An Integrated Theoretical Structure of Mental Models: Toward Understanding How Students Form Their Ideas about Science

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Abstract: When modeling students' conceptual understanding, there are several different frameworks, among which are the alternative conception framework and the mental model framework, which converge to suggest a form of knowledge representation. However, little research has explained how they are different from each other and from memory. The purpose of this study was to develop a new mental model theory that integrates the different terminologies and their background theories, which refer to students' ideas not only in science education, but also in other research areas. For this purpose, at first, we compared different terminologies including alternative conception, p-prim, and mental models, and the underlying theories used for representing students' ideas in learning science. Through such comparison, we tried to find the relationship among them. We reviewed related literature and synthesized the results from both cognitive science (related research areas) and science education approaches, especially, Vosniadou's mental model theory. Based on reviewing previous studies, we have developed a preliminary mental model theory 'an integrated theoretical structure of mental models'. We applied the new mental model theory to interpret data on students' ideas about circular motion from our previous research. We expect our new mental model theory will help us understand how students form their own ideas in science from an integrated perspective.

Key words: alternative conception, mental models, integrated theoretical structure of mental models

I. Introduction

Research in cognitive science, science education, and developmental psychology during the last decade has shown that students construct an intuitive understanding of the world, which is based on their everyday experience (Duit, 2003). Although different terms have been used to refer to this type of knowledge-such as alternative conception, preconception, misconception, folk theory, naïve theory, intuitive theory, and mental model theory- there is general agreement that this intuitive knowledge provides explanations of natural phenomena that are frequently different from the currently accepted scientific explanations and that tend to be resistant to change (Park & Lee, 2004).

The terminology 'alternative conception (or misconception)' has been preferred by many researchers in science education to describe students' intuitive understanding (Wandersee et al., 1994). Since the middle of the 1980s, much of the effort in the published science education research literature has been directed toward documenting the alternative conceptions of students and to develop instructional methods to deal with them. Researchers have found that the characteristics of alternative conceptions are very complex. Sometimes students' conceptions seem to be stable, but sometimes they can also be volatile. They can be created differently depending on the specific situation.

In recent research, many new terms have been created to describe the features of students' knowledge. A non-exhaustive list includes mental models (Vosniadou, 1994), p-prims (diSessa, 1993), facets (Minstrell, 1992), and coordination classes (diSessa & Sherin, 1998). Researchers invented these new terminologies in order to explain a finer layer of the diverse aspects of students' ideas, which were not considered in alternative conception theory. The use of the new theoretical models was not limited to

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science education. In cognitive psychology, researchers have also considered mental model theory and information processing theory. As a result, many different terminologies have been employed, sometimes leading to confusion.

Redish (2004) asserts that it is important to develop a theoretical framework, which utilizes shared language and shared assumptions and through which different theoretical models of student thinking can be compared so we can accumulate, evaluate, and refine what we have learned.

The purpose of our study was to develop a new mental model theory, which can help us to integrate the different terminologies and their background theories and to understand what we have learned from students' learning. For this purpose, we compared different terminologies (alternative conception, p-prim, facet, mental models) and the underlying theories used for representing students' ideas in learning science, and tried to find the relationship among them. We reviewed related literature and tried to synthesize the results from both cognitive science and science education approaches. We think that Vosniadou's mental model is more currently available (Park & Lee, 2004), but her mental model theory has some limitations as she mentioned (Vosniadou, 1999), especially in terms of motivation theory and information processing theory. Thus, we have developed a preliminary mental model theory that we have applied to interpret data from our previous research.

II. Theoretical Background

There are two somewhat independent research traditions (science education and cognitive psychology), which converge to suggest a form of students' ideas or knowledge representations as shown in Figure 1: we call these convergences, such as P-prim and mental models, 'alternative conceptions':

In the 1970s, a number of researchers in the area

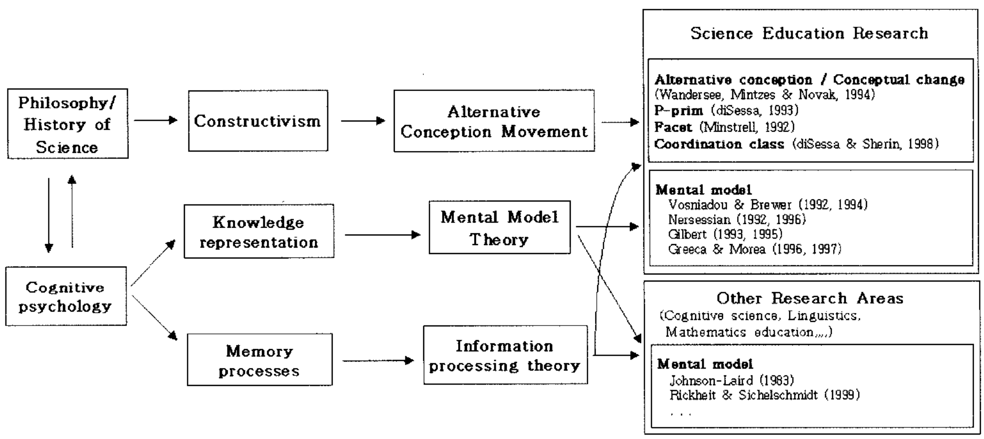

Fig. 1 *Research trend on students' ideas in science education & other research areas*

Table 1

Studies on students' conceptions in different areas (Adapted from Pfundt & Duit, 1991)

Content topic	Number of articles	Concept
Mechanics	281	Force and motion/ work, power, energy, etc.
Electricity	146	Simple, branched circuits/models of current flow/ current, voltage, etc.
Heat	68	Heat and temperature/ heat transfer, etc.
Optics	69	Light/ light propagation/ vision/ color, etc.
Particles	60	Structure of matter/ explanation of phenomena, etc.
Energy	69	Energy transformation/ energy conservation, etc.
Astronomy	36	Shape of the earth/ satellites, etc.
Modern Physics	11	Quantum physics/ special relativity, etc.
Chemistry	132	Combustion, oxidation/ chemical reactions, etc.
Biology	208	Plant nutrition/ photosynthesis/ osmosis/ life, etc.

of science education published papers describing 'alternative conceptions' in students' understanding of a variety of natural phenomena (Wandersee et al., 1994). Constructivism in the field of philosophy/history of science has affected the alternative conception movement. The research movement has produced many terminologies and related theory such as p-prim, facet, coordination class, and mental models. On the other hand, mental model theory in cognitive psychology has affected mental model research in science education and other areas. Information processing theory also has affected the development of mental model theory in other areas including mathematics education and linguistics.

Table 1 shows examples of such studies on students' alternative conceptions in different content areas. The table gives the number of articles and concepts contained in the bibliography by Pfundt and Duit (1991) in each content area.

There are significant knowledge claims emerging from the research on students' alternative conceptions. Some of these knowledge claims are: (1) Students come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events; (2) The alternative conceptions that students bring to formal science instruction cut across age, ability, gender, and cultural boundaries; (3) Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies (Wandersee et al., 1994).

Several different terminologies (such as misconceptions, p-prims, facets, and coordination classes) have been used to explain students' ideas about science. Common misconceptions include: (1) Students' conceptions that are stable and resistant to change, and (2) Students' conceptions that disagree with accepted scientific knowledge (Wandersee et al., 1994). P-prims are primitive elements of knowledge structure that explain other phenomena, but they are not themselves explained within the knowledge system (diSessa, 1993, 2002). For examples, "More effort begets more result"; "more resistance begets less result". A facet is specific statement describing the functioning of a particular phenomenon (Minstrell, 1992). A coordination class is a specific collection of knowledge and strategies that allows us to read out a distinctive class of information from the world (diSessa & Sherin, 1998). Coordination classes have two different components. One is a readout strategy, which is a set of resources that translate sensory information into meaningful and processable terms. The other component is a causal net, which is a set of relevant inferences about the relevant information and its context-dependent associations.

In cognitive psychology, Johnson-Laird (1983) introduced the term 'mental model' to refer to a form of mental representation (Mishra & Brewer, 2003). The idea of a mental model has been used in research in different areas with different meanings (Borges & Gilbert, 1999). For some researchers, a mental model is just a representation of some aspects of the world, whereas for other researchers it is an analog of objects in the world. Mental models serve as means with which to explain the relationship between one's cognitive activity and the world. In this view, mental models are unstable, naturally evolving and incomplete. The views adopted by most researchers may be seen as delimited by these two extreme positions (Borges & Gilbert, 1999).

Recently, one of the main features of science education research is the increasing importance of this concept of 'mental model'. It appears that, with the concept of the mental model, science educators are attempting to overcome some limitations of the Alternative Conceptions Movement (ACM), such as the context-specific characteristics of alternative conceptions, the difficulty of the ACM in developing overall interpretations for domain-specific alternative conceptions, and the difficulty in offering theoretically dense approaches to an understanding of such educational phenomena (Franco et al., 1999).

Mental model theory has tried to explain students' intuitive understandings of the world from integrated perspectives. From the early 1990s, Vosniadou has been publishing research papers on mental model theory. She explained that mental models "refer to a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning" (Vosniadou, 1994, 1999).

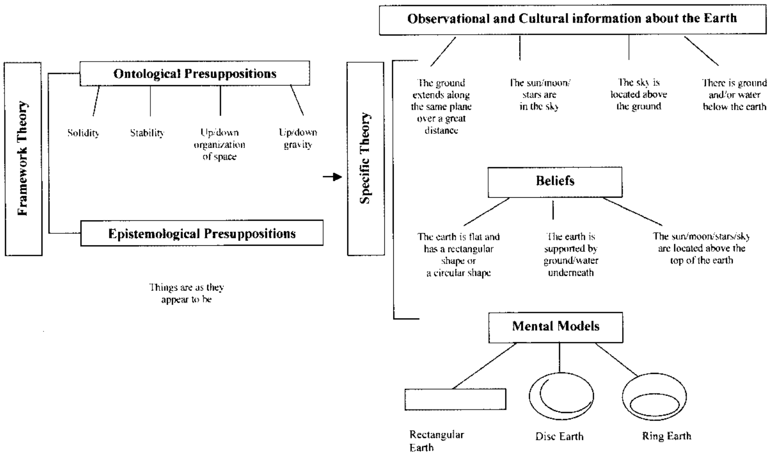

Fig. 2 *Vosniadou's mental model theory*

Throughout her study, Vosniadou has referred to her interpretations of students' conceptions as mental models.

According to Vosniadou, mental models are constructed within a conceptual structure, which has presuppositions (epistemological, ontological) and beliefs from observations in cultural context. A mental model is constrained by a set of presuppositions that are derived from everyday experiences and that are consistent with individual beliefs about physical objects.

Figure 2 shows students' mental models about the shape of earth as found by Vosniadou (1994). According to her, these mental models are formed from a conceptual structure, which has a framework theory (ontological/epistemological presuppositions) and a specific theory (beliefs). Framework theories are the basis for the formation of mental models. Figure 2 shows Vosniadou's explanation of how framework theory and specific theory construct conceptual structure and how mental models are formed from the structure.

However, in Vosniadou's theory, the terms 'framework theory', 'specific theory', and 'conceptual structure' are very ambiguous. A more detailed structure and process is needed to answer the following questions: (1) "Where are mental models?"; (2) "Where are presuppositions and beliefs?"; (3) "How do they interact with each other?" In addition to these questions, Vosniadou's mental model theory misses some important factors that can affect the formation of mental models including thinking strategies, motivation, and volition.

Where do mental models (and alternative conceptions) come from? In order to answer this question, we should first know what memory is, since memory is the place where our knowledge is stored and retrieved (Figure 3). Memory can be divided into two primary components: working memory and long-term memory. Working memory is the temporary storage and processing of information that can be used to solve problems, respond to environmental demands, or achieve goals. Working memory is rapidly accessed and severely limited in capacity. Many theorists portray working memory as playing a central executive role, in essence controlling and monitoring an individual's overall memory processes. In a nutshell, working memory is the component in which "thinking" occurs: therefore, we might think of it as the "awareness" or "consciousness" of the memory system. Long-term memory (LTM) is the part of the memory system that retains information for a relatively long period of. LTM includes both memory for specific events and knowledge that has been gleaned from those events over the years (Ormrod, 1999). Types of memory (in LTM) can be distinguished by the kind of knowledge stored and the way this knowledge is retrieved and expressed (Westen, 1999). There are two kinds of knowledge, declarative and procedural.

Since conceptions are the principal units of knowledge organization, we can say that students' alternative conceptions are one of the principal units

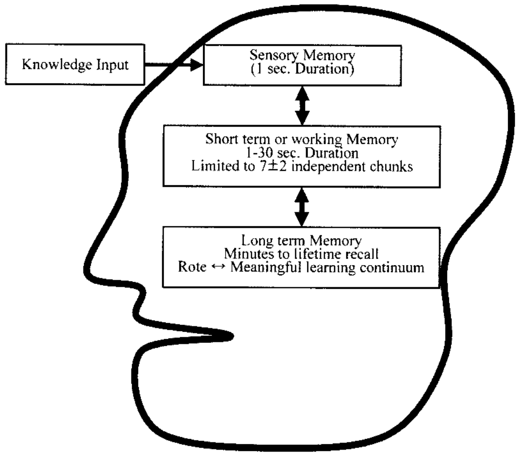

Fig. 3 *The model of the information processing theory*

of knowledge as a part of their LTM. There is little in the literature that explains how alternative conceptions are constructed even though some researchers have suggested several sources (Duit, 1991). Some examples of these suggestions include sensual impression, everyday language, and innate structures of the brain, learning in students' social environments, and instructions.

III. An Integrated Theoretical Structure of Mental Models

The definition of mental model

A mental model is a dynamic representation integrating external information recognized and individual knowledge. In terms of memory, a mental model is constructed in working memory, which involves mental representations of words or images themselves reflect an interaction between current sensory data and stored knowledge and beliefs in LTM. In terms of Vosniadou's mental model theory, presuppositions and beliefs support the formation of mental models. P-prim (or facet) theory explains the students' reasoning as a part of mental models (or the formation of mental models).

Thus, any given theory accounts for only some of the data that have been amassed about mental models. Moreover, each theory provides a particular picture of mental models that highlights some aspects and obscures others. Because the idea of mental models is such a complex matter, it is perhaps very difficult to conceive of a single theory broad enough to encompass all of the important aspects of mental models and yet still specific enough to be useful for instruction.

Because each theory only touches different parts of mental models, we need to make an effort to grasp the whole picture of mental models, especially when we try to solve the complex problems of educational practices. In order to accomplish this task, we need an integrated approach: an approach which includes not only recent main theories such as alternative conceptions, p-prims (or facet) and Vosniadou's mental model theories, but also other related theories (e.g., motivation, thinking strategies, metacognition).

Thus, in addition to the previous research trend (Figure 1), we should be open to other areas. For example, we should consider affective domain theory. Figure 4 shows the integrated perspective of our theory on mental models. It has cognitive and affective components, which can explain the structure and process of formation of mental models from diverse perspectives. For example, cognitive theories include students' conceptions, conceptual change, and cognitive development. On the other hand, affective theories include mostly motivation theory, which features branches such as goals, interest, task value, self-efficacy, control beliefs, and volitional control (Pintrich et al., 1993). We also think about other possible factors that can affect the formation of mental models, such as self-regulated factors (volition control) (Boekaerts, 1997, 2002; Corno & Kanfer, 1993; Corno & Randi, 1999; Kuhl, 1985; Zimmerman, 2001), cognitive conflict, and attitude (Pintrich & Sinatra, 2003).

These theories are all components of a more complete understanding of mental models. We have developed an integrated theoretical structure that encompasses the previous models as subsets of the more complete model (Figure 5). As can be seen in Figure 5, our theory has a structure that is the basis for the formation of mental models. Figure 5 also shows the formation process for mental models.

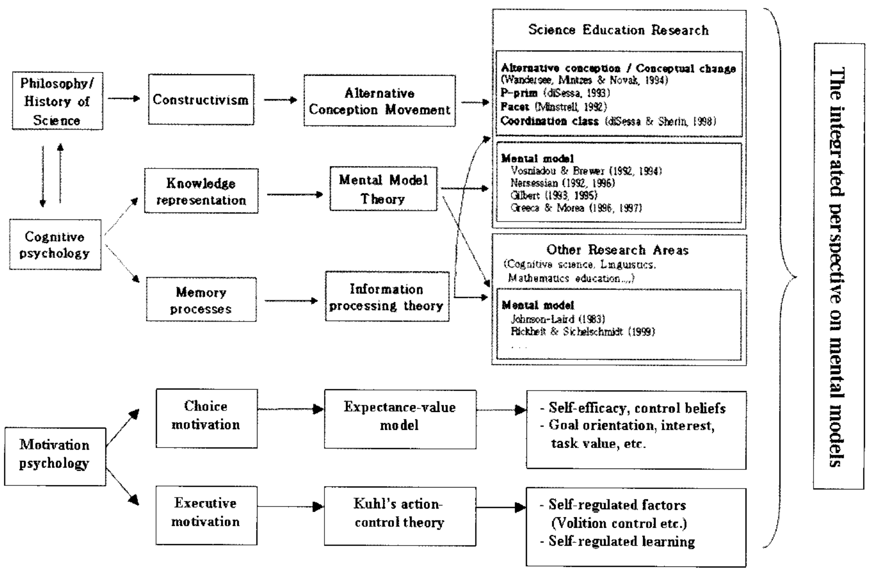

Fig. 4 *The integrated perspective on mental models*

Perception and knowledge

Perception and knowledge are generally recognized as the principal sources of mental model. The perception of visual, auditive, tactile, or haptic information marks one side of higher cognitive processes that is sometimes called 'bottom up' or 'data driven.' Mental models are contingent on external information insofar as the incoming data is a cue to particular analytical or synthetically subprocesses (Yates, 1985).

Knowledge, on the other hand, marks the other side of higher cognitive processes; the one that is sometimes called 'top down' or 'schema driven'. Knowledge is stored in the LTM. Types of memory can be distinguished by the kind of knowledge stored and the way this knowledge is retrieved and expressed (Westen, 1999).

People store two kinds of knowledge: declarative and procedural. Declarative memory is memory for facts and events. It has two kinds of memory: semantic or generic memory (general world knowledge or facts) and episodic memory (memories of particular events). Procedural memory refers to "how to" knowledge of procedures or skills.

According to retrieving (or expressing) knowledge, there are two kinds of memory. Explicit memory refers to conscious recollection, expressed through recall or recognition. Implicit memory is expressed in behavior rather than consciously retrieved.

Epistemological/ontological/motivational beliefs

Beliefs are also the components of LTM. They serve to constrain the types of knowledge and inferences people may hold in their mental models. For example, Vosniadou and Brewer (1994) stressed the role that epistemological and ontological beliefs play in the formation of mental models. Epistemological beliefs are beliefs that have to do with the nature of our knowledge. Epistemological beliefs are also beliefs that have to do with the nature of learning. These beliefs are usually the criterion individuals use when they judge whether they learn and understand something.

Ontological beliefs include the basic beliefs about the nature of objects such as physical objects are solid, stable, and if not supported, will fall down (Vosniadou & Brewer, 1994). In this, epistemological and ontological beliefs may constrain conceptual knowledge that individuals may acquire from their observations and experience in the cultural context by limiting the inferences individuals make about their observations.

Pintrich (1999) and Pintrich and Sinatra (2003) extend the logic of Vosniadou and Brewer's theory

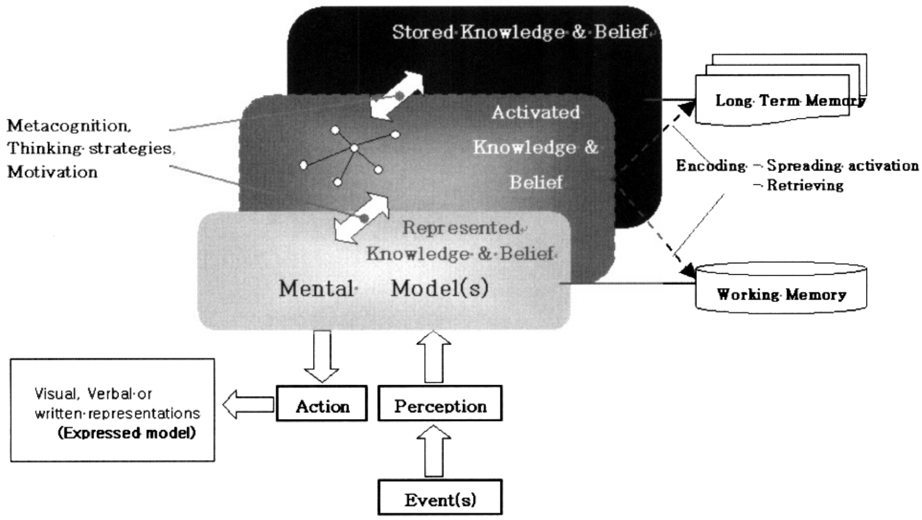

Fig. 5 *An integrated theoretical structure of mental models*

by suggesting that motivational beliefs about self and learning can play the same role in terms of being a resource to support or constrain the formation of a mental model. They argue that, "motivational beliefs, as presuppositions or theories about the self and learning, may influence the types of inferences and belief formation that take place as students acquire knowledge and build their mental models." As Pintrich (1999) has noted:

Certain types of motivational beliefs may inhibit certain types of cognitive processes from occurring, whereas other motivational beliefs may facilitate cognitive engagement. These motivational beliefs and various cognitive and metacognitive strategies are assumed to be "resources" that students can bring to bear on the task at hand to help them to learn (p.34).

Thus, we believe that mental models depend on individual knowledge insofar as the incoming data is interpreted with respect to various beliefs.

Context

Classroom context can be another factor that affects the formation of a mental model since knowledge and beliefs are embedded in various classroom contexts. For example, in a problem-solving situation, the contextual task that confronts the students can activate motivational beliefs and related knowledge. According to the pattern of the activation of knowledge (or beliefs), there might be different inferences and linked knowledge in the process of mental model formation.

Thinking strategies and metacognition with knowledge & beliefs

We can think about an example of how we form a mental model using Figure 5. If we were confronted with an event (such as a test), during perceiving (or reading) it, our knowledge and beliefs would be activated. Activation is related to working and long-term memory since working and long-term memory are not separate components, but instead simply reflect different activation states of a single memory (Ormrod, 1999). This connection is the reason why we use two dotted lines to represent the relationship between activation and memory in Fig. 5. Selective activation means that we are paying attention to and processing the information, which may include both incoming information and information previously stored in memory. There may be encoding process besides selective activation from perceiving incoming information, through representing it (forming mental model), to storing it in long-term memory.

In this process, thinking strategies and metacognition may play a crucial role in forming mental model(s) in working memory. These factors will organize activated knowledge and belief to represent or understand world as a recognized result (we call this 'mental model'). On the other hand, thinking strategies and metacognition simultaneously may help us encode incoming information into long-term memory by organizing the information. In figure 5, we use a two-way arrow to represent this process.

Expressed models

Finally, by action (such as talking and writing) we will present mental model(s), namely the expressed model. In an interview or test situation, we can only see (or listen to) the expressed model(s) students present. Using the expressed model(s), we can speculate what the students' conceptions, p-prims (as modular reasoning structure, following Redish, 2004), or mental model(s) are. We should recognize the difference between the expressed models (what we see) and the terminologies (what we speculate), which we generally refer to as students' ideas in science. Here, action reflects the amount of effort(Volition) that a student uses in a task.

IV. Reinterpreting Previous Research Data with the Integrated Theoretical Structure of Mental Models

In our previous research (Lee et al., 2004), we conducted a case study to investigate students' cognitive conflict when students were confronted with an anomalous situation (Virtual Reality Experiments). Four Korean high school students (11th grade, male) voluntarily participated in the research. For the data collection, we used individual interviews and concept maps about a circular motion. The physics problem in the interview was to find the forces acting on the coin placed on a disk rotating at constant speed. Two students were high-level students (within 5% in his class in physics achievement of school tests). The other two students were low-level students (below 70% in their class in physics achievement of school tests). The research procedure followed the POE (Prediction-Observation-Explanation). In an individual interview, we asked students to predict the direction of forces for the circular motion at a constant speed. After the students explained their prediction, they practiced a virtual reality simulation with joystick (haptic feedback) about the circular motion and observed the results on the computer screen.

In our previous research (Lee et al., 2004), we found that one student, Jinphil, had two mental models, even though he chose to write an answer that represented only one of the models. When he saw the circular motion problem with a constant speed at the beginning, he said, "There is only one force (on the object) that is toward the center of the circle. Since the direction of acceleration is toward center, the direction of force is toward center too." In this answer, he recalled what he learned in a physics class on centripetal force.

However, in the following interview, he said, "in physics it (his previous idea) makes sense. However, it does not do so in my own experiences" with representing the second model that has an acceleration in the direction of tangent. For him, "in physics" means, "It is like thinking force, acceleration, velocity···, and using them". On the other hand, "in his own experience" means, "Those are something that I have felt in my life".

As shown in Figure 6, we could interpret the Jinphil's case with our theory, which we call an integrated theoretical structure of mental models.

In the past, the student (Jinphil) had two different experiences. One was the physics class experience. The other is the real-life experience such as playing soccer and running on the field. These experiences were stored in long-term memory without being related with each other. He asserted: "Actually I had two ideas (the first & second models) in my mind from middle school year."

Afterward, when he encountered the question about circular motion during the interview, his knowledge in long-term memory was activated into working memory. They were 'running (on the ground)', 'circular motion', and 'the direction of force (centripetal force)'. After that, through the

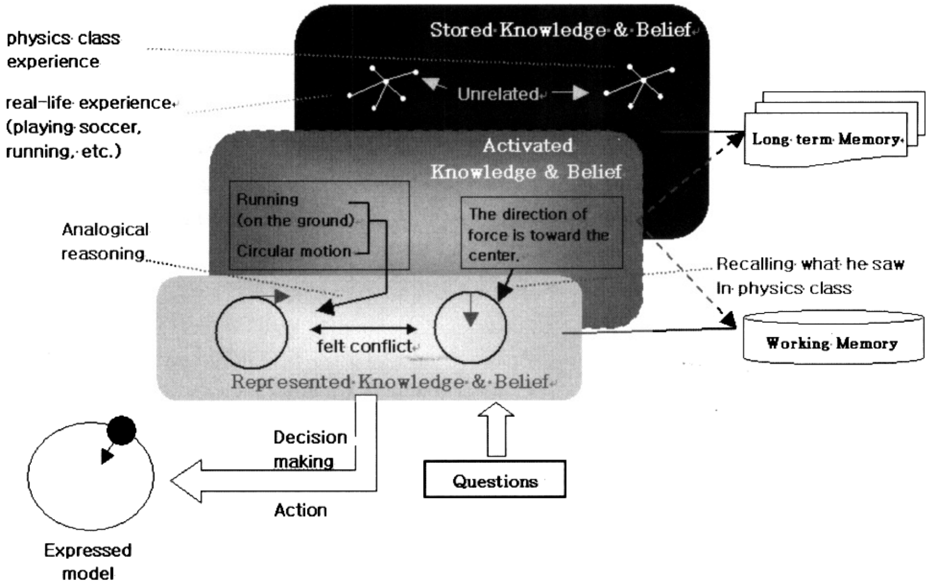

Fig. 6 *The process of forming two mental models*

thinking process, he formed two mental models. For example, through analogical reasoning between running and circular motion, he formed the model (the direction of force is the direction of motion). On the other hand, he also formed the other model, just recalling the centripetal force he saw in physics class without deep understanding. After he felt cognitive conflict between two mental models, he chose a model (the centripetal force). Finally, that model became the expressed model.

We can see Jinphil's case through different theoretical lenses that shape our interpretations. For instance, in terms of misconception theory, Jinphil had the scientific conception of circular motion since he did not talk about the second model in the theory at the first interview.

Through the lens of the Vosniadou's mental model theory, we can explain the sources (beliefs in Vosniadou's term) of the two mental models: The first source is from-out-of-school experiences, whereas the other source is from physics class experiences. Jinphil also had mixed epistemological beliefs (sources of knowing). One was internal authority (his own thinking based on his experience). The other one was external authority (his teacher). These beliefs supported two mental models. However, there are no explanations concerning these questions: (1) "Where are the beliefs?"; (2) "How do they interact and support the formation of mental models?" In addition, Vosniadou's mental model theory does not consider other factors that could affect the forming process of mental models such as thinking strategies and motivation.

P-prims are irreducible functional pieces based on direct interpretation of experience (diSessa, 1993). The p-prims are neither right nor wrong in and of themselves. Some of the p-prims are related with modular reasoning structure (general logical structure) and very abstract (closer means stronger, for example). Others refer to reasonably specific physical situations (for example, force as mover). The second type of p-prim is referred as a facet. Redish (2003) explained facets as follows, "a facet implies a mapping of the slots in the primitive into particular variables in a particular physical context" (p. 28). Basically, p-prim (or facet) theory considers the student's reasoning in a particular physical context. P-prim theory can explain how Jinphil proposed the first model through analogical reasoning (force as mover). However, it cannot explain the following questions: (1) "How does this reasoning interact with knowledge and beliefs?";

"Where did the knowledge and belief come from?" This theory also does not consider the other factors referred to above.

There is disagreement concerning the nature of students' ideas in physics (MacIsaac, 2004). The mental model view (especially, Vosniadou, 1994) argues that students' ideas are mini-theories that are applied consistently across contexts. The p-prims view claims that students' ideas are fragmented collection of ideas with no systematicity. The result of our case study (Fig. 6) shows that the two views have their own limitations. We do believe that the p-prims view is more focused on reasoning in working memory. On the other hand, Vosniadou's mental model view is more focused on conceptual structure, which is in long-term memory. Our integrated theoretical structure of mental models (see Fig. 6) can explain the result of our previous study while overcoming the limitations of each theory.

V. Summary

The mental model notion has been invoked in many fields including science education, math education, psychology, linguistics, and artificial intelligence. Now, the mental model has become a crucial terminology for explaining students' intuitive theory not only because it is located at the intersection of various disciplines, but also because it can provide science education researchers and teachers with valuable information about learners' conceptual frameworks, that is, their underlying knowledge structures from integrated perspectives.

This study has explored a wide range of issues associated with research on students' conceptions and mental models. At present, this area seems rife with terminological inconsistencies and a preponderance of conjectures rather than data. This situation may have arisen, to a great extent, because a variety of research areas have adopted the concept of mental models and proceeded to develop their own terminology and methodology, independent of past or current work in this area.

In many cases, "mental models" is simply a substitute for "knowledge" or "conception" in general. Such substitution is not particularly useful. In this study, we have suggested a more concise working definition: A mental model is a dynamic representation integrating external information recognized and individual knowledge/beliefs. Our discussion is premised on this definition.

The terminologies and their background theories identified here all offer valuable contributions to our deepening understanding of the students' conceptions. We can benefit from deeper consideration of the way each theory explains, as well as from more integration of studies from diverse areas. Accordingly, we need to continue to consider theoretical framework that suggest more integrated, organized understanding of students' conceptions.

For this reason, we have developed a theoretical model called, 'The Integrated Structure of Mental Models'. At first, we integrated diverse theories from related areas with mental models such as conceptual change, information processing, metacognition, and epistemological/ontological/ motivational beliefs. After this integration, we developed a theoretical structure that could show the location of our knowledge, as well as the activating and forming process of mental models in terms of memory.

By using this integrated structure of mental models in the case study on students' ideas about the circular motion, we tried to answer questions such as, (1) "What is a mental model?"; (2) "How is the term 'mental model" different from other terminologies, especially, alternative conception and memory?"; (3) "How is a mental model formed?"

Even though this paper is the first step in the development of a theoretical framework, we hope that the integrated structure of mental models that we proposed can guide us to useful research on students' conceptions and related issues.

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References

Boekaerts, M. (1997). Self-regulated learning: A new concept embraced by researchers, policy makers, educators, teachers, and students. Learning and Instruction, 7, 161-186.

Boekaerts, M. (2002). Bringing about change in the classroom: Strengths and weaknesses of the self-regulated learning approach-EARLI presidential address, 2001. Learning and Instruction, 12, 589-604.

Borges, A. T., & Gilbert, J. K. (1999). Mental models of electricity. International Journal of Science Education, 21, 95-117.

Corno, L., & Kanfer, R. (1993). The role of volition in learning and performance. Review of Research in Education, 19, 301-341.

Corno, L., & Randi, J. (1999). A design theory for classroom instruction in self-regulated learning? In: C. M. Reigeluth (Ed.), Instructional-design Theories and Models: A New Paradigm of Instructional Theory (Vol. II, pp. 293-318). IEA. Hillsdale, New Jersey.

diSessa, A. A. (1993). Toward an epistemology of physics. Cognition and Instruction, 10, 105-225.

diSessa, A. A., & Sherin, B. L. (1998). What change in conceptual change? International Journal of Science Education, 20, 1155-1191.

diSessa, A. A. (2002). Why conceptual ecology is a good idea. In M. Limon & L. Mason (Eds.), "Reconsidering Conceptual Change: Issues in Theory and Practice" (pp. 29-60). Dordrecht: Kluwer.

Duit, R. (1991). Students' Conceptual frameworks: Consequences for Learning Science. In S. M. Glynn, R. H. Yeany & B. K. Britton (Eds.), The Psychology of Learning Science, (pp. 65-85). NJ: Lawrence Erlbaum Associates.

Duit, R. (2003). Conceptual change: A powerful framework for improving science teaching and learning. International Journal of Science Education, 25, 671-688.

Franco, C., Barros, H. L., Colinvaux, D. Krapas, S., Queiroz, G., & Alves, F. (1999). From scientists' and inventors' minds to some scientific and technological products: Relationships between theories, models, mental models and conceptions. International Journal of Science Education, 21, 277-291.

Johnson-Laird, P. N. (1983). Mental models: Towards a cognitive science of language, inference and consciousness. Cambridge: Cambridge University Press.

Kuhl, J. (1985). Volitional mediators of cognition-behavior consistency: Self-regulator processes and action versus state orientation. In J. Kuhl & J. Beckman (Eds.), Action Control: From Cognition to Behavior, (pp. 101-128). New York: Springer-Verlag.

Lee, G., Kim, Y., & Bao, L. (2004). Another cognitive conflict in learning physics: When VE is consistent with a student's answer" in AAPT Announcer 33(4), 97.

Minstrell, J. (1992). Facets of students' knowledge and relevant instruction. In R. Duit, F. Goldberg & H. Niedderer (Eds.), Research in Physics Learning: Theoretical Issues and Empirical Studies, (pp. 110-128). Kiel, Germany: Institute for Science Education at the University of Kiel.

MacIsaac, D. (2004). Mental models or pieces of knowledge: Impetus theory in university students' understanding of force, A paper presented at 2004 NARST annual Meeting (Vancouver, BC).

Mishra, P., & Brewer, W. F. (2003). Theories as a form of mental representation and their role in the recall of text information. Contemporary Educational Psychology, 28, 277-303.

Ormrod, J. E. (1999). Human learning, (pp. 188-195). Upper Saddle River, NJ:Merrill/Prentice Hall.

Park, J., & Lee, G. (2004). Understanding students' conceptions in the research on conceptual change in science: from misconception to mental model. Journal of the Korean Association for Research in Science Education, 24, 621-637.

Pfundt, H., & Duit, R. (1991). Bibliography: Students' alternative frameworks and science education (3rd Ed.). Kiel, Germany: Institute for Science Education at the University of Kiel.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. Review of Educational Research, 63, 167-200.

Pintrich, P. R. (1999). Motivational beliefs as resources for and constraints on Conceptual change. In W. Schnotz, S. Vosniado, & M. Carretero (Eds.), New Perspectives on Conceptual Change, (pp. 33-50). Oxford: Pergamon.

Pintrich, P. R., & Sinatra, G. M. (2003). Future directions for theory and research on intentional conceptual change. In G. M. Sinatra & P. R. Pintrich (Eds.), Intentional Conceptual Change, (pp. 429-441). Lawrence Erlbaum Associates, Inc.

Redish, E. F. (2004). A theoretical framework for physics education research: Modeling student thinking. The Proceeding of Enrico Fermi Summer School in Physics.

Rickheit, G., & Sichelschmidt, L. (1999). "Mental models: Some answers, some questions, some suggestions" In G. Rickheit & C. Habel (Eds.), Mental Models in Discourse Processing and Reasoning, (pp. 9-40). North-Holland: Elsevier.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. Learning and Instruction, 4, 45-70.

Vosniadou, S. (1999). Conceptual change research: Sate of the art and future directions. In W. Schnotz, S. Vosniado, & M. Carretero (Eds.), New Perspectives on Conceptual Change, (pp. 3-13). Oxford: Pergamon.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. Cognitive Psychology, 24, 535-585.

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. Cognitive Science, 18, 123-183.

Wandersee. J., Mintzes. J., & Novak. J. (1994). "Research on alternative conceptions in Science". In D. L. Gabel (Eds.), Handbook of Research on Science Teaching and Learning, (pp.177-210). NY: Macmilan.

Westen, D. (1999). Psychology: Mind, brain, & culture, NY: Johnson Wiley & Sons, Inc, pp. 294.

Yates, J. (1985). The content of awareness is a model of the world. Psychological Review, 92, 249-284.

Zimmerman, B. J. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B. J. Zimmerman & D. H. Schunk (Eds.), Self-regulated Learning and Academic Achievement: Theoretical Perspectives. Mahwah, NJ: Erlbaum.