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AUTHOR	Yuruk, Nejla; Ozdemir, Omer; Beeth, Michael E.
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ABSTRACT

This paper describe the intertwined nature of metacognition and conceptual change and proposes a taxonomy that classifies the types of metacognitive knowledge and activities that are likely to influence the change in students' conceptions. The initial conceptual change model is introduced to provide background and context for the theoretical argument, and a summary of the other theoretical approaches is drawn to explain the change in students' conceptions. The definition of metacognition is presented along with the prominent taxonomies proposed to explain the facets of metacognition and the problems associated with these taxonomies. Finally, a review of the research that aimed to improve students' conceptual development through their metacognition is provided. (KHR)

The Role of Metacognition in Facilitating Conceptual Change

Nejla Yuruk, Omer Ozdemir, Michael E. Beeth

The Ohio State University

Columbus, OH USA

Correspondence to Nejla Yuruk: yuruk.1@osu.edu

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The Role of Metacognition in Facilitating Conceptual Change

In the last two decades, many of the studies in the field of science teaching and learning have been devoted to the identification and understanding of students' conceptions. These studies showed that students come into classrooms with existing preconceptions that are different from those accepted by scientific community and these preconceptions exist even after formal instruction. The resistance of these conceptions to change has attracted great interest among theorists and researchers in science education and cognitive psychology. This interest has resulted in different theoretical frameworks that explain the nature of students' preconceptions and describe how students change their preconceptions into scientifically accepted ones.

Despite the different theoretical frameworks to explain how conceptual change occurs, researchers who proposed these theoretical arguments all agree that conceptual change involves a major restructuring of already existing cognitive structure. However, restructuring means quite different things for these researchers. For some of them, restructuring means replacing the existing conceptions with the new ones (Posner, Strike, Hewson, & Gertzog, 1982) while, for some others, restructuring means establishing mental coherence between isolated pieces of knowledge (diSessa, 1993) or reassigning a concept into a more appropriate ontological category (Chi, Slotta, & Leeuw, 1994). Some researchers suggested that restructuring must involve a change in learners' epistemological and ontological presuppositions for conceptual change to occur (Vosniadou, 1994).

The theoretical explanations provided by these researchers suggest that conceptual change is not a simple revision of the existing conceptions with the new conception, but it requires one to recognize, integrate, and evaluate the existing and new conceptions and the associated beliefs, everyday experiences and contextual factors. Despite their different theoretical orientations, many of these researchers acknowledge the role of metacognitive awareness in facilitating or mediating conceptual change. Although many researchers have recognized the relationship between conceptual change and metacognition, a detailed base of empirical findings does not exist.

The main aim of this paper is to describe the intertwined nature of metacognition and conceptual change and propose a taxonomy that classifies the types of metacognitive knowledge and activities that are likely to influence the change in students' conceptions. In order to provide background and context for our theoretical arguments, we first will introduce the initial conceptual change model and draw a summary of the other theoretical approaches proposed to explain the change in students' conceptions. Next, we will present the definition of metacognition along with the prominent taxonomies proposed to explain the facets of metacognition and the problems associated with these taxonomies. This will provide a theoretical and explanatory basis for our arguments about the taxonomy that classifies the types of metacognitive knowledge and processes that are likely to influence the change in students' conceptions. Finally, we will provide a review of the research that aimed to improve students' conceptual development through enhancing their metacognition.

The Initial Conceptual Change Model

As the importance of students' prior or existing knowledge became recognized with researchers' acknowledgment of constructivist views of learning, a wide range of studies exploring students' conceptions have been carried out. In an early review on students' conceptions, Driver and Easley (1978) recognized that students hold "alternative frameworks" that interfere with subsequent learning of scientific conceptions and are difficult to extinguish. Recognition of students' alternative frameworks suggested that learning involves not only adding new knowledge into existing cognitive structures but also restructuring of the existing conceptions. This view of learning led researchers and philosophers to develop a theoretical framework to conceptualize how learners restructure their existing conceptions. Conceptual Change Model (CCM) was developed by Posner, Strike, Hewson and Gertzog (1982) to provide explanations to how individual's existing conceptions change when confronted with a new conception. Since its development, the theoretical framework of CCM has been a very influential and widely applied approach in science education community (Duit, 1999).

The view of learning presented in CCM is based on an analogy between knowledge construction in scientific communities and in individual learner, a view derived from the work of philosophers and historians of science, such as Kuhn (1970), Lakatos (1970), and Toulmin (1972). Thus, the initial CCM suggests that learners behave like scientists when confronted with new information. There are two major theoretical components of CCM: (1) the conditions that need to be fulfilled for an individual to experience accommodation, and (2) individual's conceptual ecology "that provides the context in which the conceptual change occurs and has meaning" (Hewson & Thorley, 1989, p. 541). Although the initial CCM was further elaborated (Hewson, 1981; Strike & Posner, 1992), the theoretical components of CCM have remained the same as presented in the original theory.

According to Posner et al. (1982), there are four conditions that need to be satisfied before conceptual change can take place: (1) the learner must be dissatisfied with the existing conception, (2) a new conception must be intelligible; (3) a new conception must be plausible, and (4) a new concept must be fruitful. The conditions apply to the learners' already existing conceptions or the new conception they consider (Hewson & Thorley, 1989).

The other theoretical component of CCM is learner's conceptual ecology that deals with different kinds of knowledge the learner hold. The learner's conceptual ecology "provides the context in which conceptual change occurs and has meaning" (Hewson & Thorley, 1989, p. 541). Posner et al. (1982) identified the components of conceptual ecology as (1) anomalies, (2) analogies and metaphors, (3) epistemological commitments, (4) metaphysical beliefs and concepts, and (5) other knowledge. Acceptance or rejection of a conception happens within the realm of conceptual ecology. The components of conceptual ecology provide a framework for determining the extent to which the conditions are met.

Hewson (1981) expanded the CCM by building the notion of status, which was identified as the "hallmark" of conceptual change (Hewson & Lemberger, 2000). Hewson and Thorley (1989) defined status as the extent to which the conception is intelligible, plausible, and fruitful. They claimed that conceptual change is about raising and lowering the status of the conditions. Thus, learning a new conception means that its status rises.

Hewson (1981) suggested that the status of the new conception and the status of the existing conception together determine whether the learner may consider changing a conception s/he holds or not. If a new conception is irreconcilable with the existing conception, the new conception can only be accepted by the learner when the status of the existing conception is lowered. The learner's conceptual ecology is important in determining the status of a conception because it provides the criteria for the learner to decide whether a given condition is met or not. In this regard, individuals' epistemological commitments and metaphysical beliefs and concepts about science play a critical role in determining the status of the new and existing conceptions.

The Revisionist Conceptual Change Model

Although the theoretical framework of initial CCM presented above has guided a great number of research and instructional practices for many years, it has also become subject to criticisms even by the researcher who developed the initial model. One line of criticisms focuses on the initial model's rational approach to students' learning. West and Pines (1983) claimed that learning in the CCM is not only a "rational process" but there are also "nonrational components" of conceptual change. They suggested that "nonrational processes are as much a part of what conceptual change is as are the rational parts" (p. 39). Similarly, Pintrich, Marx and Boyle (1993) described the initial CCM as "cold" and "isolated." They pointed out that the initial model put overemphasis on the rationality and neglects the role of motivational beliefs and classroom contextual factors in the process of conceptual development. They proposed general motivational constructs, such as goals, values, self-efficacy beliefs, and control beliefs, to be potential mediators of conceptual change.

In response to the criticism that the conceptual change model is too rationalistic, two of the researchers who proposed the initial CCM presented a critique of the initial model and acknowledge the role of affective and social factors in conceptual change (Strike & Posner, 1992). They proposed that:

> A wider range of factors need be taken in to account in attempting to describe a learner's conceptual ecology. Motives and goals and institutional and social sources of them need to be considered. The idea of conceptual ecology thus needs to be larger than the epistemological factors suggested by the history and philosophy of science. (p. 162)

In addition to the affective and social issues, their revisionist CCM concerns also with the nature of learner's misconceptions. Strike and Posner pointed out that the initial CCM assumes that learners have symbolically represented paradigm-like misconception before instructions. However, they argued that misconceptions may not be formed prior the instruction or need not to be symbolically represented, but rather they may be generated as a consequence of the instruction by the pieces of the conceptual ecology. Therefore, creating dissatisfaction with the existing conception may not result in conceptual change if students do not have well-articulated paradigm-like misconceptions. The instruction should not only focus on students' existing conceptions but also on the pieces of the conceptual ecology that generate misconception.

Strike and Posner also maintained that the initial CCM views conceptions or misconceptions as "cognitive objects" that are acted on by the pieces of conceptual ecology but are not part of it. According to them, this assumption ignores the influence of current conception on new perceptions and new ideas. Our current conceptions influence how we perceive the world. They claimed that misconceptions should also be considered as a piece in the conceptual ecology. Strike and Posner emphasized the interdependence and interconnectedness of past experiences, epistemological views of science, competing conceptions, analogies and metaphors. They argued for a developmental and interactionist view of conceptual ecology and conclude that the CCM must "be more dynamic and developmental, emphasizing the shifting patterns of mutual influence between the various components of an evolving conceptual ecology" (p.163).

Other Theoretical Perspectives on Conceptual Change

The critiques against the initial CCM have provided a framework for developing other theoretical approaches to explain conceptual change. Duit (1999) claimed that "conceptual change theory as used in science education is no longer the pure initial theory" (p. 266). The new theoretical approaches focus mainly on the nature of learners' preconceptions and the nature of resistance against changing conceptions (Schnotz, Vosniadou, & Carretero, 1999). According to the new theoretical orientations, the rational processes acting on learners' preconceptions at content level are not the only determining factor of conceptual change, but rather the nature of learners' preconceptions and the associated knowledge, beliefs and attitudes play a significant role in learning the science concepts. The new perspectives on conceptual change mainly differ in terms of the researchers' assumptions regarding the nature of human cognition (individualistic or situated cognition) and the nature of conceptions (coherent, theory-like or fragmented). In the next section, a review of the new perspectives on conceptual change will be presented.

Knowledge in Pieces

With regard to the nature of learners' preconceptions, diSessa (1993) claimed that learners' intuitive conceptions acquired from everyday experiences of the physical world do not posses a coherent structure, but rather they are isolated, fragmented "knowledge in pieces." These knowledge pieces are primitive schemata constructed as a result of "superficial interpretation of the physical reality" (p. 112). Although these fragmented knowledge pieces called "p-prims" (phenomenological primitives) play important roles in explaining physical phenomena they do not themselves need any explanations. Although these phenomenological events do not contain laws, they are known to take place without any need for justification at their occurrence. For instance, everyone knows that a book can rest on a table without considering the underlying scientific principle.

P-prims can describe small set of situations but they do not constitute a coherent and systematic theory. Although they are not explained within the knowledge system, p-prims may act as intuitive physical laws while explaining physical phenomena. Even though p-prims may serve as a few core theoretical ideas that defer to much more complex knowledge structures for experts, they are nothing more than a superficial phenomenology that intuitively act as "heuristic cues" for naïve sense thinking.

In that sense, conceptual change occurs when there is a change in the functions of p-prims from relatively isolated, self-explanatory entities to the pieces of larger system. In other words, conceptual change takes place when collection of p-prims can provide an internally coherent and systematic explanation for the complex conceptual structure.

Concepts as Coherent Mental Models

Vosniadou (1994) presented a different view about the nature of learners' preconceptions. Her theoretical framework suggests that learners' alternative conceptions do not result from the incoherent and inconsistent knowledge pieces, but they result from learners' attempts to create coherent mental models. According to Vosniadou, concepts are embedded in larger theoretical structures that constrain them. She distinguished between naive framework theories and specific theories. Framework theories consist of "entrenched" epistemological and ontological presuppositions, which are deeply rooted in and constantly confirmed from daily life experiences. Specific theories involve interrelated propositions or beliefs that explain the properties and behaviors of physical phenomena. They are domain specific assumptions that are constrained by framework theories.

Vosniadou claimed that during cognitive functioning individuals generate or retrieve mental models to provide causal explanations of physical phenomena or to predict the state of affairs in the physical world. Mental models are dynamic and generative representations which can constrain the knowledge acquisition process in a similar way to beliefs and presuppositions.

The ways in which framework theories constrain further knowledge acquisition can be seen in Vosniadou's explanation of children's mental models about the shape of the Earth. Younger children in her study constructed mental models of Earth that is shaped like a flat rectangle or like a disc which is supported by ground underneath and is surrounded by sky above its flat top. Vosniadou referred these models as "initial" because they are based on everyday experience rather than on the scientific model of the spherical Earth. Older children participated in her study generated models which combine initial models with the scientific model of the spherical Earth. For example, many of the older children in her study imagined the Earth as a hollow sphere which is similar to a goldfish bowl with a flat bottom where people are assumed to live. Vosniadou (1999) maintained that children generate "synthetic" mental models in order to reconcile the information about the spherical shape of the Earth "with their presuppositions and beliefs that the ground is flat, that the space is organized in terms of the directions of up and down and that unsupported physical objects fall in a downward direction" (p. 7). In other words, children reconcile their framework presuppositions inferred from everyday experiences with the new information. According to Vosniadou (1994), conceptual change involves gradual changes in learner's "synthetic" mental models with scientifically accepted mental models. Revision of the "synthetic" models, in other words, alternative conceptions requires a change in the naïve framework theory and specific theories. This process is very difficult especially when the framework presuppositions are entrenched because in that case conceptual change requires a revision of epistemological and ontological presuppositions which are consistently confirmed by everyday experiences.

Ontological Categories

A further theoretical framework developed by Chi, Slotta, and Leeuw (1994) is based on the assumption that there are categorical differences between science concepts. Chi et al. proposed that entities in the word belong to three different ontological categories: matter (or things), processes and mental states. There are also several subcategories embedded within each major category. For example, processes category involves "procedure," "event" and "constraint–based interaction" subcategories. Matter category is divided into "natural kind" and "artifacts" whereas mental states category is divided into "emotional" and "intentional." A category differs from the other in terms of some ontological attributes. For instance, entities within the matter category such as sand, paint, and human being have ontological attributes as "being containable," "storable," "having volume and mass," and "being colored." On the other hand, processes own their own set of ontological attributes, such as "occurring over time," "resulting in" and so forth.

According to Chi et al. (1994), many of the science concepts that belong to the "constraint-based interaction" category are subsumed under the main category of processes. Chi et al. identified ontological attributes of this category as "no beginning and end, no progression, acausal, uniform in magnitude, simultaneous, static, and on-going" (p. 32). Force, electrical current, heat and light are some examples to the physical concepts that belong to this category. Chi et al. argued that students have difficulty in encountering science concepts due to "the existence of mismatch or incompatibility between categorical representation that students bring to an individual context, and the ontological category to which the science concepts truly belongs" (p.34). According to this approach, misconceptions arise when the learner assigns a concept to a wrong ontological category. For example, students frequently assume that the force concept is under the category of matter rather than the subcategory of constraint-based interaction. As a result, they consider force as a kind of substance that an object possess and consumes. When students who categorize force as matter are presented with new information about the concept of force, the new information will be assimilated into the matter category as well. Thus, students cannot understand the concept completely if the ontological category of the concept is not changed. According to this theoretical framework, conceptual change involves the reassignment of a concept to the appropriate category within the existing structure.

Profile Change

Mortimer (1995) constructed another theoretical framework that not only considers ontological distinctions but it takes also into account the hierarchical and context-dependent nature of epistemological and ontological distinctions among different usage of a single concept. Mortimer pointed out that a new concept does not necessarily replace alternative conceptions; instead individuals even experts keep using their alternative conceptions in their daily life. His model is based on the notion of "conceptual profile" consisting of hierarchical zones, each of which is ontologically and epistemologically different from the others

The conceptual profile of one concept differs from one learner to another since the zones are strongly influenced by different personal experiences and have different cultural roots. According to the nature of concepts, there might be several zones of conceptual profile. For example, for the concept of matter he proposes four different zones: realist view of matter (continuous; no reference to particles; external appearances and sensible features), a substantialist-empirical view of matter (matter as constituted by particles; analogy between the behavior of particles and that of the substances), classical-rational atomistic view (the atom as a system of sub-particles; conservation of matter; transition from external features to internal features; interaction between particles in each physical state of matter), and a quantum-rational modern) view of matter (the atom as a system of quantum objects described by mathematical models). Each successive zone (realist, empiricist, rational classic and rational modern) within the conceptual profile has more explanatory power than lower zone. In their everyday life, even the scientists use matter as something continuous but when they deal with a problematic situation they shift to scientific profile such as developed atomistic view or quantum view. Mortimer distinguished experts from novice students in that the experts are conscious of their conceptual profile and can use each notion in their profile in the appropriate contexts.

Mortimer's theoretical framework suggests that learning science is not viewed as a conceptual change in which the new conceptions replace the previous conceptions, but rather it involves changing the conceptual profile and acquiring the capability to distinguish the different zones of the profile. Then, the aim of teaching should to help students become conscious of their conceptual profile and decide where each concept is applicable.

Contextualization of Conceptions

Researchers from a different theoretical orientation argue that conceptual change should be extended to include contextual and situational factors. According to this perspective, conceptual change is achieved by enhancing individuals' ability to differentiate between contexts. Linder (1993) referred this process as "conceptual appreciation" to emphasize how lack of appreciation for the context in which science concepts are embedded inhibits meaningful learning of science. He claimed that concepts are not "appropriate, legitimate, correct, or otherwise" (p. 295) without contexts. He provided several examples from physics to emphasize the necessity of conceptual appreciation in meaningful understanding of science. Appropriateness of a concept requires a context. For instance, the conceptualization of light as a particle or wave depends upon the context. Linder argued that science educators should put less emphasis on the efforts to change the existing conceptions and more emphasis on the efforts to enhance students' capability to appreciate functional appropriateness of science conceptions in particular context.

In response to diSessa's (1993) article about p-prims, Ueno (1993) interpreted students' difficulties in learning science concepts from the viewpoint of situated cognition. Ueno agreed with diSessa in that naïve theory is an ad hoc explanation. However, he claimed that naïve theory does not exist in individuals' minds in vacuum but rather it is socially formed and embedded in a specific "language game" in a specific community. Robustness of naïve theory is not a result of individual's cognitive system, but rather it comes from "a specific social maintenance system and the given stable natural environment" (p. 244). According to Ueno, representation of a naïve theory about a physics concept resides in an interactive system among individuals, the community and the stable natural environment, such as gravity and static state of ground. He pointed out that in everyday situations gravity and the static state of the environment are tacitly considered as natural. Implicit presuppositions are not only in individuals' minds but are socially shared in everyday discourse.

Ueno maintained that everyday discourse and scientific discourse differ in terms "metacontext." He claimed that if students do not know the metacontext of scientific conception, falsification of their predictions cannot produce conceptual change. Without clarifying metacontext, students' interpretation tends to be very local even after they can correctly predict a physical phenomenon. In order to learn scientific conceptions, students need to clarify the difference between the metacontext of everyday discourse and that of scientific conceptions. According to Ueno's view, conceptual change is not regarded as the transition from one conceptual structure to another, but rather a process involving "expansive recontextualization" (p. 247).

Summary of Perspectives on Conceptual Change

Different theoretical approaches have been proposed to explain how students learn science concepts. The theoretical frameworks of these new approaches are different from the initial CCM in terms of their emphasis on the nature of learners' conceptions and the associated explanations for the conceptual change process. These theoretical frameworks differ among each other in their assumptions about the nature of knowledge acquisition. Although some of the researchers including diSessa (1993), Vosniadou (1994) and Chi et al. (1994) considered knowledge acquisition as an event that occurs in the mind of individual, others such as Linder (1993) and Ueno (1993) emphasized the situated nature of knowledge acquisition and conceived it as a socially shared event between cognitive agents. An interesting argument, which contradicts to the theoretical framework of the initial CCM, came from Mortimer (1995). He claimed that old beliefs are not extinguished but co-exist with the scientific beliefs even after students change their conceptions. In other words, depending on the context learners may continue to use their intuitive conceptions even though they possess the scientific conception. In this case, it is important to enhance learners' ability to distinguish the functional differences of their scientific and intuitive conceptions.

Although there are differences in the assumptions of the researcher in terms of the nature of students' conceptions, researchers from the new theoretical orientations do not view conceptual change as a replacement of the previous conceptions with the new ones through rational arguments anymore. According to them, conceptual change involves integrating the phenomenological experiences appropriately into a coherent and complex knowledge structure, and evaluating and differentiating between different ontological categories, epistemological and ontological presuppositions, the everyday life experiences which led to the formation of epistemological and ontological assumptions, and the contexts associated with specific use of a conception.

Instructional Implications of the Different Perspectives on Conceptual Change

The different theoretical orientations of conceptual change bring about different views on how to facilitate conceptual change (see Table 1). For example, if alternative conceptions are assumed to be the result of mental incoherence, then, the aim of instruction should be to establish mental coherence. In other words, instead of one-by-one attack on fragmented p-prims, a deeper structural systematicity should be built among the fragmented "knowledge in pieces." This requires the teachers to help their student become aware of their fragmented and isolated pieces of knowledge, namely, their phenomenological everyday experiences and form more functional, complex and coherent mental models.

Another instructional consequence emerges if we assume that alternative conceptions are constructed due to learners' efforts to create coherent mental structures constrained by their naïve framework theories. The instructional design should take students' mental models

Table 1

Instructional implications of different perspectives on conceptual change

Theoretical Perspective	Views on Conceptual Change	Instructional Implications
Knowledge in Pieces (diSessa, 1993)	A change in the functions of p-prims from relatively isolated, self-explanatory entities to the pieces of internally coherent complex system.	Helping student become aware of their fragmented and isolated pieces of knowledge, namely, their phenomenological everyday experiences and form more functional, complex and coherent mental models.
Concepts as Mental Models (Vosniadou, 1994)	A gradual change in the coherent "synthetic" mental structures constrained by their naïve epistemological and ontological presuppositions.	Helping students differentiate between their presuppositions and scientific ones, namely, helping them be aware of their mental models and the presuppositions and beliefs that constrain their mental models.
Ontological Categories (Chi et al., 1994)	Reassignment of a conception in a scientifically appropriate ontological category.	Helping students be aware of the ontological category to which they assign their conception.
Profile Change (Mortimer, 1995)	Changing the conceptual profile and acquiring the capability to distinguish the different zones of the profile.	Fostering students' consciousness about the zones of their profile, the associated epistemological and ontological commitments, and the functional differences of ideas in each zone among different contexts.
Contextualization of Conceptions (Linder, 1993; Ueno, 1993)	Distinguishing functional appropriateness of conceptions in particular contexts.	Helping students monitor the function of a concept in different contexts.
Status Change (Hewson, 1981; Hewson &Thorley, 1989)	Lowering the status of the existing conception while rising the status of the new conception	Helping students to monitor and evaluate the status of exiting and new conceptions.

and the presuppositions and beliefs that constrain the development of mental models into consideration. Creating cognitive conflict situations that confront only students' "synthetic" mental models rather than the epistemological and ontological presuppositions of the naïve framework theory will not be adequate to facilitate the change in students' conceptions. In that case, conceptual change can be fostered by helping students be aware that their ontological and epistemological assumptions are not scientifically acceptable. In other words, instructional programs should aim to help students differentiate between their presuppositions and scientific ones. In order to do this, students must be aware of their mental models and the presuppositions and beliefs that constrain their mental models. Similarly, if we consider that alternative conceptions are resulted from assignment of a concept in a wrong ontological category, the instructional consequence is to help students be aware of the ontological attributes they assign to a conception.

If learning science is viewed as a profile change then the aim of the instruction should be to increase the rational profile zone and restrict the realist and empirical zones. In that case, the teacher should foster students' consciousness about the zones of their profile, the associated epistemological and ontological commitments, and the functional differences of ideas in each zone among different contexts.

Finally, if conceptual change is assumed to be the result of lowering the status of the existing conception while rising the status of the new conception, then, the teacher should create an instructional environment where students are encouraged to think about their conceptions and the components of their conceptual ecology, and to monitor and evaluate the status of the competing conceptions.

No matter which theoretical framework is used to explain the change in students' conceptions, the instructional consequences emerging from these different frameworks suggest that students should be helped become conscious of their conceptions and the factors that constrain their development, and monitor and evaluate the status, consistency and coherency of ideas. In other words, the instructional practices should promote students metacognitive activities to foster conceptual change. In the next section, we will propose a taxonomy for classifying the components of metacognitive knowledge and processes that are likely to influence the change in students' conceptions. In order to provide a theoretical background for the taxonomy, it is necessary to clarify the underlying processes subsumed under the term of metacognition and the deficiencies in the proposed taxonomies about metacognition. Therefore, before classifying the metacognitive knowledge and processes that are intertwined with the change in students' conceptions, we will present a brief overview of taxonomies of metacognition and some of the problematic issues related to the definition of metacognition.

Metacognition

Since its first use by Flavell more than a quarter century ago, the prefix "meta" has been used to qualify a wide range of constructs in many areas, such as metalinguistics, metareading, metacomprehension, metaperception, metamemory, and metacognition. Among the constructs qualified by the prefix "meta," metacognition is the one that has the broadest meaning and that has gained a great deal of attention. Many researchers have used a variety of theoretical frameworks and methodologies to describe and study this construct. Despite its widespread use and pronounced impact in many areas of psychological and educational research, metacognition has been described as a "fuzzy concept" (Flavell, 1981).

Metacognition is most broadly defined as "one's knowledge and control of own cognitive system" (Brown, 1987, p. 66). Although the term metacognition can be simply defined as "thinking about one's own thinking" (Rickey & Stacy, 2000), "knowledge about knowledge" or "reflections about actions" (Weinert, 1987), metacognition is a complex construct that covers a broad range mental functioning. Thus, this feature of this construct has led various researchers and theorists to propose different theoretical frameworks to describe it.

Flavell's Taxonomy of Metacognition

Among various taxonomies, Flavell's (1979) taxonomy has helped many researchers operationalize and investigate the notion of metacognition. Flavell's (1976) definition of metacognition involves knowledge about the cognitive system and its contents and the effective regulation and control of that system:

> Metacognition refers to one's knowledge concerning one's own cognitive processes and products or anything related to them, e.g., the learning-relevant properties of information or data. … Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to cognitive objects or data on which they bear, usually in the service of some concrete goal or objective. (Flavell, 1976, p. 232)

Flavell (1979) proposed a model of metacognition and cognitive monitoring. According to this model, cognitive monitoring occurs through "the actions and interactions among four classes of phenomena: "(a) metacognitive knowledge, (b) metacognitive experiences, (c) goals (or tasks), and (d) actions (or strategies)" (p. 906). Flavell (1987) stated that the key concepts in this taxonomy are metacognitive knowledge and metacognitive experience.

Metacognitive knowledge refers to one's acquired knowledge that "has to do with people as cognitive creatures and with their diverse cognitive tasks, goals, actions, and experiences" (Flavell, 1979, p. 906). This knowledge is both "statable" in that it can be assessed through verbal reports, and it is "stable" in that once the individual posses information about himself/herself as a learner and about cognition in general, s/he continues to have this information stored in her/his memory (Brown, 1987; Campione, 1987). According to Flavell (1979), metacognitive knowledge is not qualitatively different from other kinds of knowledge, but rather it differs from other kinds in its "content and function" (p. 906). Metacognitive knowledge is simply a portion of the total knowledge base that is related to cognition (Flavell, 1987). Flavell (1979) made a distinction among different types of metacognitive knowledge into person, task and strategy variables.

Person variable includes one's knowledge about oneself and the others as learners, about what factors influence her/his mental processing and about cognitive capacities. Statements such as "I can learn things better by reading than listening," "My memory span is limited," and "I am good at dealing with verbal kinds of material but not good at spatial tasks" can be subsumed under the person variable.

Task variable refers to one's knowledge about the task itself, its demands and relative difficulty. In other words, task variable is an acquired knowledge that different kinds of tasks place different kinds of demands on individuals (Flavell, 1979; 1987). For example, one's knowledge that it is easier to recall the main events of the story than to recite the story word to word or familiar-topic task is easier to understand than unfamiliar tasks can be considered as task variable. An individual's recognition of a certain type of a task and its demands indicates the existence of metacognitive knowledge of task variable. For instance, the student's recognition of a math problem as a word problem shows her/his knowledge about the task.

Strategy variable involves one's knowledge about different types of cognitive and metacognitive strategies that can be used to achieve various goals. Flavell (1979; 1987) made a distinction between cognitive and metacognitive strategies. Depending on the goal of the learner a strategy can be referred as either cognitive strategy or metacognitive strategy. Flavell (1979) described the functional differences between cognitive and metacognitive strategies by stating that "cognitive strategies are invoked to *make* cognitive progress, metacognitive strategies to *monitor* it" (p. 909; italics in original). Cognitive strategies are used to help an individual achieve a particular goal (e.g., rereading the text for understanding) while metacognitive strategies are used assess progress towards goals (e.g., asking oneself questions to evaluate one's understanding of that text).

The other key component of Flavell's (1979) taxonomy is metacognitive experiences. Flavell (1979) defined metacognitive experiences as "any conscious cognitive and affective experiences that accompany and pertain to any intellectual enterprise" (p. 906). Metacognitive experiences are mostly related to one's progress towards the goal of completing a task or cognitive activity successfully and they can arise before, during and after a cognitive activity (Garner, 1987). Flavell (1987) described metacognitive experience:

> One is having a metacognitive experience whenever one has the feeling that something is hard to perceive; comprehend, remember, or solve; if there is the feeling that one is far from the cognitive goal; if the feeling exists that one is, in fact, just about to reach the cognitive goal; or if one has the sense that the material is getting easier more difficult than it was a moment ago. (p. 24)

Unlike metacognitive knowledge, metacognitive experiences are presumed to be relatively unstable, rarely statable, and relatively independent of age (Brown 1987). For example, one's feeling a discomfort and puzzlement in response to the incomplete directions implies the existence of metacognitive experience. Similarly, a student's momentary sense that s/he does not understand something explained by the teacher can be categorized as a metacognitive experience. Garner (1987) described metacognitive experiences as awarenesses, realizations, and "ahas" (p. 19).

Although metacognition had been acknowledged earlier by many theorists and philosophers such as Locke, Dewey, Piaget and Vygotsky, Flavell's taxonomy was the first step toward a more systematic view of metacognition and provided a starting point for subsequent research. Even though it was proposed in the mid1970s, it still serves as a theoretical guide for theoretical and empirical research dealing with metacognition. However, Flavell (1987) believed that the taxonomy he created was not satisfactory to cut through the fuzziness surrounding the construct of metacognition, but he recognized its potential by saying that "at least it helps thinking about the domain" (p. 21). Flavell was a proponent of Piagetian developmental psychology. His views about metacognition have been generated within the framework of this perspective. On the other hand, theoretical ideas about metacognition have emerged within the framework of other theories about cognition and learning including information processing theory.

Metacognition as Executive Control Processes

The main focus of the immense body of research in metacognition conducted from the perspective of developmental psychology has been mainly metacognitive knowledge, awareness and conscious access (Garner, 1987; Kluwe, 1987). Another line of research paradigm that emphasized the control of mental processes has been the information processing theory. The concept of metacognition within the context of information processing theory has appeared as executive control processes (Brown, 1987; Garner, 1987). According to this paradigm, executive processes direct the activities at each possessing step and make sure that the processing system functions as a whole through many processing stages. Brown (1978) identified metacognitive skills as a component of the information processing system. These skills involve the operation of mental processes by which individuals organizes and monitors their own thinking. She maintained that executive control processes such as planning, checking, monitoring, and prediction contribute to the cognitive performance, and part of the development is the gradual increase of these processes.

One of the central concerns of the researchers from this perspective is enhancing problem solving capacity. Executive decisions the learners make are critical for efficient problem solving. Brown (1978) listed these executive control processes as follows:

> It must include the ability to (a) predict the system's capacity limitation; (b) be aware of its repertoire of heuristic routines and their appropriate domain of utility; (c) identify and characterize the problem at hand; (d) plan and schedule appropriate problem solving strategies; (e) monitor and supervise the effectiveness of those routines it calls onto service; and (f) dynamically evaluate these operations in the face of success or failure so that termination of the activities can be strategically timed. (p. 152)

According to Kluwe (1987), executive decisions are characterized as procedural knowledge. The main aim of executive decisions is to acquire "information about the own ongoing cognitive activity and about the present state of own cognitive endeavor, as well as transformation or maintenance of one's own cognitive activity and states" (p. 35). Kluwe classified executive decisions into two: executive control and executive regulation.

Executive control involves executive decisions that are directed at controlling and monitoring the ongoing cognitive activities and generates information about the activity and about the present cognitive state. Kluwe distinguished four different processes within executive control: (a) classification; (b) checking; (c) evaluation, and (d) prediction.

Classification type of activities provides answer to the question "What am I doing here?" Checking processes allow one to gain information about her/his state of cognitive activity, goals, organization, progress, success and results. Evaluation activities are directed to judge the course and the state of cognitive activity. They provide information about the quality of cognitive activities. Another metacognitive activity subsumed by Kluwe under executive control is prediction. This kind of process provides information about possible alternative options for problem solving, the possible sequence of solution steps and the possible outcomes. Prediction may take the from of verbalization,such as "If I decide to work on this problem it will be hard for me to solve it," or "I have to find someone to help me to solve this problem."

Executive regulation is the other main component of executive decisions. Kluwe (1987) defined executive regulation as the "decisions about the organization, effort, amount, course, and direction of one's own cognitive activity" (p. 41). Executive regulation does not only involve activities that are directed at the modification of the cognitive activity, it may also involve activities that result in the maintenance or continuation of a particular cognitive activity. Kluwe identified four different regulatory processes within executive regulation: regulation of processing capacity, regulation of what is processed, regulation of intensity, and regulation of the speed of information processing.

As the models and theoretical frameworks constructed to explain executive control processes suggest, researchers from information processing perspective have emphasized the control processes that are directed by a central processor that act as an interpreter and supervisor. The central processor is an executive system that is capable of monitoring and evaluating its own operations. On the other hand, researchers from a developmental psychology perspective have focused more on the metacognitive knowledge, awareness and conscious access (Garner, 1987). According to Fisher and Mandl (1984), Flavell emphasized a conscious and deliberately active thinker whereas Brown focused upon the processes regulated by executive mechanisms. They described Flavell's view as "Hegelian" in that practice can be manipulated through the manipulation of consciousness. On the other hand, they labeled Brown's view as "materialistic" in that the differences between efficient and poor learners were seen as the differences in the quality of executive processes that can be taught. Fisher and Mandl further clarified the differences between Flavell and Brown's views of metacognition:

> Brown does not search for the cognitive map in the head of the learner, as does Flavell. ... According to Brown's notion, one has to foster skill, but not the knowledge. ... Flavell tries to foster learning efficiency by enriching the cognitive map of the learner via informing him about cognitive functioning. Brown, on the other hand, seems to say: "Don't tell the learner what he has to do (or why), but rather tell him how he might proceed (and give him feedback about his efficiency after he has done it)" (pp. 227-228)

The differences explained by Fisher and Mandl clearly show that researchers from the information processing perspective view "production deficiencies" (that is, children's inability to use strategies effectively when needed) as a failure of control mechanisms or as the lack of the control skill, whereas researchers from a Piagetian developmental psychology perspective describe "production deficiencies" as the metacognitive knowledge gaps.

Although these two lines of research have different theoretical assumptions, both views see learners as active organisms who are in charge of their own cognitive functioning. Building on the contributions of researchers from both perspective to clarify and classify the components of metacognition, many other theorists and researchers have made further clarification of metacognitive knowledge or they have proposed different taxonomies to categorize and explain the aspects and components of this construct. In the next section of this paper, researchers' and theorists' attempts to contribute to the definition and categorization of metacognition will be presented.

Contributions to the Definitions of Metacognitive Knowledge

A more systematic view of metacognitive knowledge was provided by Chi (1987). According to Chi, the term "meta" can be used in two different ways: "as a reference to cognition" and "as a reference to secondary-order knowledge" (p. 249). If it is used as a reference to cognition, the word "meta" could be substituted by the word cognition or knowledge. Thus, the word metaknowledge means cognition about knowledge. For example, one's knowledge about his or her learning styles can be characterized as a metaknowledge. On the other hand, if the term "meta" is used as a reference to second-order knowledge, a function or a procedure is used on an existing declarative knowledge.

In her taxonomy of metacognitive knowledge which she called "metaknowledge," Chi (1987) categorized metaknowledge in terms of the differences in representation between the knowledge states. Chi identified three types of metaknowledge: meta-declarative knowledge, meta-procedural knowledge, and meta-strategies.

Chi proposed that there are two kinds of meta-declarative knowledge. First type of meta-declarative knowledge is one's pre-stored factual knowledge about cognition. It is stored in the memory like other kinds of knowledge and acquired through experience. The difference between stored meta-declarative knowledge and other kinds of declarative knowledge lies in its content. For example, if one has an existing knowledge about how much s/he can generally recall, or if s/he has a knowledge about what task variables are the most difficult, or that one is better at listening than reading, s/he has meta-declarative knowledge that is encoded as a result of past experiences and that can be retrieved from long-term memory like other factual knowledge in other domains. In that sense, this kind of meta-declarative knowledge is similar to Flavell's conceptualization of person and task variable.

For the second kind of meta-declarative knowledge Chi used the term meta as a function or second-order operation. If the necessary knowledge about cognition is not stored or known, meta-declarative knowledge would be "a procedure that takes as input declarative knowledge, and the action would be an evaluation or some kind of assessment" (p. 262). For example, if an individual is asked if s/he knows about force concept, s/he needs to search or activate relevant nodes in semantic network and answers when available structure is activated. However, if s/he is asked how much s/he knows about force concept and this knowledge is not stored, it is not only required to activate relevant nodes, but also some evaluation and quantification of the activated portion of the semantic network is needed. In other words, if the necessary knowledge about the cognition does not exist in the memory, "a function or a procedure is used when an evaluation or any other form of action is taken on existing declarative knowledge" (p. 250). For instance, if an individual is asked if s/he can learn better by listening or by reading and if such knowledge is not pre-stored and known, a set of complex decision processes are required. The individual needs to evaluate and compare the outcome of reading and listening processes.

Similar to the meta-declarative knowledge, meta-strategies can be defined in two ways. Meta-strategies can be either represented as pre-stored declarative knowledge or they can be viewed as second-order operations. For example, one's knowledge that her/his rehearsal production is efficient is represented like factual knowledge in other domains. This kind of knowledge is encoded through experiences and can be retrieved if it is needed. In the case of second-order operations, however, meta-strategies "take entire strategy production as inputs and output some evaluation of the production" (p. 251). For instance, if one is asked whether she/he can remember better than her/his friends and if the answer to this questions is not pre-stored, her/his response requires an evaluation of what kind of strategies s/he knows and how effective those strategies facilitate remembering. In that sense, meta-strategy is "a rule that takes as input another rule, and output some output or action" (p. 252). Representation of meta-procedural knowledge is very similar to the representation of meta-strategies. The difference between two of them lies in the domain-specificity of meta-procedural knowledge. Thus, meta-procedural knowledge involves the rules that evaluate other domain-specific rules.

Other Taxonomies of Metacognition

In addition to the attempts to clarify metacognitive knowledge, there have been different approaches to compartmentalize the components of metacognition. Recently, Schraw and Moshman (1995) proposed a taxonomy of metacognition that is similar to Flavell's (1979) taxonomy in that it distinguishes between two components of metacognition: (1) knowledge of cognition and (2) regulation of cognition. They defined knowledge of cognition as what one knows about her/his own cognition or about cognition in general. In that sense their definition of knowledge of cognition overlaps with Flavell's (1979) definition of metacognitive knowledge. The distinction between Flavell's and Schraw and Moshman's taxonomy lies in their subcategorization of this knowledge.

Schraw and Moshman (1995) classify metacognitive knowledge into declarative, procedural and conditional knowledge. Declarative knowledge refers to "knowledge about oneself as learners" and about the factors that influence one's performance. Procedural knowledge is defined as knowledge about strategies. Conditional knowledge refers to "knowing when or why to use a strategy" (pp. 352-353). If we compare Flavell's (1979) classification of metacognitive knowledge with Schraw and Moshman's (1995) categorization of knowledge about cognition, we can easily notice that Schraw and Moshman's definition of declarative knowledge is eqivalent to Flavell's definition of person variables. Moreover, there is overlap between Schraw and Moshman's notion of procedural knowledge and Flavell's strategy variable. Conditional knowledge can be considered as a synthesis of task and strategy variables.

Another component of Schraw and Moshman's (1995) taxonomy is regulation of cognition. Regulation of cognition refers to "metacognitive activities that help control one's thinking or learning" (p. 354). There are three essential metacognitive skills under this category: planning, monitoring, and evaluation. Planning includes "the selection of appropriate strategies and allocation of resources that affect performance" (p. 354). For example, deciding how much time to give to a task, how to start, what resources to gather, what order to follow, what to skim and what to give intense attention can be considered as planning activities. Monitoring is the "on-line awareness of comprehension and task performance" (p. 355). For example, one's self-questioning, such as "How am I doing?" " Is this making sense?" "Am I reading too fast?" "Do I understand what I am listening to?" is an indication of experiencing monitoring. Evaluation involves making judgments about the products and regulatory processes of thinking and learning. A typical example to this metacognitive activity can be one's evaluating a use of strategy to achieve the goal by asking "Do I need to use another strategy for the next time?" Schraw and Moshman's (1995) definition of regulation of cognition is similar to Flavell's (1979) metacognitve experiences.

The regulatory processes, including planning, monitoring, and evaluation, may not necessarily be statable and stable (Brown, 1987; Campione, 1987) According to Brown (1987), regulatory activities are relatively age independent but they are task and situation dependent compared to the metacognitive knowledge. These activities are not statable because many of these processes are highly automated and some of these processes have developed without any conscious reflection and, therefore, are difficult to report to others. Regulatory activities are automated for two reasons: the activities may not demand strategic effect or activities that once were laborious may become automatized because of extensive training and experience.

Pintrich, Wolters and Baxter (2000) proposed a different taxonomy in which they divided metacognition into three components rather than into metacognitive knowledge and metacognitive regulation. The difference in their taxonomy and in the previously proposed taxonomies lies in their distinction between metacognitive judgment and monitoring and self-regulation and control of cognition. Their taxonomy consist of three general components of metacognition: (a) metacognitive knowledge, (b) metacognitive judgments and monitoring, and (c) self-regulation and control of cognition. Pintrich et al. (2000) claimed that, in some models of metacognition, metacognitive knowledge is labeled as metacognitive awareness, although awareness indicates a more "on-line," "in the moment," or conscious experience. Therefore, they preferred to consider metacognitve awareness as an aspect of metacognitive judgment and monitoring.

Like Flavell's conceptualization of metacognitive knowledge, Pintrich et al.'s (2000) notion of metacognitive knowledge involves one's knowledge stored in long-term memory about cognition. Unlike the "static" metacognitive knowledge, "metacognitive judgments and monitoring are more process-related and reflect metacognitive awareness and ongoing metacognitive activities individuals may engage in as they perform a task" (p. 48). They categorized four metacognitive processes under the heading of metacognitive judgments and monitoring: (a) task difficulty or ease of learning judgments (EOL), (b) learning and comprehension monitoring or judgments of learning (JOL), (c) feeling of knowing (FOK), and (d) confidence judgments.

The third main component in Pintrich et al.'s taxonomy of metacognition is self-regulation and control of cognition which are the types of activities "that individuals engage in to adapt and change their cognition or behavior" (p. 50). Like metacognitive judgments and monitoring, this component of metacognition is not static but it involves processes and ongoing activities. These activities are dependent on metacognitive monitoring activities. However, Pintrich et al. (2000) conceived them as separate processes. There are four subcomponents subsumed under self-regulation and control: planning, strategy selection, resource allocation, and volitional control.

Although different taxonomies have been proposed to clarify the types of knowledge and processes subsumed under the heading of metacognition, some of the issues presented in the taxonomies still need theoretical clarity. In the next section of this paper, the issues that need further clarification will be discussed and an alternative view to classify the components of the metacognition will be presented.

Problematic Issues in the Definition of Metacognition

It is apparent in the literature that the term metacognition has been used to describe a wide range of knowledge and mental operations. Various taxonomies have been created to differentiate and emphasize certain types of metacognitive knowledge and processes. One of the purposes of creating taxonomies about a construct is to clarify and isolate the components and subcomponents that are distinguishable on some certain characteristics and functions so that the taxonomy can serve as a theoretical guide for the researchers who study this construct and it can facilitate the communication among the individuals who are interested in understanding and studying the construct. Looking at the taxonomies of metacognition that were presented in the previous section of this paper in terms of their function to facilitate communication among researchers, it is apparent that researchers who proposed these taxonomies did not use a consistent and precise terminology to label the components of metacognition. For example, although some researchers including Flavell (1979) and Garner (1987) preferred to use person, task, and strategy variable to classify the components of metacognitive knowledge, some other researchers including Chi (1987) and Schraw and Moshman (1995) chose to categorize knowledge component of metacognition in terms of the differences in the representation of knowledge. Chi's notion of pre-stored meta-declarative knowledge and Schraw and Moshman's conceptualization of declarative knowledge are the same with Flavell's categorization of person variable. Although this type of metacognitive knowledge has the same content and function, it has been labeled differently.

In addition to researchers' use of inconsistent terminology across different taxonomies, they have also used imprecise labels to name the component of metacognition within the same taxonomy. Chi (1987) described meta-declarative, meta-procedural knowledge and meta-strategies as pre-stored knowledge about cognition and second-order operations. On the other hand, Alexander, Schallert and Hare (1991) defined knowledge as "an individual's personal stock of information, skills, experiences, beliefs and memories" (p. 317). This definition suggests that knowledge is an acquired entity rather than a process. Although Chi's definition of metaknowledge involves both knowledge as pre-stored information and processes as second-order operations, she preferred to subsume both pre-stored knowledge about cognition and second-order operations on existing knowledge under the heading of meta-knowledge.

Chi (1987) made a distinction between strategic and procedural knowledge. According to her theoretical framework, strategic knowledge includes domain-general condition-action rules whereas procedural knowledge involves one's domain-specific knowledge about how to do things. On the other hand, Schraw and Moshman (1995) used the term procedural knowledge for one's knowledge about strategies. In other words, a domain-specific label was used to qualify a domain-general knowledge. Using an inconsistent terminology to define the same construct may hinder or slow down the researchers' understanding of it as well as their communication about the construct.

In addition to the use of inconsistent and imprecise terminology, some of the components of metacognition defined in the taxonomies lack theoretical clarity. For example, the nature and function of the metacognitive knowledge is not clearly described in the proposed taxonomies. In some studies, metacognitive knowledge was assessed through verbal reports obtained during and after the participants performed a task or it was assessed by asking participants to describe how they would act in certain hypothetical situations. Researchers considered participants as having metacognitive knowledge if they are consciously aware of their knowledge about person, task and strategy variables and if they use this knowledge while performing the task or while describing how they would act in imaginary situations. Metacognitive knowledge was equated with being aware of the factors that affects one's cognition, being aware of the task characteristics that may influence one's own cognition or using consciously strategies to perform the given task. In the taxonomies proposed it was not made clear whether we should ascribe metacognitive competence to individuals who can consciously use the acquired knowledge about cognition during an ongoing attempt to perform a task or to individuals who only have this knowledge but are not necessarily aware of it. Schraw and Moshman (1995) suggested that individuals might acquire or construct tacit theories about cognition without being aware of them. Although individuals may not report having these theories, these implicit theories may systematically influence their behavior. Therefore, researchers should make clear what they understand from metacognitive knowledge. Does metacognitive knowledge refers to pre-stored knowledge about cognition or does it refer to the conscious use of this knowledge? If it is only having the acquired knowledge about cognition but individuals are not necessarily aware of it, metacognitive knowledge is nothing more than a static entity. However, if metacognitive knowledge is conceptualized as the conscious use of this knowledge, retrieving it from long-term memory and using it when it is needed is an on-line, in the moment activity rather than a static entity.

The issue of consciousness is not only problematic for conceptualizing metacognitive knowledge, but it is also a controversial issue for defining regulatory processes. Is it legitimate to ascribe metacognitive competence to individuals who automatically engage in regulatory processes without being aware of them? Brown (1987) described regulatory processes as "unstable" and not "statable." If an individual demonstrates a planning activity during performing a problem-solving task, but is not aware that s/he is engaged in a planning activity, nor able to describe them to others, does s/he have metacognitive skill? Sometimes when reading a text we notice in the middle of reading that we read a couple of paragraphs without understanding them. Although we did not set a goal to monitor our comprehension before starting reading, we may unconsciously monitor our comprehension and we may say in the middle of reading "Oops! I did not understand what the author means." Even though we may not be aware of the monitoring activity, it may occur at the subconscious level.

Although different taxonomies have been proposed to provide a more systematic view of the types of knowledge and processes under the heading of metacognition, the theoretical problems explained above suggest that the vagueness about the controversial issues is still repeating. Deeper insights based on the systematic analysis of the metacognitive processes and as well as the interaction between the metacognitive processes are still needed. In order to facilitate the progress towards a more systematic view of metacognition, researchers need to use a consistent and precise terminology to label the components of this construct.

An Alternative View for the Conceptualization of Metacognition

Although in many theoretical and research articles metacognition is defined as one's knowledge and control (Brown, 1987; Flavell, 1979) as well as the awareness of and reflection on one's own cognitive processes (Baird, 1990; Weinert, 1987), awareness of the cognitive processes was usually subsumed under the heading of metacognitive knowledge. However, having metacognitive knowledge implies that one has a stock of information about the factors that affect one's learning. In other words, individuals have metacognitive knowledge if they acquired information about cognition as a result of their experiences. This knowledge can be explicit or implicit. That is, individuals can use this knowledge consciously or they can systematically use this knowledge at subconscious level without being aware of it. Thus, awareness does not necessarily mean having metacognitive knowledge.

Individuals can also be aware of their own thought processes by reflecting on existing knowledge, the content of which is not about cognition. For example, suppose that in a classroom setting students are being introduced to a new concept, such as the force concept. Some of the students may ask themselves questions, such as "What do I know about this concept?" "What kind of experiences do I have about this newly presented information?" "What kind of ontological or epistemological assumptions do I make?" and "What is my rationale believing in this concept?" In order to give answers to these questions, individuals need to be aware of and reflect on their existing knowledge. Although the content of the knowledge on which individuals reflect is not about cognition, awareness of and reflection on previously stored knowledge may provide individuals with information about their knowledge acquisition or cognitive processing. In other words, even though the object of reflection is not cognition itself, the information acquired as a result of this reflection gives the individual an idea about her/his learning process. For example, reflecting on the past experiences about force concept may provide the individual with the information that s/he or did not interpret those experiences in the way the scientists do.

It should be noted that reflection on existing knowledge is different from one's awareness of metacognitive knowledge. Awareness of metacognitive knowledge requires one to be conscious of an acquired knowledge that is about cognition, tasks or strategies. Thus, it is necessary to have a stock of information about cognition, tasks, or strategies. For example, one's knowledge that s/he is better at memory tasks than at problem-solving tasks is a static knowledge about one's cognitive abilities. Reflecting on existing knowledge, such as the past experiences about a concept or ontological presuppositions, on the other hand, is simply activating knowledge the content of which is not about one's cognitive activities, tasks, or strategies. That is, the knowledge about past experiences are not necessarily be about cognition or the factors influencing cognition, but it is simply a kind of declarative knowledge stored in long–term memory. Therefore, there is a need to distinguish one's awareness of his/her metacognitive knowledge from one's awareness of and reflection on existing knowledge. For that reason, it is necessary to add one more component to the earlier classifications of metacognition. We prefer to label this component as metacognitive knowing. We used the term "knowing" to emphasize that reflecting on an existing knowledge is a process rather than a static entity.

It must be noted that metacognitive knowing is not merely being aware of or reflecting on any existing knowledge. Information gathered as a result of this reflection must be related to one's own learning process. For example, one's awareness that s/he went to a movie last week is not related to one's learning or cognitive processes. On the other hand, one's awareness on the ontological category to which the individual assigns as concept is related to her/his learning of this concept. Moreover, reflection on existing knowledge does not only mean retrieving the existing knowledge from the long-term memory and making it the subject of the short-term memory but it may also involve one's reasoning, judgments or evaluation of existing knowledge. For instance, one's attempts to assign a concept, such as heat to an ontological category requires one to reason about the conceptual attributes of the heat concept and to judge whether it is a process or a matter. In that case, the individual is not thinking with her/his previously stored knowledge about heat concept, but rather, s/he is thinking about her/his existing concept of heat.

Taxonomies proposed in the literature mainly differentiated two components: metacognitive knowledge and regulation of cognition. Considering metacognitive knowing as another component of metacognition, we can classify metacognition in three components: metacognitive knowledge, metacognitive knowing and regulation and control of cognition. Table 2 shows how the components of our model fit in the previous taxonomies of metacognition discussed in this paper. Like Flavell's (1979) notion of metacognitive knowledge, metacognitive knowledge component involves one's acquired knowledge about cognition. This knowledge can be either explicit or implicit. Even though individuals may not be aware of this stored knowledge, it may systematically influence one's cognitive processes and decisions s/he makes about her/his cognitive activity. The nature of the metacognitive knowing is discussed above. Although there is an overlapping between Chi's (1987) notion of metaknowledge as second-order operations on existing knowledge and metacognitive knowing, Chi's definition of metaknowledge is limited to evaluation and quantification of existing knowledge, such as one's evaluation and the activation of the semantic network about force concept to answer a question about how much one knows

Table 2 Components of metacognition in previous taxonomies

	Components of Metacognition		
	Metacognitive Knowledge	Metacognitive Knowing	Regulation of Cognition
Flavell (1979, 1981, 1987)	*Metacognitive knowledge:* Person, task, strategy variables		*Metacognitive Experience*
Brown (1978)			*Executive control processes*: Predicting the system's capacity limitation, being aware of its repertoire of heuristic routines and their appropriate domain of utility, identifying and characterize the problem at hand, planning and scheduling appropriate problem-solving strategies, monitoring and supervising the effectiveness of those routines it calls onto service, evaluating these operations in the face of success or failure
Kluwe (1987)			*Executive control decisions*: Classification, checking, evaluation, prediction *Executive regulation decisions*: Regulation of processing capacity, regulation of what is processed, regulation of intensity, regulation of the speed of information processing
Chi (1987)	*Metaknowledge* (as stored knowledge about cognition): metadeclarative knowledge, metaprocedural knowledge metastrategies	*Metaknowledge* (as second-order operations on existing knowledge): metadeclarative knowledge, metaprocedural knowledge metastrategies	
Schraw and Moshman (1995)	*Knowledge about cognition:* Declarative, procedural, conditional knowledge		*Regulation of cognition*: Planning, monitoring evaluation
Pintrich, Wolters and Baxter (2000)	Metacognitive knowledge		*Metacognitive judgments and monitoring:* Task difficulty or ease of learning judgments (EOL), learning and comprehension monitoring or judgments of learning (JOL), feeling of knowing (FOK), confidence judgments *Self-regulation and control of cognition*: Planning, strategy selection, resource allocation, volitional control

about force concept. Metacognitive knowing involves, on the other hand, one's reasoning, judgments or evaluation of existing knowledge that is related to the learning of a concept, such as reflecting on the previous experiences about force concept or ontological attributes one assigns to the concept of force. Thus, our characterization of metacognitive knowing is broader than Chi's conceptualization of metaknowledge as second order operations on existing knowledge. Moreover, Chi subsumed both one's prestored knowledge about cognition and second order operations on existing knowledge under the heading metaknowledge. We prefer to use the label metacognitive knowing to emphasize an online process rather than a static entity. Regulation of cognition mainly involves planning, monitoring and evaluation. Regulation of cognition involves activities that are directed at controlling, modification or continuation of a particular cognitive activity of a cognitive entity.

Figure 1 presents a simple schematic diagram of this taxonomy. This taxonomy is represented as a triadic form to emphasize the reciprocal interrelationship among the components. For example, an individual who has an acquired knowledge that "previous knowledge influences subsequent learning" is more likely to reflect on her/his previous knowledge. In other words, having metacognitive knowledge may stimulate metacognitive knowing. Likewise, engaging in a metacognitive knowing activity may provide one with knowledge about her/his cognition. For example, if one needs to make a decision about the difficulty of a problem-solving task and if this knowledge regarding the task difficulty does not exist in her/his memory, s/he is required to reflect on her/his past experiences or existing knowledge about the given task in order make a decision about the task difficulty. In that

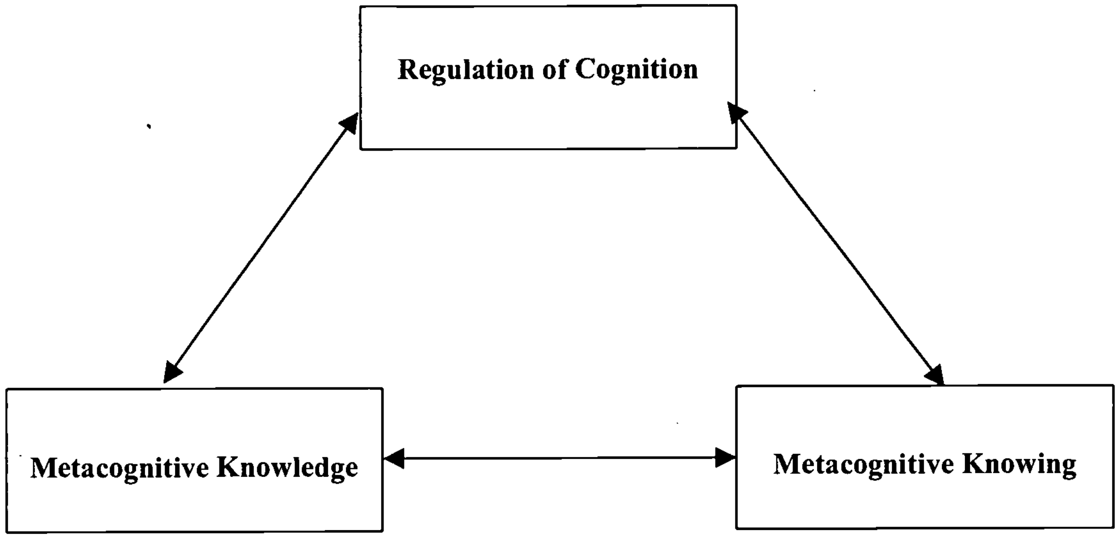

Figure 1. Components of metacognition

case, metacognitive knowing serves as a mediator for obtaining the knowledge about the task difficulty. Similarly, metacognitive knowing activity may also serve as a mediator for control and regulatory activities. For instance, in order to evaluate our performance in learning the newly presented concept we need to reflect on our previous knowledge about the concept. Control and regulatory processes may also lead one to engage in metacognitive knowing activity or may provide the individual with information about her/his own cognition. For example, an individual who detects the conceptual inconsistency between her/his previous and current knowledge as a result of monitoring activity is likely to reflect on her/his past experiences related to concept being encountered. Likewise, an individual who monitors her/his comprehension may acquire knowledge about the factors influencing her/his learning. For example, suppose that an individual who monitors her/his comprehension of a reading passage about philosophy realizes that s/he did not understand the given text. S/he may relate the task characteristics with her cognition and may acquire the following knowledge:

"Philosophical texts are difficult to understand." In order to acquire this kind of knowledge s/he needs to monitor her/his cognitive experience.

Although metacognitive knowing has not been acknowledged as a different component of metacognition in the literature, involving this type of process as a component in the taxonomies of metacognition is fruitful for understanding the interrelationship between the components of metacognition and also for attracting researchers to study the influence of metacognitive activities in conceptual learning and belief change.

Metaconceptual Learning

Recently, many researchers in science education acknowledge the role of metacognitive processes in facilitating or mediating change in students' conceptions (Beeth, 1998; Hennessey, 1999; Vosniadou, 1994; White & Gunstone, 1989). They emphasize the importance of students' awareness of their own conceptions in changing their conceptions. Despite the recognition of the role of metacognition in changing students' conceptions, the nature and the mechanisms of the metacognitive knowledge and processes that are likely to influence conceptual change are not well studied.

Although there are various theoretical and empirical studies which investigated the role of metacognition in memory performance, reading comprehension and problem solving, the nature and the role of metacognitive processes that facilitate the change in students' conceptions have not been well identified in the literature. The term metacognition has been used as a blanket term that covers a wide range of knowledge and processes. In order to foster the communication among researchers as well as to enhance the productivity of researchers' attempts to study the role of metacognition in changing students' conceptions, the types of metacognitive knowledge and process that are more likely to influence the change in students conceptions should be clarified. In order to clarify the critical components of metacognition in terms of the conceptual change process there is a need to focus on knowledge and processes that are related to and acting on one's conceptions. Therefore, as Thorley (1990) suggested it is necessary to make a distinction between "metaconceptual" and "metacognitive" components of metacognition. Based on this suggestion, we prefer to subsume the metacognitive knowledge and processes that are likely to influence the change in students' conceptions under the heading of metaconceptual learning.

It should be noted that metaconceptual learning does not include all kinds of metacognitive knowledge and processes, but rather it involves the kinds of metacognitive knowledge and processes that are likely to influence the change in students' conceptions. Our aim is not to create a new taxonomy to explain all the mental processes subsumed under metacognition, but rather our aim is to emphasize the role of some of the metacognitive knowledge and processes, which we argue are more related to the change in students' conceptions. Therefore, metaconceptual learning is only a portion of the total knowledge and activities that are metacognitive in their nature. Our rationale for including some of the metacognitive processes and restricting others is not based on the results of comprehensive research studies since there is only little research that provides us with an insight into the role of metacognition in conceptual knowledge development. Rather, our rationale is based on theoretical arguments synthesized from our understanding of the theoretical frameworks to explain the change in students' conception and metacognition. In this regard, we are conscious that the theoretical framework of the taxonomy for metaconceptual learning may convey an incomplete representation of all the metacognitive processes that are critical for conceptual change, but it is potentially fruitful for stimulating research practices in this area.

We are also aware that the knowledge and processes subsumed under the heading of metaconceptual learning are not the only mechanisms by which individuals achieve change in their existing conceptual structure. There are other constructs that may influence the change in students' conceptions, such as motivational and affective factors. However, metaconceptual learning is one of the ways that warrants relative permanence of the newly constructed conception.

In line with the taxonomy presented in the previous section, we propose that metaconceptual learning includes metaconceptual knowledge, metaconceptual knowing, and metaconceptual regulation. Metaconceptual knowledge is one's stable and statable knowledge about concept learning and the factors influencing concept formation. This kind of knowledge is acquired through experience and stored in the memory. It can be retrieved from the memory explicitly or implicitly when needed. Metaconceptual knowledge is similar to Flavell's (1979) notion of metacognitive knowledge. The difference between metaconceptual knowledge and metacognitive knowledge lies in their content. The content of metaconceptual knowledge is narrower than that of metacognitive knowledge in that it is only about the concept learning and the factors related to concept learning. For example, one's stored knowledge that "Analogies help me to understand concepts," "My interpretation of daily life experiences influences my learning of the new conception" and "My preexisting knowledge may contradict to the new information presented" can be subsumed under metaconceptual knowledge. An example to the metaconceptual knowledge can be seen in the interview excepts of a study conducted by Thomas and McRobbie (2001) to investigate the effectiveness of an intervention using a metaphor "learning is constructing" on students' metacognition and learning processes. Before the intervention, a participant, Debbie, had a metaconceptual knowledge congruent with transmissionsist view of learning. After the intervention it was apparent that her metaconceptual knowledge became more congruent with a constructivist perspective on learning science concepts:

> The new ideas fit into what I know...into the construction. There's less gap so to speak. There is more links and less gaps. I don't learn each concept as a separate and unrelated subject. By linking and relating and processing information I try to end with understanding of each concept in relation to other concepts that I've learned. (p.240)

The excerpt above indicates that Debbie has the knowledge that her existing knowledge structure influences her learning of a new concept. Such a metaconceptual knowledge will probably lead her to reflect on her existing knowledge and try to make a connection between existing and the new conception.

Metaconceptual knowing is one's online awareness of and reflection on previous concepts, elements of conceptual ecology including past experiences, ontological and epistemological presuppositions. In this case, the learner does not have an already existing knowledge about concept learning, but rather s/he is reflecting on an existing concept the content of which is not about cognition. For example, if an individual asks herself/himself questions, such as "What do I know about this newly presented topic?" "What kind of experiences do I have about this concept?" or "What is my rationale believing in this concept?" s/he is not reflecting on an acquired knowledge about concept learning (metaconceptual knowledge), but rather s/he is reflecting on her/his concept itself, experiences and presuppositions related to the concept. Therefore, retrieving metaconceptual knowledge explicitly differs from metaconceptual knowing. Although explicit use of metaconceptual knowledge implies conscious and on-line activity, metaconceptual knowledge is a stored knowledge about concept learning. On the other hand, the object of reflection in the case of metaconceptual knowing is not a stored knowledge about concept learning but one's concept itself, the relevant experiences, ontological and epistemological presuppositions. For instances, one's statements, such as "I believe that static objects cannot exert force," or "The Earth is flat because it appears to me flat" implies that s/he is reflecting on her/his existing conception and epistemological presupposition. As the examples suggest, metaconceptual knowing is not only retrieving a stored declarative knowledge, but rather it involves one's reasoning about this knowledge.

The other component of metaconceptual learning is metaconceptual regulation. Metaconceptual regulation involves the control and regulatory processes that are directed at the maintenance or transformation of one's own cognitive activity and states during her/his attempts to learn a conception. Examples to those regulatory processes are monitoring the comprehension of conceptions, the coherency between the previous and new conception, the coherency between knowledge pieces that form a conception, the status of competing conceptions, the context in which a conception is used and evaluating the relative ability of the competing conceptions to explain the real phenomenon. For instance, asking questions, such as "Do I understand this concept?" "Which conception is plausible, the one that I already know or the one presented by the teacher?" "Is this concept consistent with what I already know?" "Do I use scientific principles while interpreting my experiences?" "If the earth is a sphere, how does gravity apply force on objects from up to down? What makes me confused about this concept?" "Do I use the same principles in frictionless environment?" and "Is this the best explanation for this phenomenon?" shows one's engagement in metaconceptual regulatory processes. Table 3 summarizes the components of metaconceptual

Table 2 Components of metaconceptual learning taxonomy

Metaconceptual Knowledge	Metaconceptual Knowing	Metaconceptual Regulation
One's stable and statable knowledge about concept learning and the factors that influence concept learning. It is acquired through experience and stored in the memory. It can be used both explicitly and implicitly.	One's online awareness of, reflection on and reasoning of his/her existing conceptions and the factors that influence concept learning including ontological and epistemological suppositions, analogies and experiences.	Ones' control and regulatory activities that are directed at the transformation or maintenance of one's own cognitive activity and states in the process of learning a new conception. These control and regulatory processes are monitoring the comprehension of conceptions, the coherency between the previous and new conception, the coherency between knowledge pieces that form a conception, the status of competing conceptions, the context in which a conception is used and evaluating the relative ability of the competing conceptions to explain the real phenomenon.
Examples: *My preexisting conceptions may contradict to the new information presented. *There must be a reason to think this way than the other. *There might be multiple explanations for an individual concept. *There might be more fruitful and general conceptions which solves many of the encountered problems. *It is important to know the context in which the conception is applicable.	Examples: *What do I know about this newly presented topic? *Do I have any experience related to this concept? *What makes me believe that the Earth is flat? *Are the teacher and me speaking the same language? What do I mean and what does the teacher mean when we refer to …(force, heat, light, mass, weight etc.?) *What kind of assumptions do I make about force concept?	Examples: *Do I understand this concept? *Which conception is plausible, the one that I already know or the one presented by the teacher? *Is this concept consistent with what I already know? *If the earth is a sphere, how does gravity apply force on objects from up to down? What makes me confused about this concept? *Is this the best explanation for this phenomenon? *Am I using a scientific principle to explain this phenomenon? *How do I consider atom in this context? As a quantum object or as a material object?

learning taxonomy along with examples for each components.

The following extract is taken from a written response of a six-grade student who participated in project META study (Hennessey & Beeth, 1993). It serves as a remarkable example to children's ability to engage in metaconceptual knowing and metaconceptual regulation:

> My past ideas. In the past I thought for instance the BOOK ON THE TABLE had only 1 force, and that force was gravity. I could not see that something that was not living could push back. I thought that this push back force wasn't a real push force but just an in the way "force," or an outside influence on the book. However, my ideas have changed since the beginning of this year. Sr. helped me to see the difference between the macroscopic level and the microscopic level that was last year. But I never really thought this difference very much. Then this year I began to think about the book on the table differently—then [last school year] I was thinking on the macroscopic level and not on the microscopic level. This year I was not looking at the table from the same perspective as last year. Last year I was looking at living being the important focus and now I am looking at the molecules as being the important focus. (Hennessey & Beeth, 1993, p. 19)

In this extract it is clear that this student was thinking about her concepts not with her concepts. She was not only aware of her previous concept of force but she was also aware of her ontological presupposition that only living organisms can exert force. She did not only activate her knowledge of her previous concept but she was also able to reason why she believed so in the past. In other words, she was able to reflect on her previous conception about force and the presuppositions that constrained her previous conception. Reflecting on the previous concept and the presuppositions behind the concept provided her with information about her previous mental representation of the force concept. Her engagement in this process shows that she was able to perform a metaconceptual knowing activity. She was also able to compare the differences between her perspective in interpreting her previous concept and her current concept by saying that she looked at the "book on the table" task that are likely to influence conceptual change process is crucial for teachers and researchers who aim to facilitate the development of scientifically acceptable concepts through improving students' metacognitive abilities or who aim to investigate the characteristics or dynamics of the relationship between metacognition and the change in students' conceptions. There is only a limited number of empirical research that aimed to facilitate the change in students' conceptions through enhancing students' metacognitive activities. Theoretical arguments to identify and classify the types of knowledge and processes are fruitful in terms of providing a theoretical background for the progression of empirical research in this area. In the next section of this paper, a review of empirical research studies that investigated the role of metacognition in changing students' conception will be presented.

Research Efforts to Facilitate Conceptual Change Through Metacognition

The instructional implications of the different theoretical frameworks that explain the change in students' conceptions emphasize students' engagement in metacognitive activities. The intertwined nature of metacognitive activities and conceptual change has been acknowledged by various researchers (Baird, Fensham, Gunstone, & White, 1991; Gunstone, 1994; Gunstone & Mitchell, 1998; Rickey & Stacy, 2000). White and Gunstone (1989) pointed out the importance of metacognition in promoting conceptual change by saying that "If metalearning can be taught, then the problem of how to bring about conceptual change may be solved" (p. 581). It is apparent that the metaconceptual processes explained above require a higher level of thinking which is not easy to achieve through traditional instruction. These activities can be mediated by creating learning environments in which students are assisted and encouraged to think about, monitor and evaluate their conceptions and the associated components of their conceptual ecology.

There have been encouraging but only a few investigations that aimed to promote the development of scientific conceptions through improving students' metacognition. The Project to Enhance Effective Learning (PEEL) is one of the research studies that attempted to facilitate the change in students' conceptions through enhancing their metacognitive activities. The main aim of this long-term and "naturalistic" case study is to "foster students' independent learning through training for enhanced metacognition" and to "change teachers' attitudes and behaviours to ones that promote such learning" (Baird & Northfield, 1992, p. iii). Many academics and voluntary groups of teachers participated in this project to develop and investigate classroom approaches that would stimulate and support a more informed, purposeful, intellectually active and independent student learning.

Baird (1986), one of the researchers in the PEEL Project, worked with a science teacher and three of his classes for six months to improve students metacognition. At the beginning of the study the students were passive and ignorant about how to improve their learning. Baird provided students with instructional materials and procedures including questionnaires about learning, discussions about learning and a checklist of questions that encourage them to think metacognitively. Baird concluded that students became more aware of their learning style, became more purposeful and attained a greater understanding of the content as a result of this intervention. However, there were noteworthy factors that worked against metacognition including students' lack of motivation to accept metacognitive activities as a means of learning. White and Gunstone (1989) quoted the following discourse that took place between a teacher and students who participated in the PEEL study:

> We see what this is all about now,' one said. 'You are trying to get us to think and to learn for ourselves.'
> 'Yes, yes,' replied the teacher, heartened by this long-delayed breakthrough, 'that's it exactly.'

'Well,' said the student, 'we don't want to do that.' (p. 585)

This quote is a salient example illustrating the difficulties in motivating students to engage in the efforts necessary for improving metacognition. White and Gunstone (1989) argued that learners must be "dissatisfied with their present style of their learning" and must "find metacognition plausible, intelligible and fruitful" (p. 585) in order to accept metacognition as a means of effective learning.

Another factor that worked against metacognition was the inconsistent curriculum across different subject areas. Although the normal practices of other teachers in other subject areas did not interfere with the project, students did not find it fruitful to be metacognitive in other classes since their teachers complained that students were disrupting the lessons by asking questions. White and Gunstone (1989) also pointed out the type of assessment methods may lead students to adopt short-term goals which make both metacognition and conceptual change "fragile and artificial" (p. 585).

The Project META (Metacognitive Enhancing Teaching Activities) is another research study conducted by Hennessey (1999) to promote metacognition and conceptual change. She designed a system of instruction to improve metacognition within a naturalistic classroom setting. Through collecting data from six cohorts of elementary students (grade1-6) over a three consecutive academic years, Hennessey aimed to gain insight in the nature of metacognition, the features of higher-level metacognitive thought, processes that lead to change students metacognitive capacities with experience and the role of pedagogical practices in facilitating changes in metacognition and changes in students' conceptual understanding.

Throughout this study, three types of learning activities were used to improve metacognition: poster productions about students conceptions, conceptual models designed by the students to represent their conceptual frameworks, and technology in the from of word-processing, computer-based graphic programs, student generated audio and video recordings. During the use of these instructional practices both small group and large discussions about the conception themselves and their representation took place.

The analysis of the data demonstrated that metacognition is multifaceted in its nature and is within the capabilities of elementary school students. Although Hennessey (1999) was cautious about the conclusion of a causal relationship between the change in students' metacognitive ability and the change in their conceptions, she argued that metacognition is an integral component of conceptual understanding. She noted that "metacognitive sophistication and conceptual understanding need to be supported by pedagogical approach that emphasizes reflection on and evaluation of personal claims"(p. 47).

Beeth (1998) used a different approach in which the status language was used as a "metacognitive tool" by the students to reflect on their science conceptions. The participants of the study consisted of 12 fifth grade students attending a small suburban parochial school and their teacher (Sister M. Gertrude Hennessey) who has been working as a science specialist for more than 20 years in parochial schools. In this study, the teacher and the students first negotiated the definitions for the status terms (eg., intelligibility and plausibility). This negotiation process took about 7 weeks for the definition of intelligibility and 4 weeks for the definition of plausibility.

After a shared understanding of the status terms was established, the teacher continually requested and encouraged students to use the status constructs when talking about their conceptions related to force and motion. The students in this study were able to apply the status language in a powerful way while reflecting on their conceptions. This metacognitive reflection helped students gain deep insight into their conceptions and allowed the teacher to monitor students' conceptual development to plan future instructional activities. Beeth emphasized the "dynamic role" (p. 355) of the teacher in providing students with metacognitive tools and in creating a learning environment that is conducive to conceptual change learning. In this study the teacher was able to facilitate students' development of scientific concepts by designing a responsive instruction based on the students' ideas and the reasons behind their idea.

Wiser and Amin (2001) investigated the role of metaconceptual teaching on the ontological change in students' conception of heat and temperature. The metaconceptual teaching implemented in this study mainly addressed the fact that students and scientists may use the same word for different conceptual referents. Metaconceptual teaching lead to a ontological reorganization in terms of students' conceptions of heat. Before the metaconceptual teaching students understood heat as an intensive physical entity with the essential property of hotness. Metaconceptual teaching allowed students to differentiate among heat as an extensive and temperature as an intensive quantity. After the metaconceptual teaching students were able to describe heat as energy that propagates from the hotter object to the cold one and causes temperature and phase changes. The results of this study indicates that students were able to differentiate hotness and heat in terms their ontological attributes, thus, they were able to engage in metaconceptual knowing.

The results of the research studies that aimed to promote students' conceptual understanding through improving their metacognitive reflections are fruitful in terms of providing an empirical support for the relationship between metacognition and conceptual change. On the other hand, they do not provide us with a rich knowledge base for the nature and the dynamics of the relationship between metacognition and conceptual change. The role of some of the metaconceptual activities, such as reflecting on epistemological and ontological presuppositions, reflecting on and monitoring the function of a conception in a given context, or monitoring the coherency among the knowledge pieces, in changing students' conception still needs further empirical clarification.

However, students' ability to engage in metaconceptual activities such as their ability to reflect on the status of their conception is promising for further research. The studies demonstrated that even elementary school children can think about their ideas and provide reasons for their ideas if the teacher uses instructional strategies that support students' exploration their own and others' ideas. However, it is apparent that improving metaconceptual sophistication and conceptual understanding takes a lot of time and requires a wide range of instructional activities. In Beeth's (1998) study, for example, it took 11 weeks for only teaching students the status language. This result implies that both the teacher and the curriculum needs to be flexible in order to create an instructional environment that allows the teacher to respond to the students' developing of science content ideas and to meet the on-going needs of the students during the process. As White and Gunstone (1989) pointed out, students' lack of motivation to engage in the training practices is the greatest barrier for the improvement of the metacognition. No matter the quality of instruction is, metacognitive sophistication cannot be gained if students do not actively engage in the instructional process. Therefore, it is very critical to make students dissatisfied with their present state of learning progress and to encourage them to set learning goals. Finally, the cognitive and metacognitive demands required from the students must be consistent across different subject areas, different contents within a subject area and different contexts of instruction to keep students responsible for their own learning.

Conclusion

The difficulty of learning a scientific conception that is inconsistent with the existing conceptions has attracted a lot of researchers to develop various theoretical frameworks that explain the change in students' conceptions. Among the theoretical frameworks proposed, the initial CCM has been widely accepted, but at the same time it has been criticized by various researchers in terms of it's over emphasis on the rationality and negligence of motivational factors and the context. The other theoretical frameworks have offered different explanations for the conceptual change based on their different theoretical orientations to describe the nature of conceptions and human learning. Despite to the initial CCM that views conceptual change as the replacement of the existing conception with the new conception, the other theoretical perspectives mainly point out that old conceptions are not extinguished but rather individuals may continue to use them in other contexts. In these new perspectives to explain students' learning of science conceptions, the role of the epistemological and ontological presuppositions, everyday experiences and the context in which the conceptions are used is highly acknowledged.

The theoretical arguments presented in the new perspectives on conceptual change suggest that conceptual change is not a simple process. Rather it is complicated and multifaceted process in the sense that it does not only involve as basic replacement of the existing conception with the new conception but also a major restructuring of the mental structure and its underlying elements. This complex restructuring involves integrating the phenomenological experiences appropriately into a coherent and complex knowledge structure, and evaluating and differentiating between different ontological categories, epistemological and ontological presuppositions, the everyday life experiences which led to the formation of epistemological and ontological assumptions, and the contexts associated with specific use of a conception. It is apparent that such a complex restructuring requires higher order thinking skills including recognizing, integrating, monitoring and evaluating existing conceptual structure, its associated elements, the new conception and the context. These processes which require knowledge, awareness and regulation are all metacognitive in their nature. Hewson, Beeth and Thorley (1998) pointed out that processes, such as "commenting on, comparing and contrasting these explanations, considering arguments to support or contradict one or another explanation, and choosing one of these possible explanations are metaconceptual activities" (p. 205) and are inherent in the conceptual change process.

Although the intertwined nature of the metacognition and conceptual change has been acknowledged by several researchers, the metacognitive processes that are likely to influence the change in students' conceptions have not been well clarified in the literature. The current literature on metacognition gives more emphasis on general metacognitive knowledge, strategies, and processes which is isolated from conceptual knowledge. Although these general elements of metacognition has significant role in learning and problem solving situations we believe that it is necessary to outline the specific types of metacognitive knowledge and processes that are critical for conceptual change. Various research studies (Beeth's, 1998; Hennessey, 1999; Hewson, Beeth and Thorley,1998; Wiser and Amin, 2001) explicitly show that metacognitive knowledge and processes based on conceptual knowledge such as awareness and reflection on existing conceptions are important mediators of conceptual change in terms of restructuring the existing conceptual system.

The term, "metaconceptual learning", is deliberately chosen to emphasize the role of students' own act of learning. Based on the constructivist tradition we assume that knowledge acquisition is an adaptive process that organizes one's experiential world. We interpret this organization as conceptual restructuring in the process of acquiring scientific conceptions. Based on several researchers' (Chi, Slotta, & Leeuw, 1994; diSessa, 1993; diSessa, 1983; Vosniadou, 1994) deep analysis on the nature of conceptions and conceptual development, we contend that conceptual restructuring is not a simple replacement of existing conceptions instead it involves major restructuring of conceptual system with underlying epistemologies and attributed ontological categories. Although the external stimulations such as providing anomalous data, using analogies and anchoring conceptions have significant roles in the process of restructuring, it is finally an internal process and the trigger of this process is individuals' intention and motivation.

Considering the acquisition of scientific conceptions as an internal and intentional process, we contend that it is crucial for learners to engage in conceptual based metacognitive activities. In this preliminary study, we outlined three elements of conceptual based metacognition as metaconceptual knowledge, metaconceptual knowing and metaconceptual control and regulation, and subsumed these elements under the heading of metaconceptual learning. Although the theoretical framework of metaconceptual learning is not based on a comprehensive research studies, some of the metaconceptual activities have potential to solve some of the problematic issues in concept learning, including durability and transferability of the conceptions.

One of the frequently encountered problems of science education is students' inability to transfer science conceptions into different contexts and situations. Georghiades (2000) argued that conceptual change usually cannot go beyond "conceptual correlation" which is "a process in which the learner correlates specific scientific conceptions with specific settings, within which the former can be applicable" (p. 123). He noted that instruction that aims to promote metacognition could be effectively used to deal with transferability of the conceptions to different contexts. If the learner's ability to reflect on the function of a conception in different contexts is enhanced, the application of the conception in different contexts can be promoted. Moreover, one's reflection on epistemological and ontological presuppositions may lead to a major restructuring of the mental model of the learner about the conception. A replacement of the old conception with the new conception without restructuring the presuppositions will only be a surface level modification and may not last long. Therefore, one's engagements in metaconceptual activities may potentially enhance the transferability and durability of the conceptions. There is a need for empirical research studies that investigate the role of metaconceptual learning activities in the transferability and the durability of the conceptions.

The limited number of research studies have been conducted to improve students' metacognitive abilities for facilitating the change in their conceptions show that enhancing metaconceptual learning is not straightforward process by any means. Encouraging students' to engage in metaconceptual activities requires changes in curriculum, instructional activities and assessment techniques. In this regard, students' reflections about their conceptions and their regulatory processes acting on their conceptions should be as valued as their cognitive processes at the content level.

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