated with regard to complex and dynamic problem situations.
2. Identify a desired outcome and key variables and points of leverage with respect attaining that outcome; this is consistent with the coaching method in cognitive apprenticeship but is again elaborated with regard to critical aspects of a complex and dynamic problem situation.
3. Identify and explain alternative causes for observed phenomena; this can be combined the first method and is consistent with the expectation that people naturally seek cause and effect relationships; asking learners to accomplish this step at some point is consistent with the articulation method in cognitive apprenticeship.
4. Reflect on how the system and associated variables seem to change over time and through interventions; this challenge requires perceptual processing but the critical aspect is the ability to focus on key problem components and how they change over time and with intervention; this is also consistent with the reflection method in cognitive apprenticeship.
5. Develop a rationale to explain complex phenomena in terms of an underlying system structure, including decision-making and policy formulation guidelines; this challenge is aligned with both articulation and reflection in the cognitive apprenticeship model.
6. Broaden understanding through diverse and new problem situations; this challenge addresses near and far transfer of learning, is consistent with Gagné's (1985) ninth event of instruction as well as with the exploration method in cognitive apprenticeship.

Further Research

The ability to solve complex problems depends in large part on the ability of individuals to construct productive mental models and activate relevant schemas. Mental models are useful in explaining puzzling phenomena and complex systems, especially in terms of cause and effect (Hale & Barsalou, 1995; Seel, 1999). Those who are confronting challenging problems are likely to construct mental models in order to provide explanations for the new or unusual phenomena. Greeno (1989) suggested that productive mental models should be encouraged along with the significant properties of external situations and appropriate interactions; this principle has strong implications for the design of learning and instruction. Moreover, such a principle is consistent with a constructivist approach to learning that suggests that the learning environment should serve as an information resource which can be used by a learner to focus on relevant aspects of a problem and activate relevant schemas and prior knowledge. Learning activities are, consequently, required that enable learners to explore and interact with the learning environment in a meaningful, problem-centered context. Consistent with cognitive apprenticeship and model-facilitated learning, support and scaffolding should be provided to help problem solvers to be successful and develop both competence and confidence (Keller, 2010). This general approach can also be found in what is currently being called learning by design (Kafai & Ching, 2004; Kolodner et al., 2004). Additionally, Kirschner, Sweller, and Clark (2006) and Mayer (2004) have argued that minimal guidance during instruction, especially with learners new to a problem-solving domain, is not effective. Consistent with cognitive apprenticeship and model-facilitated learning, explicit coaching and overt learning support should be provided to those inexperienced in the domain.

What is not known or well established is how best to support the development of expertise and insight with regard to complex, problem-solving activities in specific problem domains (Spector, 2010). Future research is necessary to determine with confidence how well and in what circumstances MFL-based instruction works in terms of developing competence and expertise, especially in comparison with other instructional methodologies. Which kinds of models (student-created, expert-created, partially complete, etc.) are effective with different learners and learning tasks is also not well known, nor is it well known how external models align with internal models in specific problem-solving situations. While versions of MFL have been implemented and evaluated in the first two stages indicated above (problem orientation and inquiry exploration), very few MFL environments exist to promote learning at the last stage of learner development (policy development). As a result, research on effective MFL techniques to promote policy development knowledge remains very open for further research and development, and additional research is needed in the first two stages as well. Additionally, effective MFL instructional sequences for complex problem task domains is not very well established. A central underlying problem concerns the need for well-developed means to assess the progressive development of student understanding in complex task domains. This requires validated means to elicit and evaluate student generated models in response to a wide variety of problem types and scenarios, yet those means are still in the early stages of development. Finally, integrating external models of various kinds and aligned those with individually generated internal models remains an important area open for further exploration.

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