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Reconceptualizing Change in the Cognitive Construction of Knowledge

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How is knowledge acquired and represented in memory? By what process do individuals come to change their ideas, conceptions, or knowledge? Although the first question has been central to cognitive psychologists' research agendas for many years, relatively less is known about the change process. We examine 3 research literatures to broaden our understanding of the process of knowledge change. In particular, we draw on models of conceptual change from cognitive psychology, social psychology, and science education. Each model adds a new perspective on the change process. Based on the literature from these models of change, we developed a new model that represents our reconceptualization of the change process. We describe the model and use it to point out new areas of research to be addressed.

Psychology has, at its foundation, an abiding interest in understanding the construction of knowledge. How do individuals come to perceive, know, remember, and learn? How do individuals acquire new knowledge? How is knowledge represented and organized in memory? How do individuals come to change their knowledge? These questions have served as conceptual frameworks for psychological, as well as philosophical, thought for centuries (Hunt, 1993).

A major contribution of cognitive psychology has been the conceptualization of knowledge as memory representations in the form of scripts, frames, or schemata (Anderson & Pearson, 1984; Rumelhart & Ortony, 1977; Shank & Abelson, 1977; Spiro, 1980). Schemata are defined as "packets of integrated information on various topics" (Hunt, 1993, p. 530). Throughout the 1970s and 1980s, cognitive psychologists were interested in describing the nature of these packets of information. Spiro (1980) demonstrated the constructive and complex nature of schemata and highlighted contextual factors—including tasks, texts, and situational contexts—that influenced how knowledge is organized in memory.

Recently, cognitive researchers have come to view knowledge and schemata as multidimensional (Jetton, Rupley, & Willson, 1995). For example, researchers have differentiated novice and experts' knowledge structures in subject-matter domains (Chase & Simon, 1973; Chi, Glaser, & Rees, 1982;

Larkin, McDermott, Simon, & Simon, 1981; Voss, Greene, Post, & Penner, 1983). Researchers have examined discourse knowledge—knowledge about language and how it works (McCutchen, 1986). Another aspect of knowledge that has been extensively studied is strategic knowledge—knowledge about procedures for accomplishing a goal or task (Alexander & Judy, 1988; J. R. Anderson, 1983a; Prawat, 1989).

Until recently, questions about the nature of knowledge and its representation have received far more theoretical and research attention than have questions about how individuals acquire knowledge. Piaget distinguished himself as a notable exception to his contemporaries in that he spent his life studying knowledge acquisition. He described two processes involved in acquisition. He used the term *assimilation* for the addition of information to existing knowledge structures and *accommodation* for the modification or change of existing knowledge structures (Piaget, 1985). More recently, these views of knowledge acquisition are well captured by the perspective of *cognitive constructivism* (Cobb, 1994). Constructivism places prime importance on the individual's active role in the knowledge acquisition process.

Researchers after Piaget fine-tuned the constructs of assimilation and accommodation. Schema theorists used the term *accretion* for the assimilation of new factual information that fits into existing knowledge structures (Rumelhart & Norman, 1981). Cognitive psychologists described various mechanisms of knowledge acquisition, such as addition, deletion, discrimination, and generalization (Chi, 1992), that result in assimilation or "weak restructuring" (Vosniadou &

Brewer, 1987). For example, students who attend a biology lecture may readily assimilate new knowledge about plant reproduction into their existing knowledge base about plants.

By contrast, the change process, or accommodation, has been a much more thorny issue for researchers interested in knowledge acquisition. Suppose those same students who attended the biology lecture on plant reproduction attended another session on human reproduction. This time, students may not easily assimilate new information about how human beings reproduce. Students may have their own ideas about human reproduction. They may not be willing to hear the instructor's ideas, or they may listen to them but reject them (Chinn & Brewer, 1993). If students do make radical shifts in their thinking, then accommodation would be said to have taken place.

Vosniadou and Brewer (1987) described the accommodation process as "radical restructuring" or "change in knowledge that involves the creation of new structures [which] are constructed either to reinterpret old information or to account for new information" (p. 52). Chi (1992) referred to such knowledge reorganization as "radical conceptual change," and Thagard (1992) used the term "conceptual revolution" to describe how one conceptual system can replace another. Regardless of the terms used, radical changes in one's thinking about any topic are usually difficult to attain.

Despite differences among theorists in their description of the accommodation process, there is one issue on which change theorists appear to agree. That is, we still do not know enough about the mechanisms that produce knowledge change (Siegler, 1996). Smith, di Sessa, and Roschelle (1993) argued that an adequate theory of learning must not only describe knowledge, but also provide richer descriptions of how knowledge is transformed. Chi (1992) argued that too little is known about the conditions of knowledge representations that may lead to change, such as how learners come to recognize that new information does not fit with their existing conceptions.

Under what conditions is knowledge change likely or unlikely to occur? What are potential sources of influences in bringing about change? Is change likely to be temporary or relatively long lasting? Weak or strong? What can educators do to facilitate the change process? These questions are of central interest to educational researchers.

To explore these issues, we turn to models in cognitive psychology, science education, and social psychology for new insights into the change process. First, we examine recent work on conceptual change within a cognitive psychological framework. How concepts come to be represented in memory and change in children's conceptual knowledge have been central issues of concern in cognitive psychology since its inception (for examples of classic works in these areas, see Markman, 1979, and Rosch & Mervis, 1978). Current cognitive psychological researchers investigating change in concept representation have elaborated on early Piagetian and schema-theoretic notions of accommodation. These re-

searchers have attempted to more fully describe the process whereby conceptual knowledge comes to be reorganized (see Carey, 1992; Chi, 1992; Thagard, 1992).

Second, we turn to work in science education. Science-education researchers have been more influenced by the history and philosophy of science and have described how knowledge acquisition and restructuring in scientific communities is similar to knowledge acquisition and restructuring in learners (Carey, 1985; Driver & Easley, 1978; Osborne & Wittrock, 1983; Posner, Strike, Hewson, & Gertzog, 1982). These researchers likened the paradigm shifts made by the scientific community (Kuhn, 1970) to conceptual changes made by students as they developed new frameworks through constructing their understanding of various scientific phenomena. Despite critiques that the process of knowledge restructuring in students differs fundamentally from that of the scientific community (Pintrich, Marx, & Boyle, 1993), the Conceptual Change Model (CCM) still provides many useful insights into the nature of the change process.

We also turn to the field of social psychology. Social psychologists have had a long-standing interest in change and have generated an extensive body of research on how beliefs and attitudes can be changed. Researchers have studied factors related to learners, presenters, and specific contexts that make individuals more or less likely to consider and learn new information. Petty and Cacioppo's (1986) Elaboration Likelihood Model (ELM) described the conditions necessary for change. Together, these perspectives and the research base provide a framework from which to reconceptualize our view of the change process.

We begin by defining key concepts in the cognitive and social psychological literature as a context for describing current models of change. Next, we review change models with particular attention to their similarities and differences. Then we present our reconceptualization of the change process. Finally, we present a discussion of unaddressed research issues related to change models within a cognitive constructivist framework.

Our purpose in generating a new model of change is to provide researchers interested in the change process with new insights and perspectives from three fields of research. Our model was not developed to resolve a specific empirical issue, but rather to integrate current theory and research from different disciplinary domains. We believe such an integration will point to possible new and fruitful areas for research for those interested in learning as change.

COGNITIVE CONSTRUCTIVIST PERSPECTIVES ON CHANGE

Cognitive psychologists have traditionally focused more attention on describing the structure and function of knowledge than on change and growth in knowledge (e.g., Anderson & Pearson, 1984; Rumelhart, 1980; Spiro, 1980). However,

change (although not labeled as such) has been a central topic of study in cognition if one considers that in general, cognitive psychologists view *learning* as synonymous with *change*.

The conceptual linkage of change and learning within cognitive psychology probably has a number of historical roots (see Figure 1). Behavioral psychologists equated learning with a change in behavior. Piaget described the processes and mechanisms whereby children come to change their ways of thinking and their views of the world. Beginning in the 1960s, cognitive information processing led theorists to posit mechanisms for change in the structure of knowledge primarily through the acquisition of new schemata and changes in existing schemata (Anderson & Pearson, 1984; Rumelhart & Norman, 1981).

Cognitive Psychological Models of Change

Cognitive psychologists have always been interested in concepts, how they come to be represented in memory, how their meaning is constructed, and how such meanings change. Concepts are central constructs in cognition because they constitute "units of mental representation" (Carey, 1992).

Cognitive psychologists have used the term *conceptual change* to mean both the process and the outcome of change. That is, conceptual change can refer both to the process by which a concept takes on new meaning and to the resulting change in meaning (Chi, 1992). In either instance, the site of change is the mental representation of conceptual knowledge.

There is considerable variability among theoretical treatises on the cognitive process of conceptual change (e.g., Carey, 1992; Carey & Spelke, 1994; Chi, 1992; Siegler, 1996; Smith et al., 1993; Thagard, 1992). Researchers have identified various degrees of change (Thagard, 1992). Some reserve the term *radical conceptual change* for only the most extreme form of restructuring (Chi, 1992). Researchers also differ as to whether the process of conceptual change should be characterized as *revolutionary* or *evolutionary*.

Change theorists, such as Carey (1992), Chi (1992), and Thagard (1992), acknowledged that change exists on a continuum from weak revision to radical restructuring. These researchers characterized radical conceptual change as dramatic reorganizations of knowledge structures. Theorists who hold the evolving view depict conceptual change as a gradual process of modification of existing knowledge structures (Siegler, 1996; Smith et al., 1993).
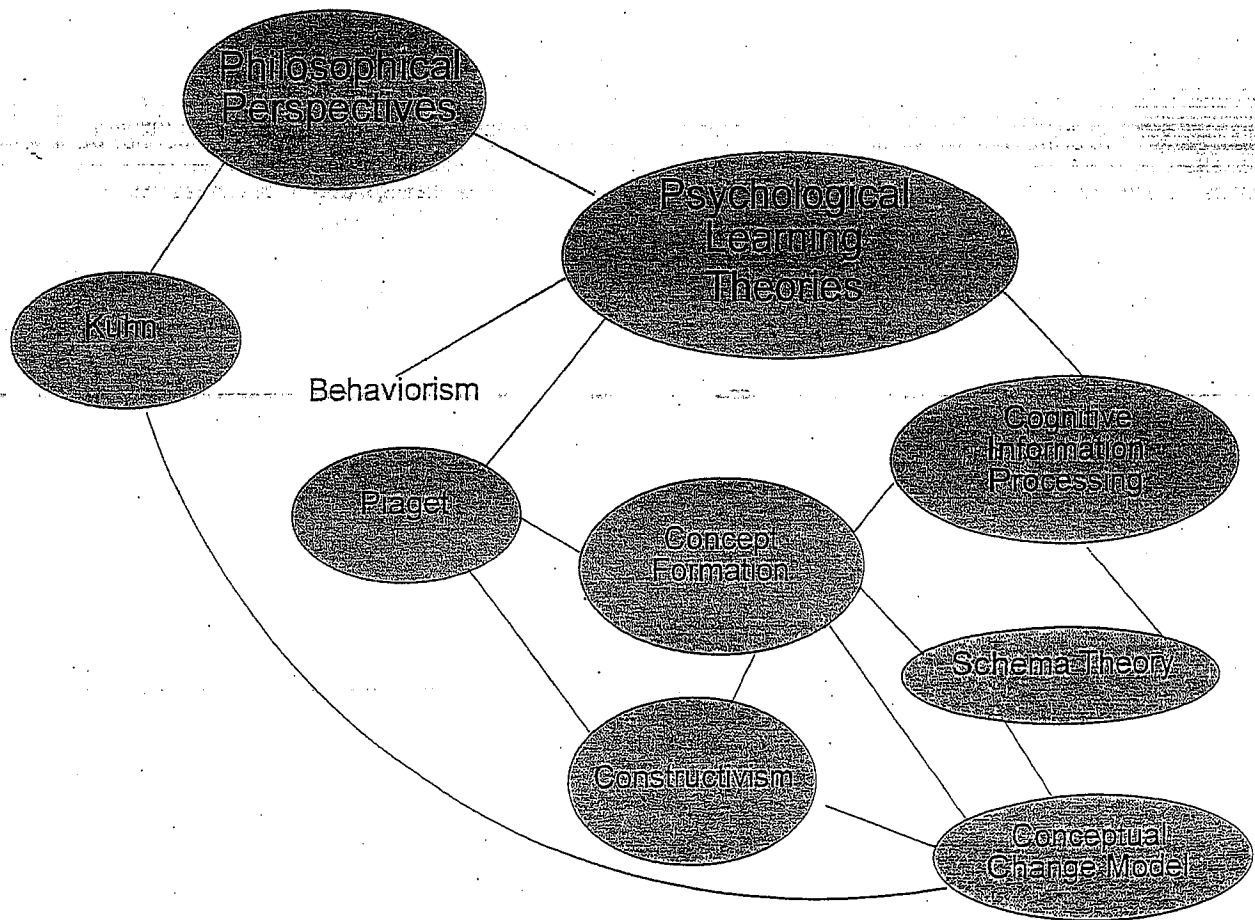

FIGURE 1   Routes of change.

Chi (1992), Carey (1992; Carey & Spelke, 1994), and Thagard (1992) have posited conceptual shifts as radical restructuring. Such changes are profound and fundamental in that new conceptions replace old. According to this perspective, the new concept is so distinct from the old that the original concept plays no role in further thinking within the domain. Thus, the change is revolutionary and results in "the emergence of new principles, incommensurable with the old, which carve the world at different joints" (Carey & Spelke, 1994, p. 179).

Such fundamental change in the mental representations of concepts cannot occur through assimilation processes of addition, deletion, discrimination, and generalization. Rather, conceptual categories must be reconfigured through a process Chi (1992) described as *categorical reassignment*. According to Chi, radical conceptual change occurs when concepts are reassigned to a new category that is fundamentally different in kind. For categorical reassignment to occur, a learner must learn about the new category's properties and about concepts that exist within the new category. This can occur through traditional assimilation mechanisms. Then, the learner must reassign a concept to the new category. An example of such a conceptual shift would be a physics student who recategorizes heat as an process rather than a property of a material substance.

Thagard (1992) described radical conceptual change as *branch jumping* or *tree switching*. If one considers concepts to be organized hierarchically, then a radical conceptual change would involve moving a concept from one tree to another. Such a change in the hierarchical organization of concepts in memory is analogous to Darwin's repositioning of humans under the category of animal when previously humans were considered to be a different kind of creature.

Not unlike science educators interested in change, Chi (1992) and Thagard (1992) drew analogies between the scientific revolutions described by Kuhn (1970) and the knowledge change process in learners. That is, in science, information accumulates until anomalies are discovered that cannot be accounted for with existing theories. A new theory receives acceptance by scientists if it provides a more coherent explanation of phenomena. So too, individuals encounter new information, notice discrepancies between their existing knowledge and new ideas, and reorganize their knowledge structures to more coherently account for the new information. This conceptualization of the change process from cognitive psychology is similar to conceptions of knowledge change in the field of science education.

In contrast to the view of knowledge change as revolutionary, Smith et al. (1993) and Siegler (1996) described the change process as evolutionary. These theorists described how knowledge is gradually transformed from one state to another. According to this view, conceptual change occurs by transforming and refining prior knowledge into more and more sophisticated forms. Substantial change does not occur quickly, and relatively stable intermediate states of understanding exist for some time before new concepts are fully formed.

Smith et al. (1993) argued that their position is based on a fundamental tenant of constructivism; that is, prior knowledge plays a significant role in learning. According to this view, conceptual replacement is "neither plausible nor always desirable" (p. 153). Rather than wholesale replacement of one concept with another, or radical reorganization of knowledge, existing knowledge forms the basis for new conceptions and remains important in the new understanding.

Siegler (1996) borrowed a metaphor from evolutionary biology to describe incremental change in the conceptual development of children. He argued that children think about a phenomena in a variety of ways, rather than having a unitary understanding. In his view, change results as children choose adaptively among these various ideas. In other words, a particular conception becomes the more prevalent one when it proves to be more successful over time. According to Siegler, thinking changes continuously as it becomes more adaptive.

A View of Conceptual Change From Science Education

During the 1980s, science educators adopted a cognitive constructivist view of knowledge consistent with cognitive psychology and Piagetian theory to explain how children acquire knowledge about scientific phenomena (White & Tisher, 1986). According to this constructivist perspective, knowledge is not transmitted from teacher to learner but constructed by individuals through the processes of assimilation and accommodation. Because the accommodation process described change in existing knowledge structures, accommodation was viewed by science educators as the central mechanism for conceptual change.

Posner et al. (1982) developed the CCM to explain (a) why so many students held on to their existing conceptions in spite of instruction, and (b) what conditions were necessary for change to take place. As researchers developed the CCM, they drew from the literature on the history and philosophy of science as well as cognitive theory and research. Science educators' focus has been on what they call bodies of organized knowledge—such as Newtonian physics, the earth and gravity, and scientific explanations of photosynthesis, light, and heat (West & Pines, 1985). These coherent bodies of knowledge consist of a set of concepts and interrelated ideas that take time and effort to learn and are often inconsistent with intuitive experiences and everyday beliefs about the world. Research on conceptual change learning has been conducted on students of many different ages—from young children to adults (for a review, see West & Pines, 1985).

To understand mechanisms for change, science educators, like cognitive psychologists interested in change, drew parallels between the accommodation process that individuals

experience and the process scientists undergo as they do normal science (Anderson & Smith, 1987). Philosophers and historians of science, such as Toulmin (1972) and Kuhn (1970), argued that "scientific revolutions," "paradigm shifts" (Kuhn, 1970), or "changes in research programs" (Lakatos, 1970) result from the accommodation process made by the scientific community. Toulmin (1972) referred to this accommodation process, whether occurring in individuals or in science, as "conceptual change."

Posner et al. (1982) described the similarity between the conceptual change process in scientific communities and the accommodation process in learners. For example, most young children, like many early European scientists, believe that the earth is flat. Children's ideas come from numerous sensory experiences with a flat horizon. Like the early European scientists, children eventually encounter new information suggesting that the earth is a sphere. At some point, children reject their belief that the earth is flat and replace it with a new conceptualization of the earth as a sphere (Nussbaum, 1985). The process whereby the spherical notion of the earth comes to replace children's flat earth views is called conceptual change.

Posner et al. (1982) identified four critical variables in the conceptual change process (see Figure 2). First, they argued that when scientists and students' knowledge structures are crystallized, coherent, and firmly entrenched, they are highly resistant to radical change. Of course, not all conceptions are so resolute. Knowledge of scientific phenomena is often characteristically entrenched in the scientist because it is based on a coherent body of knowledge and in the individual because of personal experience with scientific phenomena (the sun appears to travel across the sky). Radical change of such entrenched ideas requires considerable cognitive effort, and individuals are unlikely to engage in such effort unless they believe that a less radical change will not work. According to the conceptual change model, individuals must become dissatisfied with their existing conceptions as explanations for data. Second, individuals must find that the new conceptions are intelligible and make sense. That is, they must understand the new conceptions if they are to adopt them. Third, scientists and students must perceive the new conceptions to be plausible ones. Thus, the new conceptions must not only make sense and be comprehensible, but they must be believable. To be believable, the new conceptions must fit into existing and related ideas. Last, scientists and students must find that the new conceptions are fruitful, or open to "new areas of inquiry" (p. 214). Thus, the new conceptions must lead to new insights and further hypotheses.

Science educators have used conceptual change as the theoretical framework for explaining a multitude of studies showing how individuals fail to develop conceptual understandings about numerous scientific phenomena (e.g., Carey, 1985; Chinn & Brewer, 1993; West & Pines, 1985). Further, the model has been used to propose instructional interventions that have proven promising in helping students change their preconceptions or naive theories about scientific phenomena. We will not review these studies, as they have been reviewed extensively elsewhere (e.g., Guzzetti, Snyder, Glass, & Gamas, 1993; Nickerson, 1985; Nussbaum, 1985; West & Pines, 1985).

SOCIAL PSYCHOLOGICAL PERSPECTIVES ON CHANGE

Although cognitive psychologists have only recently begun to examine the change process, social psychologists have had a long-standing interest in change. Two constructs of traditional interest to social psychologists are beliefs and attitudes. Beliefs are characterized as the thoughts that people have about attitude objects. Beliefs are the building blocks of attitudes (Eagly & Chaiken, 1993) in that an attitude consists of an interrelated and interconnected set of beliefs that have a positive or negative valence for an individual. Thus, a person's attitude toward gun control exists along a positive-to-negative continuum. It consists of a related set of beliefs about guns—who uses them and for what purpose, when and where they can and should be used—as well as beliefs about gun owners, the National Rifle Association, and a host of gun-related issues. It is interesting to note that even if individuals have a neutral position about gun control, it would still be considered an attitude by social psychologists (Eagly & Chaiken, 1993).

Beliefs and attitudes can be propositional in nature, or they can be represented by mental images or a set of experiences and behaviors. For example, when asked about one's beliefs about guns, an individual may think about an image of a militia-dressed man shooting at a target, a gang member in a drive-by shooting, or a hunting trip in Montana. Such thoughts may be associated with negative or positive evaluations about guns. Eagly and Chaiken (1993) argued that "these images no doubt carry evaluative meaning, just as propositional beliefs do" (p. 104).

To provide a theoretical framework to understand beliefs better, social psychologists adopted some of the theory and methodology of cognitive psychology (Fiske & Taylor, 1991). In particular, the construct of *schema* (J. Anderson, 1983a, 1983b; R. C. Anderson & Pearson, 1984) was borrowed from cognitive psychology to explain how beliefs are stored and organized in memory. Social psychologists conceptualized beliefs as memory representations consisting of networks of associations or schemata (Tesser & Shaffer, 1990), just as cognitive psychologists conceptualized knowledge. Like knowledge schemata, beliefs can be conceptualized as simple or complex. For example, a less complex belief schema about a presidential candidate may contain beliefs about the candidate's position on a single issue, such as the role of the federal government. A more complex belief schema about that candidate, however, may entail a richer and more detailed understanding about who the candidate is, what
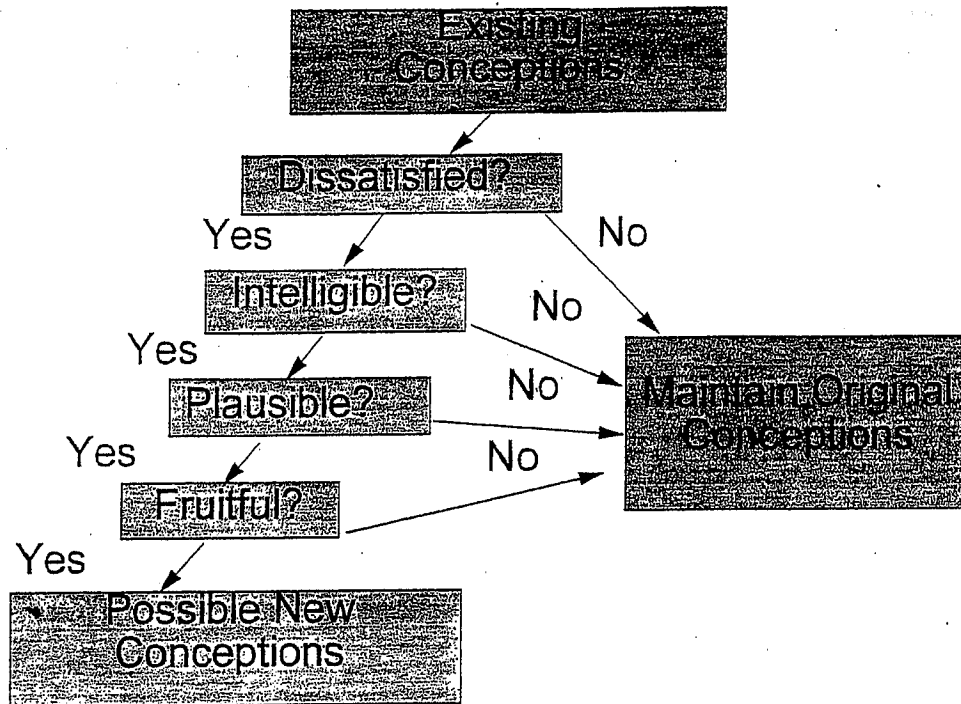
FIGURE 2   Posner et al.'s (1982) Conceptual Change Model.

the candidate's personal and professional background is, how the candidate voted on important state and federal issues in the past, and knowledge about who is supporting and opposing the candidate and why.

This characterization of beliefs corresponds with a cognitive view of knowledge representation. According to a schema-theoretic perspective on knowledge, an activist for a particular presidential candidate would have a rich schema with many knowledge nodes related to the candidate and many connections to other related knowledge nodes. A high school student studying civics, on the other hand, may have fewer knowledge nodes about the candidate and fewer connections to other related concepts.

As far as we can tell, there are few differences in the way social psychologists and cognitive psychologists use and apply the term *schemata*. It does appear, however, that social psychologists include a full range of affective factors in their discussions about schemata. Although Bartlett (1932) and some later theorists may have originally conceptualized schemata in the same way (e.g., Spiro, 1980), the focus of cognitive psychologists on the information-processing metaphor likely resulted in the elimination of such affective components in later discussions about schemata (Fiske & Taylor, 1991).

In sum, social psychologists have adopted some of the theory and methodology of cognitive psychology to explain how attitudes and beliefs are represented in memory. Social psychologists view beliefs similar to the way cognitive psychologists view knowledge—as schemata with related, associative networks. These similarities between social and cognitive psychology lead us to contend that social psychology

research may well prove useful to educational researchers traditionally operating within a cognitive framework.

As part of their interest in basic cognitive processes, one branch of social psychology—attitude formation and change—has primarily focused on how people acquire their views, how likely they are to change them, and under what conditions they do so. The social psychology framework for understanding the change process has been conceptualized through many different models and hundreds of studies. For our purposes, we have chosen to look at information-processing models of attitude and belief change, because these models were formed using theory and methods similar to those in cognitive psychology. The similarity of these models to the cognitive constructivist orientation make them particularly useful for our view of knowledge restructuring.

Models of attitude and belief change in social psychology come out of research on persuasion. These models can be categorized into two types: combinatorial and process models (see Figure 3). Combinatorial models consist of highly specific quantitative descriptions of how individuals combine particular pieces of information to form new beliefs and change old ones (e.g., McGuire 1960; Wyer, 1970). These models place numerical weights on the components of change that reflect their relative contribution to the change process. Mathematical computations are then calculated using equations that contain the weighted components. Eagly and Chaiken (1993) argued that combinatorial models are useful for describing attitude structure. Further, they adequately explain how individuals integrate new information with existing information once they have accepted it. However,
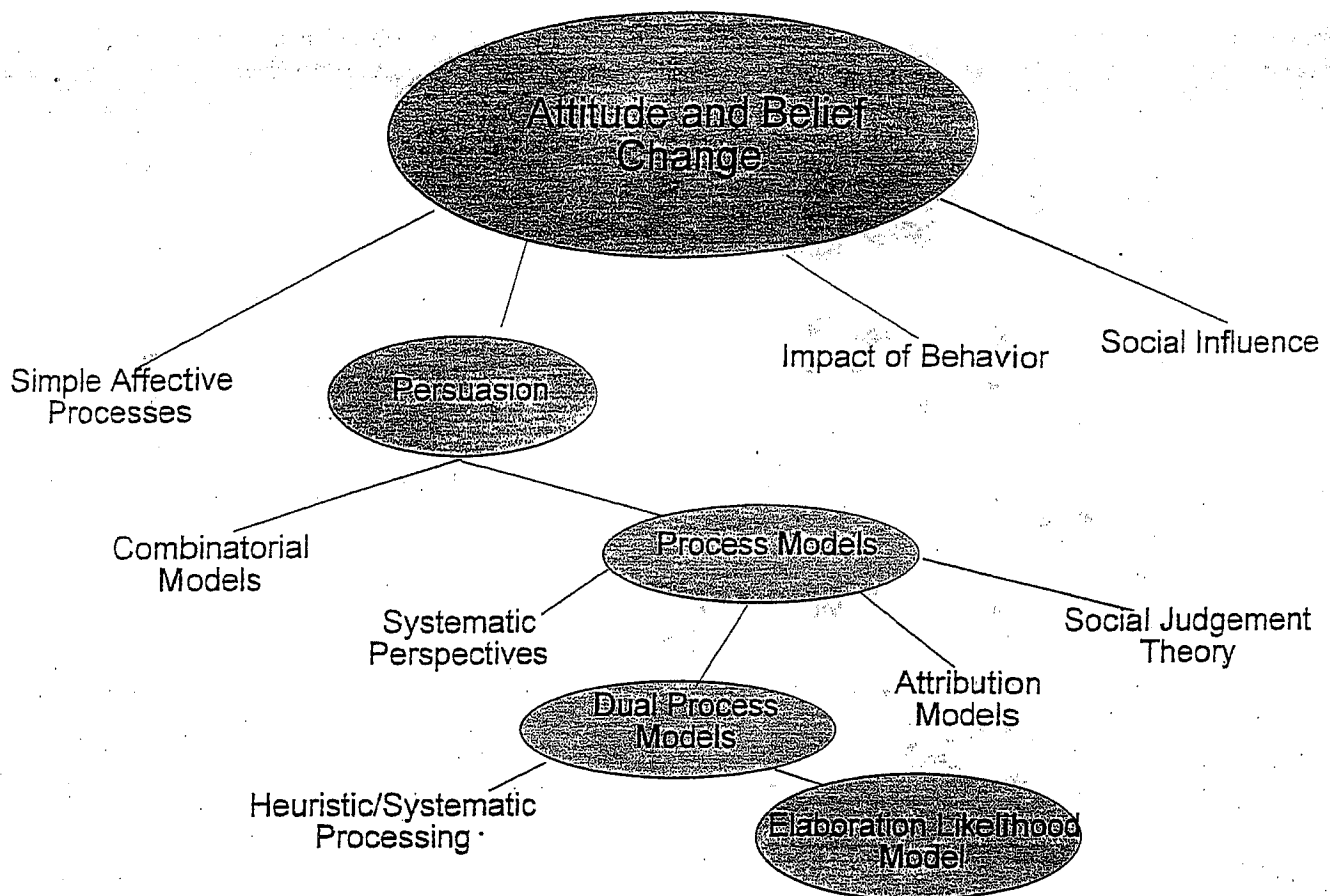
FIGURE 3 Models of attitude and belief change.

combinatorial models do not adequately explain how individuals come to accept new information in the first place, and therefore, they do not elaborate the cognitive processes underlying attitude change.

Process models, on the other hand, have a decidedly cognitive orientation in that they attempt to describe and explain cognitive mechanisms for attitude and belief change (Eagly & Chaiken, 1993). In contrast to the quantitative orientation of combinatorial models, process models are qualitative descriptions of persuasion that show how individuals can come to accept new information. There are several types of process models. Dual process models (e.g., Chaiken, 1980; Petty & Cacioppo, 1986) represent a synthesis of the findings from various process models. Dual process models provide a cognitive processing account of how individuals who hold a particular set of beliefs can change those beliefs based on exposure to a complex message.

Social psychology researchers have examined the many factors involved in how individuals can be persuaded to change their beliefs. After a flurry of highly controlled laboratory studies from the 1930s through the 1960s, interest in attitude and belief change diminished because "there was so little agreement concerning if, when, and how [different variables] affected attitude change" (Petty & Cacioppo, 1986,

p. 125). The lack of agreement stemmed from the diversity of findings and conflicting accounts of belief change in the literature.

During the 1970s and 1980s, social psychologists began to examine these contradictory empirical findings. Several models of attitude change were considered. Some models assumed that thoughtful consideration of message content was necessary for attitude change (Fiske & Tayor, 1991). Other models assumed that individuals did not always need to engage in thoughtful evaluation for attitude change to occur. A new set of models, called dual process models, were developed to account for both of these possibilities. Dual process models postulated two routes to attitude change. One route involved an individual's thoughtful consideration of issue-relevant information, and the other route involved an individual's quick and cursory judgment based on variables peripheral to the message content. Petty and Cacioppo's (1986) ELM is one such dual process model (see Figure 4).

Elaboration Likelihood Model

The ELM specifies the processes underlying belief change, known in the social psychology literature as persuasion (see
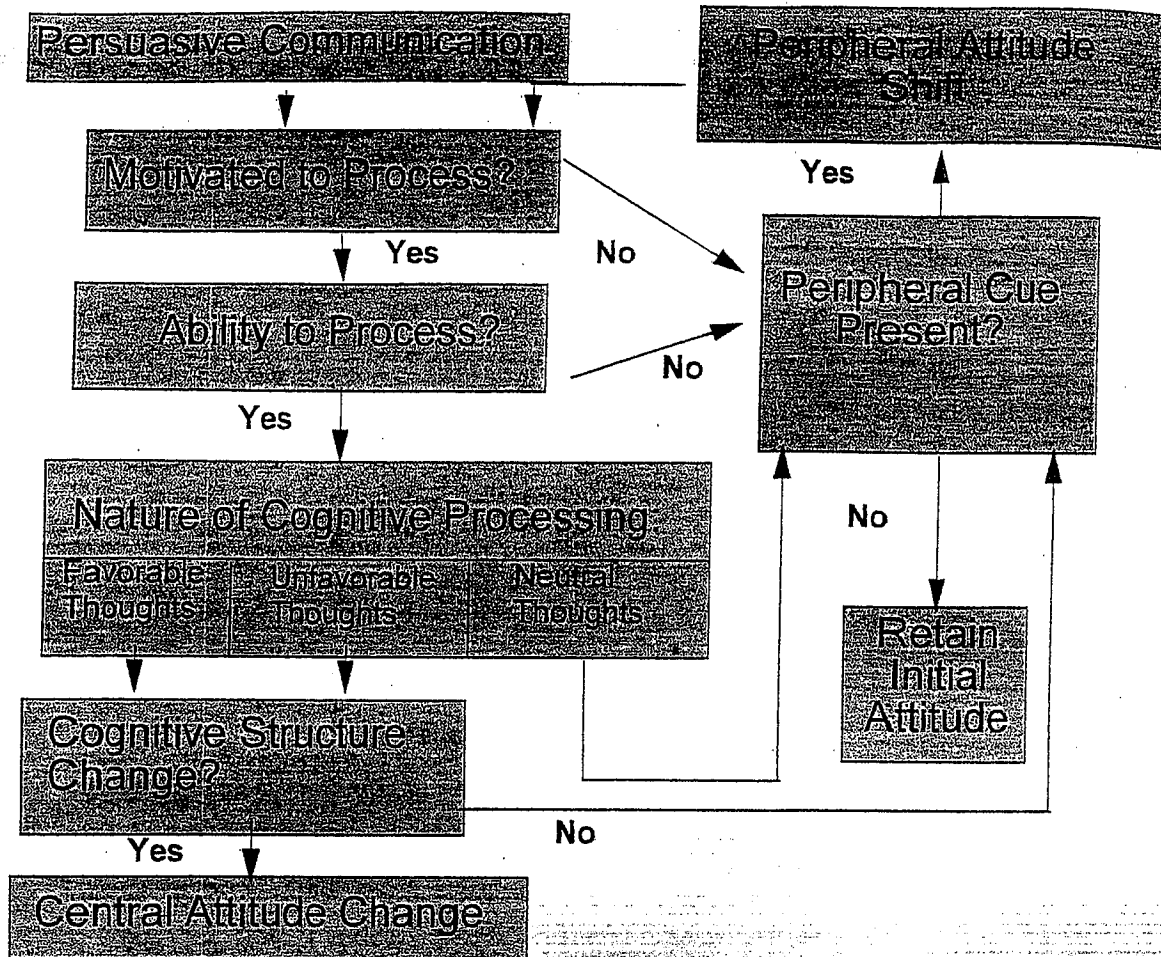
FIGURE 4   Petty and Cacioppo's Elaboration Likelihood Model. From "The Elaboration Likelihood Model of Persuasion," by R. E Petty and J. T. Cacioppo, in *Advances in Experimental Social Psychology* (Vol. 19), L. Berkowitz (Ed.), 1986, New York: Academic. Adapted with permission.

also the heuristic-systematic model, Chaiken, 1987; Chaiken, Liberman, & Eagly, 1989). The key construct in the model is that of elaboration. Elaboration is the extent to which individuals think about "issue-relevant arguments contained in a message" (Petty & Cacioppo, 1986, p. 128). Elaboration exists on a continuum from high to low. High elaboration occurs when individuals engage in issue-relevant thinking; low elaboration occurs when individuals do not.

The two key factors contributing to high elaboration are motivation and ability. Petty and Cacioppo (1986) use *motivation* as an overarching category for several constructs. For one, personally relevant topics, or topics in which individuals have a stake in the outcome, will promote motivation to process a message (for a review, see Chaiken & Stangor, 1987). Personally relevant topics are intrinsically important because they have significance for individuals' personal lives (Sherif & Hovland, 1961). For example, Petty, Ostrom, and Brock (1981) manipulated the personal relevance of a policy change that would directly affect university students. They told undergraduates that the proposed change would take place in 1 year or in 10 years. Students who were told that the

change would take place in 1 year were more likely to be motivated to process information about the policy change. In a meta-analysis of "involvement effects" such as personal relevance, Johnson and Eagly (1989) showed that individuals who were more involved because they cared about the outcome of a debated issue were more persuaded by strong arguments. In general, social psychologists posit that personally relevant topics stimulate thought, which, in turn, can lead to high elaboration.

Petty and Cacioppo (1986) noted two caveats, however, regarding the influence of personal relevance. First, a topic may be so intensely tied into individuals' values that they are not willing to process the message at all (Greenwald, 1980; 1982). For example, individuals who espouse a creationist view of the origins of humans may be unwilling to process a message related to evolutionary theory. The second caveat involves message repetition. Sometimes individuals feel that they have heard a message and its arguments and counterarguments so many times that they are unwilling to listen to and process the new ideas in the message. For example, smokers may be unwilling to process new information about added nicotine in cigarettes because they have heard so many argu-

ments against smoking in the past (for the effect of message repetition, see Caccioppo & Petty, 1979, 1985).

Another construct related to individuals' motivation to process a message is a personality trait that social psychologists describe as a "need for cognition" (Cacioppo & Petty, 1982). Social psychologists describe this individual difference as a "need to structure relevant situations in meaningful, integrated ways" or a need to "understand and make reasonable the experiential world" (Cohen, Stotland, & Wolfe, 1955, p. 291). Some individuals have a high need for cognition, where they enjoy the effortful engagement of arguments, the evaluation of ideas, and the analysis of problems and their solutions. These individuals by their very nature are more likely to engage in high elaboration. Other individuals will, by their very nature, not be motivated to engage in effortful, thoughtful evaluation and analysis of ideas. These individuals will be more likely to process the information heuristically, that is, with low elaboration (Chaiken, 1987).

Finally, high interest in a topic can promote motivation to process a message. This is not unlike the finding in educational research that situational interest (interest stemming from environmental conditions) can promote text comprehension, learning, and achievement (Alexander, Kulikowich, & Schulze, 1994; Shraw, Bruning, & Svoboda, 1995).

The other key factor contributing to high elaboration is ability. For a message to be processed, it must be comprehensible and not too difficult conceptually. Further, individuals must have sufficient background knowledge to make sense of the message. Research in this area has shown that the more comprehensible the message, the more the recipients of the message can think about what was said. Then, if the arguments are good, recipients can agree with the presenter (Ratneshwar & Chaiken, 1991; Wood & Eagly, 1981). In contrast, an incomprehensible argument can elicit frustration and negative feelings. These negative feelings can become associated with the message and the presenter—in effect discouraging high elaboration (Fiske & Taylor, 1991).

Research has also shown that message effects interact with the degree to which the listener has a stake in the outcome to produce different levels of elaboration. For example, if the message is difficult, the extent to which someone will try to process the message will depend on their involvement. Fiske and Tayor (1991) explained how involvement affects the likelihood that students will process a difficult statistics lecture with high elaboration. A student who has already given up on the course will likely daydream and not process the message. A student who will be a teaching assistant for the course next semester will make the effort to understand the lecture, despite its difficulty. Students moderately involved are the ones most likely to be affected by the difficulty of the lecture. The added difficulty may induce greater processing of the information and thus high elaboration.

Two routes to persuasion. Through positing two routes to persuasion—central and peripheral—social psychologists resolved the apparently contradictory findings in the literature on attitude change. Research participants in social psychological studies changed their beliefs either through the thoughtful weighing of ideas or through attention to a peripheral cue. Under conditions of high elaboration, individuals engage in thoughtful and effortful processing, which may lead to relatively strong and long-lasting change in beliefs. Petty and Cacioppo (1980) called this the *central route to persuasion.* However, the model also predicts that a weak change may occur. Under conditions of low elaboration, individuals engage in quick and superficial evaluations that may lead to a change in beliefs that is weak and can, over time, dissipate. Petty and Cacioppo called this weak change the *peripheral route to persuasion.*

The central route to persuasion describes a process leading to relatively strong and long-lasting change in attitudes or beliefs, not unlike the process of conceptual change. This route begins with a message that is intended to persuade individuals to adopt a particular attitude or belief. For example, a health teacher presents information regarding the risk of AIDS to high school seniors. If students are motivated and able to process the information, then the ELM predicts they can consider the issues. This involves effortful, thoughtful processing of the information students find relevant. This type of evaluation and analysis of arguments is analogous to "deep processing of information" resulting in the formation of memory representations or learning (Craik & Lockhart, 1972).

At this point, the quality of the argument is a key factor in whether or not individuals will be persuaded to change their minds. If students engage in deep processing of a message on AIDS, a strong argument will be needed to promote change.

The ELM, like the CCM, suggests that the process leading to relatively strong and permanent belief change is a difficult one. Individuals may not be motivated to process the message because they may not be interested in the topic. Individuals may not see the personal relevance of the issue, or they may not have a stake in the outcome of the issue.

Even if they are motivated, individuals may not have the ability to process the information. Individuals may be distracted; they may not have the background knowledge; or the message may be incomprehensible. Further, because processing the message takes time, cognitive effort, and energy, individuals may not be willing to process the information at all.

One of the unique features of the ELM is that it posits another set of factors that can lead to the peripheral route to persuasion. For example, students listening to a lecture on AIDS may not be motivated or committed to engage in high elaboration of the issues and arguments. For these individuals, the quality or strength of the arguments does not matter (Eagly & Chaiken, 1993). However, these same students may be persuaded by an attractive, credible, or trustworthy source; by a pleasant context (Petty & Cacioppo, 1980); or by a simple

message that they understand easily (Eagly & Chaiken, 1993). These students are not persuaded by the strength of the arguments, but rather by the peripheral cue itself. Under these circumstances, the resulting beliefs are less strong than centrally processed ones. In time, individuals are likely to return to their previously held beliefs (Petty & Cacioppo, 1986).

Although the attention to peripheral cues with low elaboration can lead to weak belief change, peripheral cues may still be useful in promoting change. The ELM predicts that peripheral cues can serve as an impetus toward high elaboration, which may lead to central change and strong beliefs (Petty & Cacioppo, 1986). For example, consider unmotivated students in a health class who hear a lecture from someone they admire who is HIV positive. The speaker may act as a peripheral cue that then leads to deep and thoughtful processing of information about HIV safety precautions. The thoughtful processing of information could then lead students toward change in their thinking about taking precautions against infection.

In sum, the ELM predicts change in one of two ways—through high or low elaboration. A quick, heuristic evaluation of a message that occurs because of a peripheral cue—an attractive, credible, or trustworthy source—can lead to change. But the change is weak and may not be long-lasting. The only way strong and relatively long-lasting change can occur, and the hallmark of the model, is through high elaboration of the issues and arguments involved in a message.

A RECONCEPTUALIZATION OF CHANGE: THE COGNITIVE RECONSTRUCTION OF KNOWLEDGE MODEL

Because of the similarities among the theoretical assumptions of the various change models, cognitive psychology, science education and social psychological research can be used to reconceptualize change within a cognitive constructivist framework. We present here our reconceptualization of change. We call our reconceptualization the Cognitive Reconstruction of Knowledge Model (CRKM). Our model takes into account research within a cognitive psychological perspective, science education research, and social psychology.

Our reconceptualization of the change process begins by examining the interaction of learner and message characteristics (see Figure 5). The first learner characteristic of importance in the change process is an individual's *existing conception* regarding an idea, topic, event, or phenomenon. Social psychologists have often ignored existing conceptions or prior knowledge in their research on persuasion (P. White, personal communication, 1996). Sometimes these researchers selected subjects who self-reported that they held particular stances on issues, and in so doing, provided some control of prior knowledge in their research. However, for the most part,

individuals' existing conceptions were not assessed before the persuasion intervention (Eagly & Chaiken, 1993).

Research in science education (West & Pines, 1985), as well as in reading research using a schema-theoretic approach (Anderson & Pearson, 1984), and more recently, in constructivist theories of knowledge (e.g., Steffe & Gale, 1995) has shown that understanding students' existing conceptions is critical to understanding the knowledge reconstruction process. This research indicates that one's prior knowledge regarding an issue is not an all-or-none construct. Instead, individuals differ on how much prior knowledge they have and also on the quality of that knowledge. Sometimes prior knowledge can get in the way of processing new information (Guzzetti et al., 1993; Lipson, 1982). Prior knowledge also influences individuals' interpretation of the same events (Gaskins, 1996).

Therefore, we note three relevant qualities of a learner's existing conception that influence the likelihood of change: *strength, coherence,* and *commitment.* Strength refers to the richness of a learner's existing idea; that is, is it well formed and detailed or sparse and fragmented? Research suggests that the strength of an existing conception is a factor influencing the likelihood of change (Eagly & Chaiken, 1993). The stronger the idea, the less likely it is that change will occur.

Coherence refers to the conceptual coherence of the individual's existing knowledge. That is, does the existing conception provide a explanation of the phenomenon, idea, or event that fits together all the evidence, leaving no loose ends? Thagard (1992) argued that the likelihood of change is affected by the conceptual coherence of the existing conception. When existing ideas lack conceptual coherence, they are more susceptible to change.

Finally, individuals can be more or less committed to their existing conception, regardless of the idea's strength, coherence, or both. Individuals' commitment to their ideas can come from a variety of sources, such as sensory experience, social group membership, or cultural background. Sinatra and Dole (1998), in their work examining creationists' views of evolutionary biology, identified what they called a "need to believe." Individuals in their study reported that they could not accept the idea that humans were animals because they were committed to the conflicting notion that humans beings are a special creation. This need to believe cuts across individuals with high and low background knowledge in both creationism and evolution. Individuals who are very committed to their existing ideas are less likely to change those ideas. Thus, it is imperative that a model of knowledge change examine the strength, coherence, and commitment of an individual's existing conception to assess the likelihood of conceptual change.

Another critical, albeit interrelated, characteristic of learners is whether they are *motivated to process* the new information. Motivation has been identified indirectly in the CCM and more directly in Strike and Posner's reconceptualization of the CCM (Strike & Posner, 1992). Posner et al. (1982) used
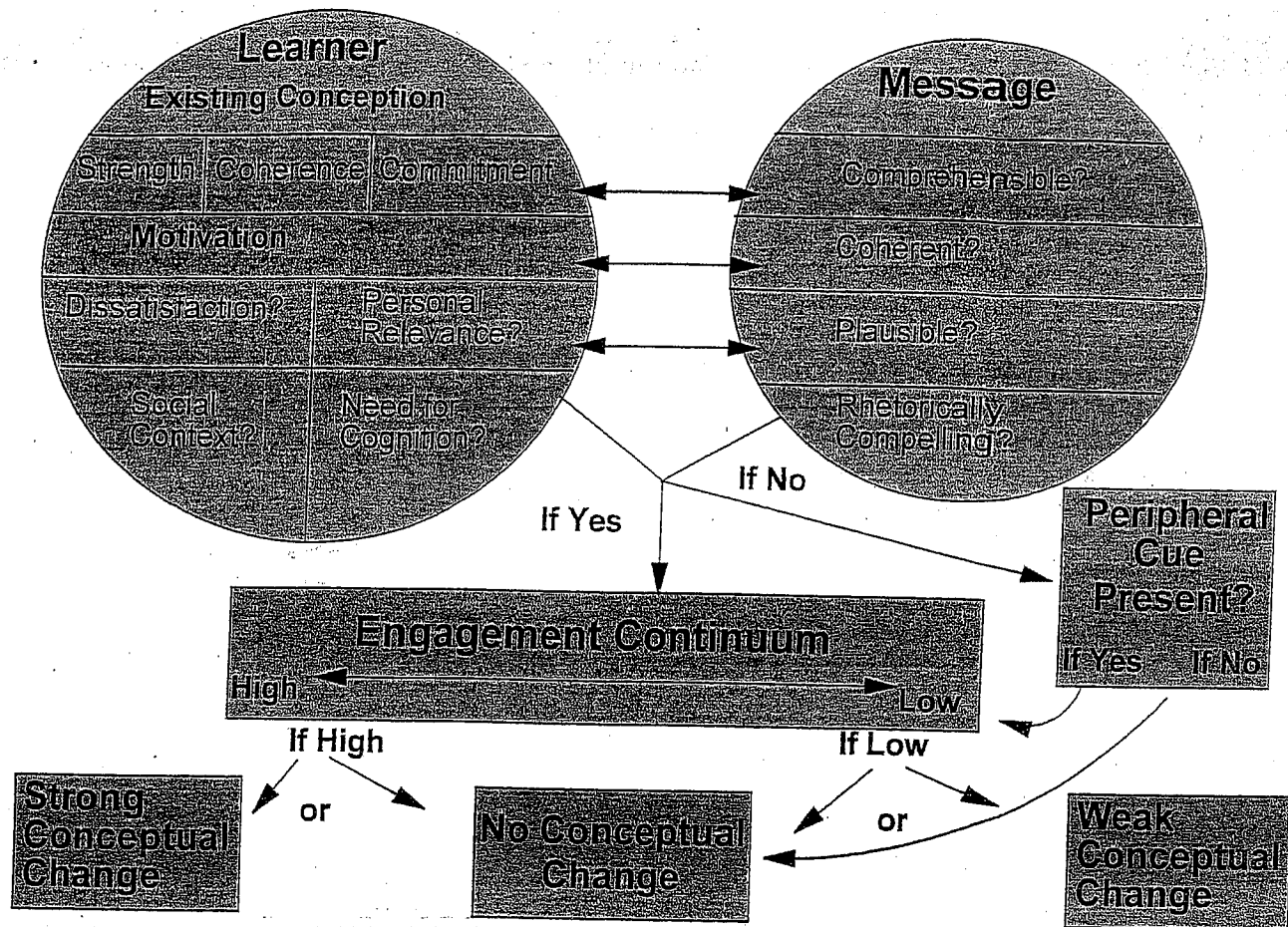
FIGURE 5. Cognitive reconstruction of knowledge.

the term *dissatisfaction* for describing what motivates individuals to change their ideas. They argued that individuals, whether scientists or students, must experience something like cognitive conflict or dissonance (West & Pines, 1985) to consider change. The conflict or dissatisfaction comes from seeing anomalies between their existing conceptions and new data (Chinn & Brewer, 1993). Cognitive conflict can also arise when individuals hold two views simultaneously that contradict one another (Head & Sutton, 1985).

In contrast to the CCM, our model posits *dissatisfaction* as just one of many reasons why individuals may be motivated to process new information. In fact, the CRKM includes four facets of motivation, of which dissatisfaction is one. Dissatisfaction may be the critical motivating element when scientific ideas conflict with intuitive ideas about how the world works. Intuitive ideas are formed directly from sensory experiences—like the sun appearing on the horizon—and are therefore particularly resistant to change.

However, it seems clear from the research in both cognitive and social psychology that at least in domains other than science, individuals can be motivated to change their minds without being dissatisfied with their existing ideas. For example, they may have a stake in the outcome (Chaiken & Stangor,

1987) or an interest in the topic (Alexander, Kulikowich, & Jetton, 1994; Hidi, 1990; Schiefele, 1991). They may be emotionally involved (Gaskins, 1996) or have high self-efficacy related to the topic or task at hand (Dole, Brown, & Trathen, 1996; Parajes, 1997). Thus, we consider these elements as possible alternative sources of motivation to process new and conflicting information. We use the term *personal relevance* from the ELM to capture the motivation factor stemming from these personal factors.

The third factor we subsume under motivation is a host of *social contexts* that may persuade an individual to process information with high engagement. Students may be motivated to process a message because their peers show interest in the topic. Often, school administrators or teachers invite guest speakers to give talks to their students to convince them not to drink and drive, not to smoke, or to practice safe sex. Depending on the credibility of this individual, the students' respect for this individual, or their peers' reactions to the speaker, the guest could provide a motivating context to process a message that otherwise students would not want to hear. Alternatively, students in a group discussion may be motivated to consider new or conflicting information they have disregarded in the past because they value their peers'

viewpoints. In sum, the context in which the message is considered contains a variety of social context variables. Interactions with members of a community, school, or peer group may motivate individuals to process information they would not otherwise consider.

Finally, some individuals, by their very nature, are inherently motivated to process information. These individuals have a need for cognition (Petty & Cacioppo, 1986). They are challenged by considering many sides of an issue and enjoy the cognitive processing inherent in high elaboration. Motivation researchers might characterize someone with a high need for cognition as "intrinsically motivated" to engage with ideas, information, or concepts. Pintrich and Schunk (1996) described intrinsic motivation as willingness to "engage in an activity for its own sake" (p. 257). Individuals with a high need for cognition are also willing to persist in their consideration of ideas. This persistence is akin to the motivational construct of "volition." Corno (1993) described volition as "a dynamic system of psychological control processes that protect concentration and directed effort in the face of personal and/or environmental distraction" (p. 16).

Certainly, we do not consider these four elements to be the only motivators that may contribute to the change process. However, based on existing research in cognitive and social psychology and science education, we think there is sufficient evidence to support them as elements that may lead toward motivation to process information.

Interacting with the learner's existing conception and his or her motivation to process a message are critical features of the message itself. The message carries with it a set of variables that are unique to that particular message, such as the format, organization, and the task implied by the message. These variables interact with learners' existing conceptions and motivation to make the message more or less comprehensible, plausible, coherent, and rhetorically compelling to each individual.

Following the CCM, we hypothesize that a message must be *comprehensible* and *plausible* to a particular individual. For the message to be comprehensible, it must not be too conceptually difficult for a particular individual to grasp. Further, the individual must have sufficient background knowledge to relate to the message.

For a message to be considered plausible, an individual must decide that the message could reasonably be true. That is, the individual would have to weigh the quality of the evidence and decide on the probability of its truthfulness. For example, recently in California, 14 members of the Heaven's Gate cult committed suicide. They believed that their souls would be saved by aliens in spaceships flying behind Halley's comet. Although it is not hard to comprehend the explanation offered by the cult members for their plan, most of us would decide that the explanation fails to meet the plausibility criterion. Specifically, the evidence supporting their views seems tenuous at best, and the probability that their explanation portrays a likely scenario seems to be quite small. Unless information is both understandable (comprehensible) and credible (plausible), an individual will not be motivated to process it.

Individuals must also find the message to have a certain level of explanatory coherence (Thagard, 1992) in accounting for the phenomena. In other words, it must provide an explanation of the phenomenon that links ideas into a conceptual whole. Last, a message must be *rhetorically compelling* to an individual. That is, the language usage, the sources of information that form the argument, and the justifications provided must be convincing and persuasive to the individual. Some individuals may be more compelled by an impassioned and emotional speech given by a politician on the plight of the homeless, whereas another individual may be more compelled by a candidate who presents data on growing housing costs and statistics on population growth to make his or her point. Conversely, a message cannot be rhetorically compelling if it is ambiguous, confusing, or disjointed.

We conceptualize existing conceptions, motivation, and a given message to form an interacting, dynamic system. A comprehensible message may be personally meaningful to one individual and yet meaningless to another. Some individuals who are initially disinterested in a topic may become motivated to attend to a message if they find the message rhetorically compelling, but others may not find the argument persuasive. Students may be more willing to work at comprehending a confusing message about a university's conversion from quarters to semesters if the information is personally relevant—that is, if the conversion will take place before they graduate. Therefore, the qualities of a message can only be considered as they interact with a given individual's existing conceptions and motivation.

It is interesting to note that the ELM begins with message effects that in time, may lead to motivation, whereas the CCM begins with dissatisfaction—a kind of motivation to process—and then message effects (comprehensibility and plausibility) come into play. The reverse order of these components in the ELM and the CCM may be the result of differences in the bodies of research the two models try to explain. The ELM synthesizes experimental research, which typically begins by introducing participants to a message in a laboratory setting. The participants are there because they have generally received some sort of compensation for their time. Thus, they may be motivated by the experimental conditions. If the message is comprehensible to the participant, the experimenter can then assess whether the individual is motivated to process the information further. But this order of events may be an artifact of the experimental situation.

On the other hand, the CCM tries to explain conceptual change within a classroom context. In a classroom, students are not always motivated to process every bit of new information they hear. The CCM suggests that if students are not motivated to process new and conflicting information, they are unlikely to attend to the message. Thus, the

process begins with motivation for the CCM but with the message in the ELM.

In our model, we hypothesize that learner characteristics and message effects are not linear at all. Rather than suggesting that the process starts at one particular point and proceeds in a step-by-step fashion, we wish to capture the iterative nature of the change process. We imagine that there are circumstances under which the change process can be initiated at the learner or at the message level.

So, if the interaction between learner and message characteristics occur in a positive manner, then the individual will likely process the information. However, this processing, like prior knowledge, is not an all-or-none phenomenon. We suggest that the processing of the information itself lies on a continuum from *low cognitive engagement* to *high metacognitive engagement*. The notion of a continuum of engagement relates to what persuasion researchers call the continuum of elaboration. High elaboration occurs when individuals engage in effortful, analytical processing of information. At the other end of the continuum, individuals may engage in more superficial or heuristic processing of information or low elaboration.

We use the term *engagement* to reflect a cognitive–constructivist view of information processing, strategy use, and reflectivity (for their notions of reading engagement, see Guthrie, 1996; Guthrie & Wigfield, 1997). We hypothesize that engagement can exist on a continuum from low to high. Individuals engaged in a low amount of processing may attend to new information and actively process that information through relatively simple strategies, such as maintenance rehearsal or mnemonics, processes requiring little reflective or metacognitive thought. This may lead to the assimilation of the new information into existing conceptions without significant change to those conceptions. These new ideas could also be remembered but not integrated into existing conceptions, leading individuals to compartmentalize the information (Chinn & Brewer, 1993). Compartmentalization would result in no change to the existing conception. Thus, as depicted in Figure 5, low engagement will often result in no conceptual change.

Individuals also may engage in a more moderate level of engagement. They may make meaningful connections with their existing conceptions through such activities as answering inferential questions during reading (Benton, Glover, & Bruning, 1983) or drawing personal connections to the content (Alvermann & Hayes, 1989; Morrow, Pressley, Smith, & Smith, 1997). This moderate amount of engagement involves greater depth of processing, more elaborate strategy use, and some reflective thought or metacognitive regulation. Here we take the ELM one step further, largely based on the substantial body of research on metacognition (Baker & Brown, 1984; Garner, 1987).

We posit that engagement at the highest end of the continuum would involve deep processing, elaborative strategy use, and significant metacognitive reflection. We propose that individuals involved in the highest form of elaboration would not only engage in the cognitive strategies of connecting and comparing existing conceptions with new information, but they would be reflective about what they were thinking and why. They would think deeply about the arguments and counterarguments related to the message. This is the highest form of metacognitive engagement. It is only through high metacognitive engagement that strong conceptual change is possible (see Figure 5).

In what context would such high engagement occur? Bereiter (1990) described a learning situation that captures what we mean by metacognitive engagement. He called this situation *intentional learners* in *inquiring classrooms*. In these classrooms, students are aware of their ideas and have control over their own learning. Such classrooms become settings where students ask: How do I learn? How do I solve problems? How do I think things through critically? Am I aware of what I believe? What would it take to convince me otherwise? Students in such classrooms would be taught to think critically, possibly through instructional techniques such as discussion (Alvermann & Hayes, 1989), critical inquiry, or questioning the intent of the author in communicating a message (Beck, McKeown, Hamilton, & Kucan, 1997).

It seems to us that the continuum of engagement is the most important element of the change process. Individuals' processing of a message is not an all-or-none phenomenon, even if they are motivated to process the message. Instead, individuals' processing lies on a continuum from low cognitive engagement—active consideration of ideas—to high metacognitive engagement—deep, analytic, critical reflection and awareness and regulation of thought processes.

Note that even if individuals process a message at a high metacognitive level of engagement, conceptual change is still not guaranteed. For example, after reports of cold fusion had been publicized, many scientists engaged in high elaboration by weighing the issues and arguments carefully and thoroughly. In fact, many conducted experiments in an attempt to replicate the reported results. But scientists finally rejected the new information about cold fusion, even though they engaged in high elaboration. Whether high elaboration leads to conceptual change depends on a complex interaction among existing conceptions, motivation, and the incoming message (e.g., results from the new experiments). Scientists may have been very motivated to consider the information, but they may have found the new message about cold fusion to be less coherent or less rhetorically compelling than their own existing conception about fusion. In fact, their existing conceptions were likely strengthened by their failures to replicate the cold fusion effect.[1]

Depending on the outcome of the engagement with the issues, an individual may respond in one of several different ways (Chinn & Brewer, 1993). In the cold fusion example,

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[1] Our thanks go to an anonymous reviewer for suggesting this example.

scientists rejected the new information and held onto their existing conceptions. But they could have had other reactions. For example, if their own findings proved inconclusive, they could have suspended their judgment until additional information was available. Thus, conceptual change depends on the outcome of the engagement process as it interacts with the learner and message characteristics.

Our reconceptualization of change posits that even if individuals are not motivated to change and do not find the new information comprehensible or compelling, change is still possible. As depicted in Figure 5, a peripheral cue can induce low cognitive engagement, which can, in turn, cause a superficial change in conceptions. This is analogous to the peripheral route to attitude change identified in the ELM. It is important to keep in mind that engagement that occurs through peripheral cues is often low, and thus change is likely weak, temporary, and strongly susceptible to further change. Science education research is replete with studies showing students who perform well on measures of knowledge after instruction but revert back to their old conceptions over time (Guzzetti et al., 1993; West & Pines, 1985). Thus, peripheral cues that induce low engagement may produce the appearance of change or weak conceptual change (see Figure 5), but such change is likely superficial and temporary.

However, as research on the ELM suggests, a peripheral cue has the potential to draw an individual into high engagement with the issues and arguments. For example, if a group of ranchers who are opposed to the reintroduction of wolves into Yellowstone National Park hear new information about efforts to control the wolves' predation on livestock from a fellow rancher, they might be willing to take a closer look at the issue. They might be interested in gaining further information about these control efforts and the success rates of such measures. In other words, the fellow rancher could serve as a peripheral cue, drawing the ranchers into the type of high metacognitive engagement that could lead to conceptual change.

The CRKM describes a complex interaction of existing knowledge, motivation, message effects, and engagement. Thus, it illustrates why radical conceptual change as described by Chi (1992) is so rare. Changing naive or intuitive existing conceptions often requires individuals to reassign concepts across what Chi called ontological categories. This type of change is necessary in the study of physics, for example, if students are to accept what are often counterintuitive scientific explanations for phenomena. One reason such profound changes are extremely difficult to achieve, according to the CRKM, is that naive or intuitive existing conceptions are likely strong and coherent. Further, individuals may be very committed to these conceptions because they are based on their everyday experiences.

What would it take to produce radical conceptual change according to the CRKM? It would take an exceptionally well-formed message that an individual found to be very coherent, comprehensible, plausible, and rhetorically com-

pelling. It would also require the individual to be motivated to interact with the message at the highest end of the engagement continuum. It seems clear why radical conceptual change is so difficult for teachers to promote: The conditions necessary for radical change are challenging to produce in a classroom setting.

In sum, our reconceptualization of the change process combines what we see as critical elements from the cognitive psychological, science education, and social psychological literatures. The model begins with the interaction of learner and message characteristics. It considers the individual's existing conceptions and his or her motivation to process the information. Motivation is seen as stemming from at least four sources: dissatisfaction with existing ideas, personal relevance of the information, individuals' need for cognition, and social influences. Features of the message, such as comprehensibility and plausibility, interact with the individual's perception of the information. If the message makes sense to the individual and if he or she is motivated to do so, the individual can then proceed to engage with the information. In turn, motivation can influence an individual's willingness to struggle with a complex or confusing message. If the individual processes the information with high metacognitive engagement, strong, relatively long-lasting conceptual change is possible. If the engagement is not deep, but superficial, change may come about, but it is likely weak, temporary, and susceptible to further change. Finally, a peripheral cue can also lead to high engagement that could lead to change.

RESEARCH IMPLICATIONS OF THE CRKM

We have presented a model of the conditions that need to occur for the cognitive reconstruction of knowledge. In developing the model, we drew from theory and research in three areas. In this way, we hope to combine the best features of these perspectives to develop a more general model of conceptual change. Next, we examine each component of the CRKM as it relates to the existing research and suggest areas for future research that need to be addressed to more fully understand the change process.

Existing Conceptions

Identifying existing conceptions about a topic remains a basic problem for researchers. One issue that has made this problem particularly complex is that existing conceptions consist of different types of knowledge, e.g., topic knowledge, domain knowledge, and metacognitive and strategic knowledge (for a review of knowledge terminology, see Alexander, Shallert, & Hare, 1991). The implications of this issue for those of us interested in conceptual change research is whether we could identify differences in the conceptual change process dependent on the type of knowledge.

Given that there are these different types of knowledge, another issue comes to the fore: Can these different types of knowledge be assessed? Alexander, Jetton, and Kulikowich (1995) developed two types of questions to separately assess domain and topic knowledge. Questions used to assess domain knowledge consisted of items measuring key concepts and principles in the domain. Questions used to assess topic knowledge consisted of detailed knowledge tied specifically to a given text on a topic.

The critical issue for the CRKM, however, is not only how to assess different types of knowledge, but how to assess the strength, coherence, and commitment of an individual's existing conceptions. Clearly, empirical research is needed to establish whether these constructs can be measured. However, much existing work in knowledge representation and assessment suggests it may be possible (see Jonassen, Beissner, & Yacci, 1993). Recall that strength refers to the richness of an individual's conceptual knowledge, whether it is well formed and interconnected or sparse and fragmented. Strength could be determined by asking individuals to construct network representations, such as webs or semantic maps (Fisher, 1990). It may be possible to assess the relative strength of individuals' conceptual knowledge by determining the number of branches and instances they produce in generating the maps.

Similarly, conceptual coherence could be assessed by asking individuals to produce concept maps or causal maps (Jonassen et al., 1993). In these network representations, individuals must not only generate nodes and connections, but they must label the links in terms of the relation they represent (using labels such as *caused by, type of, characteristic of, necessitates, affects,* etc.) The nodes and labeling of the links could be judged as depicting more or less explanatory coherence of a phenomenon, idea, or event. Another method that may prove useful for assessing coherence is the use of similarity ratings (Diekhoff & Diekhoff, 1982). This method involves asking individuals to generate a list of terms related to a concept and judge the degree of similarity or dissimilarity between each pair of listed terms. These ratings can be assessed using statistical techniques, such as cluster analysis or multidimensional scaling, and individuals' ratings can be compared to each other's or to an expert's.

Assessing individuals' commitment to their ideas may prove to be the most challenging. One technique we are exploring is asking questions such as "What could someone tell you that would change your view?" and then scoring responses based on a rubric ranging from highly committed (respondents indicate that there is nothing anyone could say that would change their thinking) to weakly committed (respondents indicate an openness to hearing evidence in opposition to their view).

Clearly, different types of measures may be needed to identify the strength, coherence, and commitment of individuals' existing knowledge. A program of research examining possible measures is likely to produce new and helpful information regarding the characterization of existing conceptions. As well, it may be that different measures may work better in some domains than others. Identifying the interactions between measures and domains may be an important contribution toward understanding how to tap the nuances of students' existing conceptions as they affect the likelihood of conceptual change.

Motivation

A critically important construct related to learner characteristics in the CRKM is motivation. The construct of motivation has a long-standing tradition of research in the field of psychology, including social psychology. Within educational psychology as well, research has been extensive, particularly as motivation relates to academic achievement and school learning (e.g., Graham & Weiner, 1996; Stipek, 1996).

What does the body of research on motivation within these traditions tell us about what might motivate individuals to consider new information about a topic about which they already have beliefs? To consider changing one's mind means to be willing to engage in the deep cognitive and metacognitive processing necessary to reexamine issues and arguments. For example, one of the authors is currently working with teachers and students in the Southwest. Some students come to school with negative stereotypes about Native Americans (or Anglos). In fact, some teachers come into classrooms with the same stereotypes. The stereotypes influence the way teachers view students and their work. The stereotypes also influence the way students view each other and the many topics that come up in social studies, science, and history classes.

What happens when Anglo students read a text (or hear a lecture or audiotape) describing the negative effects of settlers of the American West on the Native American culture? Or, what happens when Anglo teachers read about (or are told) the negative impact of Native American stereotypes on Native American children's learning? Will Anglo students and teachers consider the message when it contradicts their existing beliefs and conceptions?

Existing social psychology theory and research has shown that individuals can be motivated by the personal relevance of an issue or because they have a stake in the outcome. Thus, students and teachers in the Southwest may be more willing to consider a message about Native American (or Anglo) culture than about other cultures. In this case, Native American culture may have more personal relevance to some Southwest students and teachers than, for example, other cultures may have. As well, the ELM predicts that certain peripheral cues—a close friend or a trustworthy source, perhaps—might serve to facilitate later deep processing and rethinking of issues related to these topics.

What additional insights on motivation to change do current cognitive perspectives give us? Motivation researchers

have developed constructs related to achievement and learning in general (Dembo & Eaton, 1997). We see the value of this research as helping us envision a general disposition toward self-regulated learning and deep metacognitive processing. Students who have self-confidence in their abilities to learn, who have the ability to self-monitor and self-regulate their learning, and who are intrinsically motivated and have a mastery goal orientation would be in a better position to reexamine their existing beliefs (Pintrich et al., 1993). Such behaviors would be consistent with Bereiter's (1990) inquiring, self-regulating learners (see also Paris, Wasik, & Turner, 1991; Zimmerman & Risemberg, 1997) and with social psychologists' construct of a "need for cognition." On the other hand, students who are motivated by the need to get a good grade, who want to look good to their peers, or who view the classroom as a competitive environment are less likely to engage in the deep processing necessary to change their conceptions or beliefs (Guzzetti & Hynd, 1998).

Thus, the cognitive research on motivation identifies characteristics that promote in students a general disposition to learn. However, this general disposition may or may not be the same as a disposition to reexamine issues critically and to engage in deep metacognitive processing. Thus, the research has not focused on motivation to relearn or reconsider something that is inconsistent with existing beliefs. It is one thing to gain knowledge and beliefs about something. But it is very different to reconsider and rethink critically new and conflicting ideas for which you already have knowledge and beliefs. Does it take a different level of motivation to be motivated to reexamine existing ideas than it does to examine something with which one is unfamiliar? Does this type of motivation differ only in degree or in kind?

A second focus of cognitive research on motivation is the identification of contextual variables that might promote motivation to learn something that conflicts with existing beliefs. Motivation research has given educators important ideas about contextual variables that are more or less likely to promote motivation to learn. These can be used to understand better the context that can be created to maximize the possibility that students can reconsider their existing beliefs. For example, classroom contexts that promote cooperation rather than competition, that use intrinsic rather than extrinsic incentives, that promote mastery rather than performance goals, and that provide students with moderately difficult tasks tend to create learners who are more likely to engage in strategies that foster self-regulated learning (Dembo & Eaton, 1997; Stipek, 1996).

As we examined the cognitive and social psychology research on motivation as it relates to change, it is clear that we are looking at different types of motivation. We need knowledge about general motivation to learn, motivation to consider a particular message on a particular topic, motivation to change, and motivation to engage in high, metacognitive reflection. Although we have more research in some areas than in others (e.g., motivation to learn vs.

motivation to consider a particular message), the general area of motivation for reconsidering one's ideas in light of new and conflicting information remains a topic for further research.

Comprehensibility and Plausibility

Comprehensibility has been studied extensively by cognitive psychologists and social psychologists. It is interesting that both areas have examined written texts (messages) for comprehensibility. Meyer and Rice (1984) reviewed a body of early cognitive work on text structures and how they affect recall and learning. Additional research within a cognitive perspective identified numerous ways in which text can be "inconsiderate" (Armbruster, 1984).

However, more research is needed on the interaction of comprehensibility and text difficulty. The research has focused on comprehensibility as easing the amount of cognitive effort needed to understand. The persuasion research suggests that sometimes easier may not be better. This would be consistent with research by Chall, Conard, and Harris (1991), who found that high school students considered some textbooks "too easy." These students reported losing interest in books that they found to be too simplistic. Further, Renninger (1992) found that students who were interested in a topic comprehended text better even when the material was more difficult for them to read. Thus, motivation may interact with comprehensibility in interesting ways. It would be useful to know how this finding relates to conceptual change.

It is interesting that plausibility has not been studied in detail. But Posner and his colleagues (Posner et al., 1982) recognized that not only must a claim be understandable, it must make sense and be logical. This is consistent with a study by Dole, Sinatra, and Reynolds (1991), who found that an important determiner of students' acceptance of creationism or evolution is whether the arguments "made sense." We believe this holds true for domains of knowledge other than science. But how do individuals know if something "makes sense"? We think this is an interesting area to explore in terms of conceptual change. Unless an argument "makes sense," it is unlikely to be considered by individuals—no matter how motivated they may be.

High Metacognitive Engagement

Finally, we believe the CRKM builds on the strengths of the persuasion and cognitive research to identify an engagement continuum that has not been discussed in previous research. The CRKM predicts that students can engage in thinking about an issue at many different levels, from very low levels of engagement, to medium, to high levels of engagement. Consistent with the research on metacognition, we propose that the highest level of engagement involves deep thinking

and processing of the information and reflection on one's progression through the process.

However, neither the cognitive nor the social psychology research has described the engagement process very well. Case studies of students who are variously engaged in a topic may generate some ideas about what engagement looks like in a classroom. Guzzetti and Hynd (1998) presented classroom vignettes in which students varied in their levels of engagement in science activities. Then, students' levels of engagement and the reasons behind those levels were postulated by researchers from different theoretical perspectives. Studies such as these should add significantly to our understanding of engagement. Developmental data may be appropriate here, as well. It is likely that high engagement at the first-grade level will look very different from high engagement at the secondary level.

The interrelation between high metacognitive engagement about learning and high metacognitive engagement about a topic needs to be examined more closely. We believe there is more to learn about motivation to learn particular topics. This is currently being done at the National Reading Research Center (e.g., Guthrie & Wigfield, 1997), where researchers are examining students' motivation to read. But we need to conduct further research on how motivation to learn interacts with engagement with specific topics.

Another fruitful area for research on conceptual change is to explore engagement for learning about a topic in one individual over time. This would be productive for examining the acquisition of beliefs as well as conceptual change. Two issues are important here. First, we need to learn how beliefs are developed initially. What levels of engagement are needed to form a belief? Research in neither social nor cognitive psychology has addressed this important issue. Second, once a belief is formed, what particular experiences contribute to belief change? How are issues and arguments weighed, rejected, or counted over time? It would be interesting to follow the thinking of individuals who are in the process of changing their ideas. Studies can be done with adults, but they also must be done with middle and secondary students. Many years ago, Anderson (1977) noted, "no doubt schemata change by gradual extension, articulation and refinement" (p. 424). It would be interesting and informative to make a fine-grained analysis of extension, articulation, and refinement of the change process.

Peripheral Route to Persuasion

A final contribution of the CRKM, and one that we think is critically important, is the identification of alternative variables related to change. The CRKM predicts that change can come about through the peripheral route. When this happens, students are not involved in high engagement and elaboration but in quick heuristic judgments that do not lead to strong and long-lasting change.

But the model also predicts that a peripheral cue can lead to high engagement that will eventually lead to conceptual change. Social psychology research has validated what many educators know intuitively. Outside speakers, especially those to whom students can relate, can often have more of an effect on students than teachers can. Significant cues can act as triggers to induce or promote high cognitive engagement, which eventually can lead to change.

The CRKM offers an explanation for why students return to their previously held conceptions over time (e.g., Dole & Niederhauser, 1989). It is likely they engaged with the material at a fairly low cognitive level, rather than at a high level. Therefore, when researchers evaluate students' thinking through oral or written assessments, they need to be aware that change may appear just after instruction but disappear over time. We think an important methodological issue is to assess students' knowledge through delayed, as well as immediate, posttests.

CONCLUSION

We do not want to leave the impression that we believe schools are all about conceptual change. This certainly is not the case. Most knowledge is assimilated by students through extending, expanding, and refining existing conceptions. Moreover, when students are confronted with anomalous data, we do not mean to imply that the only response should be conceptual change. Quite the contrary, educators hope that students have inquiring minds and that they challenge, critique, analyze, and critically evaluate what they experience as conflicting data.

So how important is conceptual change for educators? After all, how often are students confronted with information that conflicts with their prior knowledge? In fact, both adults and children are confronted with anomalous data as a part of their everyday experiences. We believe this trend will increase as technology, computers, and the Information Age become more entrenched in our society. The more we communicate with others around the world, the more likely we will be confronted with anomalous data.

Regardless of students' existing views, educators hope that students will gain more insight into critical issues facing society and be able to view them from multiple perspectives. This is possible, however, only to the extent that students become highly engaged with the issues and arguments. A better understanding of the change process will help educators create an environment in which students can engage with multiple perspectives.

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