ORIGINAL ARTICLE

The Role of Metacognition in Students' Mental Models of the Quantization

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ABSTRACT

As part of a multiphase study (Didiş et al., 2014; Didiş et al., 2016), this research focused on the effective issues on cognition, and it examined the role of metacognition in the construction of mental models. With the identification of students' mental models of quantization of physical observables in the previous parts of the project, we considered metacognition theory to identify how knowledge about cognition influenced the construction of their mental models. Semi-structured interviews were conducted with students by considering their knowledge and experiences about learning quantum theory during the semester. Based on the determined metacognitive behaviors, students' mental models were reinterpreted by considering the metacognitive theory. The qualitative analysis results indicated that (1) students presenting more metacognitive behaviors constructed more coherent and scientific knowledge structures than the others and (2) satisfaction with knowledge was a breaking point for students' reorganization of their knowledge. These findings are important to indicate the influence of metacognition on the construction and revision of mental models about physics concepts. In teaching of science at university level, students' metacognitive evaluations should be taken into consideration together with their conceptions for scientific understanding.

KEY WORDS: science education; quantization; mental model; metacognition

INTRODUCTION

Metacognition is an act of thinking about one's own mental process, which can be defined as the cognition of cognition, and it plays an important role in reading and oral comprehension, writing, problem-solving, etc. (Flavell, 1979). It is widely studied in educational, instructional, and developmental psychology (Tobias and Everson, 2009). It was first related to learning by Flavell and has been described as the most powerful predictor of learning (Wang et al., 1990).

Metacognition is basically explained with two metacognitive elements: Knowledge and experiences (Flavell, 1979). Metacognitive knowledge involves awareness of one's own cognition, i.e., awareness of variables influencing thinking (Schraw and Moshman, 1995), as well as general knowledge about cognition (Pintrich, 2002). It is composed of ideas and beliefs of self, task, strategies, goals, or cognitive functions (Flavell, 1979). Metacognitive knowledge is mainly declarative knowledge, which is composed of factual information (Efklides, 2006; Veenman, 2011; 2012), but it may be procedural when knowing "how" to implement learning strategies and conditional when knowing "when" and "why" to use learning procedures (Schraw and Dennison, 1994). It comes from external information sources such as an individual's judgments and feedback and internal sources such as metacognitive experiences (Flavell, 1979, Efklides, 2006; Veenman, 2012). Metacognitive knowledge needs not to be stable to be useful; it may facilitate thinking and self-regulation with conscious access to that knowledge (Schraw and Moshman, 1995). It is different from metacognitive experiences (Flavell, 1979; Veenman et al., 2006); however, metacognitive knowledge and experiences are not independent from each other (Schraw and Moshman, 1995) and originate from metacognitive monitoring (Veenman, 2012).

Flavell (1979) described metacognitive experiences as conscious and affective experiences accompanying and pertaining to intellectual enterprise. The metacognitive experience is considered to be the regulative or control part (Brown, 1987; Efklides, 2006; Pintrich, 2002; Schraw et al., 2006; Schraw and Dennison, 1994; Schraw and Moshman, 1995) and includes metacognitive skills, which are composed of conscious activities and strategies such as planning, checking, and regulating cognitive processing and evaluating (Efklides, 2006). Metacognitive experiences have cognitive and affective dimensions that accompany cognition (Flavell, 1979) with feelings of familiarity, difficulty, knowing, satisfaction, judgments of learning, estimations of time, and effort (Efklides, 2006; Thomas, 2012; Veenman, 2012; Zohar and Barzilai, 2013).

While learning upper-level science concepts, students' feelings may be important for their understanding of these upper-level concepts. If they have positive experiences, for example, they are satisfied with their understanding of the topics, and they may seek some strategies to understand and learn more to be a better physicist and a physics teacher. Alternatively, if they do not understand, they may also seek some strategies to learn better. In the end, they may examine the effectiveness of these strategies for their learning of concepts. In other words, the metacognitive behavior of students allows them to know themselves better, select, and use strategies and reflect about the effectiveness of these strategies for themselves. Knowledge of the selected strategies' effectiveness is also important for the transfer of learning (Pintrich, 2002). In this way, metacognitive experiences are important for both metacognitive knowledge and cognition.

Metacognition is one of the elements interacting with an individual's knowledge on a topic (Gredler, 2001). For example, Schraw and Dennison (1994) identified that individuals who are metacognitively aware presented better reading test performance, and their findings also indicated that metacognitive awareness was a valuable predictor of subsequent performance. In their review of metacognition research, Zohar and Barzilai (2013) explained that metacognition research in science education is expanding. Metacognition is mostly studied in specific domains (61.2%), and most of this research focuses on conceptual knowledge (e.g., content knowledge, conceptual understanding, and models). For example, Vosniadou and Ioannides (1998) identified that students' conceptual learning involved metaconceptual awareness. Cooper et al. (2008) examined students' use of metacognition in chemistry problem solving with multi instruments. Their results indicated that students' ability to measure the problem difficulty was significantly correlated with their metacognitive activities. In addition, students using more metacognitive strategies had higher metacognitive activity scores than the students using fewer metacognitive strategies. Similarly, Sandi-Urena et al. (2011) examined facilitation of a well-established cooperative problem-based chemistry laboratory how positively affected graduate teaching assistants' metacognitive development. Georghiades (2004) examined the effect of metacognitive activities on the permanence of 5th grade (11 year-old) students' conceptions of electricity. He identified that the children engaging in these activities achieved more permanent understanding. Similar to Georghiades (2004), Yuruk et al. (2009) showed that teaching activities focusing on metacognitive knowledge and processes acting on one's conceptual system (the authors called this process "metaconceptual teaching practices") provided students with a significantly better conceptual understanding of Newtonian mechanics compared with traditional teacher-centered, didactic lecturing in high school physics classes.

Students' Mental Models of Quantization

Quantization is one of the fundamental ideas of quantum theory. It is a threshold concept for students' discriminating between classical and quantum perspectives and making sense and constructing the knowledge of new phenomena that emerged with quantum theory. As quantization is a reflection of the paradigm shift from the classical to quantum perspective, it is not a concept isolated to a specific topic, and it is an important phenomenon for an understanding of many contexts. In previous research (Didiş et al., 2014), we examined how students constructed their mental models of quantization of physical observables in the photoelectric effect, blackbody radiation and ultraviolet catastrophe, energy levels and atomic spectra, particle in a box, harmonic oscillator, and H-atom contexts. With the integration of different data sources such as conceptual interviews during the teaching of the phenomena, tests, and students' selected coursework, we identified that students had six mental models of the quantization of physical observables. These were scientific model (SM), primitive SM (PSM), shredding model (ShM), alternating model (AM), integrative model (IM), and evolution model (EM) (Appendix 1). Students did not only present coherent knowledge structures when they were explaining quantization, they also presented disconnected and irrelevant knowledge, and in some instances, they did not provide any answer. To summarize, the use of mental model percentage among all instances was 25%, and the use of SM among all instances was 10%. This indicated that students had difficulty in organizing their knowledge of the quantum concepts to have a scientific understanding of quantization phenomena. Therefore, the examination of mental modeling is a good framework to understand better students' learning in terms of the construction of coherent knowledge organizations.

Research Focus

Mental modeling is a cognitive process, and mental models can be explained as "cognitive representations that include the declarative, procedural, and inferential knowledge necessary to understand how a complex system functions" (Greene and Azevedo, 2009, p. 19). They are robust and coherent structures with a strongly associated set of knowledge elements (Bao and Redish, 2006). Individuals need to select information and construct their own knowledge to explain phenomena, make interpretations, or solve problems (Gentner, 2002).

Learning the concepts of quantum theory is focused on by physics and chemistry educators, who teach this theory in university-level courses such as quantum physics, quantum chemistry, and quantum mechanics (Didiş et al., 2016). However, many instructors have difficulty in teaching quantum theory (Sadaghiani, 2005; Wattanakasiwich, 2005). Previous research has shown that students also have great problems in learning the concepts of quantum theory (see for example Bao, 1999; Çataloğlu and Robinett, 2002; Sadaghiani, 2005; Singh, 2001; 2008; Wattanakasiwich, 2005). How students organize their new knowledge, which is very different from their previous knowledge, is significant: If the new knowledge is consistent with previous learning, mental models promote learning (Gentner, 2002). In this way, these researchers developed ideas about what was happening in students' minds when they were learning and constructing new perspectives that are very different from their previous ones. These researchers also explained students' understandings of new, counter-intuitive, and abstract quantum concepts through a mental modeling framework.

In this research, we have focused on the role of metacognition in students' construction and use of coherent knowledge structures regarding the quantization phenomenon. More specifically, we studied students' metacognitive behaviors because monitoring new information and comparing it with their previous learning may have a role in the construction of coherent knowledge structures of quantum phenomena. Our aim in this research was first to understand to what extent students were aware of their learning of quantum theory and then whether their mental models vary with metacognitive behaviors. This was our aim because the concepts of quantum theory are very new for students and it introduces new ideas to revise their previous knowledge (classical) to understand quantum ideas.

Since monitoring cognition and/or knowledge is a mental activity, like the construction of mental models, the presence of metacognition was not observed but inferred (White, 1998 as cited in Thomas, 2012) in this research. Although there are some methodological similarities with the previous research examining students' mental models about the concepts of quantum theory (Bao, 1999; Didiş et al., 2014; Didiş et al., 2016; Özcan, 2015; Park and Light, 2009), this study differs from previous research by examining students' metacognitive behaviors in the construction and use of mental models.

METHODOLOGY

General Background of Research: Examination of Students' Metacognitive Behaviors

Research on metacognition basically has been conducted in two ways. One way is an observation of students' performances on cognitively complex tasks, and the other is by obtaining students' self-reports about their performance (Tobias and Everson, 2009). To make inferences about students' metacognitive behaviors, we have followed the second method. To be able to understand students' metacognitive behaviors, we conducted "self-evaluation interviews" focusing on three issues in metacognition: (1) Awareness: Being aware of what an individual knows and does not know, how she or he thinks, etc.; (2) Satisfaction: feeling frustration or satisfaction with one's own knowledge; and (3) strategy selection: Strategies for one's own cognitive process. The first of these elements was to determine students' metacognitive knowledge; the second and third elements were for understanding their metacognitive experiences when they were learning quantum theory concepts. In this study, we considered students' reflections about their knowledge of cognition fundamental for metacognitive behavior, and then, we considered their satisfaction of knowledge and their strategies to control their cognition. For this reason, we asked eight questions based on these elements. As Table 1 presents, the first three questions of the interview aimed to examine students' awareness of their own knowledge, the next two questions were about satisfaction with their own knowledge, and the rest of the questions focused on their cognition and strategy selection.

Data Collection

As presented in Table 1, the interview protocol contained metacognitive questions that reveal the students' ideas about their learning of quantization phenomenon in the modern physics course in a university in Turkey in 2009. This study purposively selected 31 students, who were taking a modern physics course. They were asked conceptual questions to reveal their mental models of quantization. Then, to identify their metacognitive behaviors to match with their mental models, the interview questions in Table 1 were asked to these students. Since an interview for metacognitive behaviors could not be conducted with 2 of the 31 students, 29 participants completed the "self-evaluation interview" in an average time of 20 min. After the student interviews, we obtained the instructor's opinions about the students' learning. The verbal data of the students were transcribed first. The code list was developed by the researchers in light of the metacognition theoretical framework. Then, the data were qualitatively analyzed using the code list presented in Appendix 2.

Data Analysis: Relating Mental Models with Metacognitive Behaviors

In the examination of students' metacognitive behaviors, we first focused on whether they were aware or not of their cognitive process and knowledge. Then, we identified the students who were satisfied or dissatisfied with their knowledge, and due to this, their use of some strategies to control their cognitive process and knowledge was examined. Table 2 presents the number of students and their metacognitive behaviors.

With the self-evaluation interview, the students provided explicit evidence of their metacognitive behaviors by

Table 1: Interview questions in the interview protocol

No	Questions
1	When you consider your learning, did you ask yourself questions such as "What am I doing? How do I learn? Why do I learn?"
2	Do you have any idea about your knowledge (what you know and do not know) and your cognitive process? Do you have some strategies about how you obtain the knowledge better?
3	In the Modern Physics course, how often did you hear the terms "quantization" and "quantized"? In which topics have you heard them?
4	What can you say about the conceptual development of these concepts when you first heard about them? Do you feel a development in your understanding of these concepts?
5	Do you believe you understand the quantization of some physical observables?
6	What are the most effective factors that shape your understanding of the quantization phenomenon?
7	Did studying for the final examination contribute to your understanding of this phenomenon?
8	Would you like to say anything else to explain quantization and your understanding of this phenomenon?

considering all processes they used to accomplish a better understanding of quantum theory concepts during the 15-week semester. Analyses of the interview transcripts identified more than half of the students (15 students) explained that they asked themselves metacognitive questions about their learning process. The other 14 students were not aware of their learning. At this step, we determined that 15 students were willing to know more about their knowledge or cognition. Eight of these 15 students were both aware of and satisfied with their learning; the remaining seven were aware of but dissatisfied with their knowledge of quantization phenomena. At this step, we considered the "satisfaction of one's own knowledge" an important feeling when students experienced learning quantum theory because the nature of quantum theory is different from the classical mechanics, as it presents new perspectives and ideas and is abstract and counterintuitive. In this way, we could examine their approach to learn more whether they are satisfied or not or to find new ways to learn better or to stop learning. Next, we considered students' use of some strategies to control their cognitive process. Six of eight students were aware of their learning, were satisfied, and had strategies; four of seven students were aware of their learning and dissatisfied but had strategies for their learning. After we compiled explicit data about students' metacognitive behavior about their learning, we categorized students according to these metacognitive behaviors and interpreted the findings together with the identified mental models of students (Didiş et al., 2014). Finally, graphs were constructed after integration of the findings about students' mental models and metacognitive knowledge and experiences.

RESULTS

Reinterpretation of Mental Models with Students' Metacognitive Behaviors

First, students' awareness of their knowledge was considered for metacognitive behaviors. As seen in Table 2, 14 students were not aware of their knowledge. Among these 14, two students, who never displayed a model across contexts, explained that they did not examine their knowledge. For example, St16 explained her reasons for why she did not query her learning:

> *St16: No... I did not ask myself... (Smiling). Actually, I told myself "I should learn them", and then I learned.*

Table 2: Students' metacognitive behaviors

Metacognitive behavior	Number of students
Unaware of knowledge	14
Aware of knowledge	15
Aware and satisfied with knowledge	
Aware and satisfied but without strategies	2
Aware, satisfied, and with strategies	6
Aware and dissatisfied with knowledge	
Aware and dissatisfied but without strategies	3
Aware, dissatisfied, and with strategies	4

Another example is from St24, a student who used an unscientific model (AM) in one context. She mainly did not answer the conceptual questions asked to identify mental models. She explained her knowledge about her cognition as follows:

> *St24: No, I never queried myself (smiling). I mainly do not think about why I took the courses. I never think why they would be useful for me or not.*

At first, among the participating 21 students, 15 students displayed metacognitive awareness. We matched students' metacognitive behaviors (with awareness and satisfaction of knowledge and use of strategies) with their mental models and constructed as shown in Figure 1. It summarizes the percentages of mental model use, the use of SM among models, and the use of SM among all instances for metacognitive behaviors starting with metacognitive awareness (i.e., for: Only aware; aware and satisfied; and aware, satisfied, and having strategies).

The percentage of displayed models by the 15 students who were aware of their learning was 26.7%. The use of the SM among all other models was 36.1%, and among all other knowledge structures, it was 9.6%. This type of knowledge includes factual information, so it is considered basic for metacognitive awareness. Although we observed that the students who were aware of themselves presented more organized knowledge structures than the others, this information did not provide extra information about the reasons for using specific mental models across contexts. Metacognitive knowledge is important for the organization of scientific elements. However, in addition to students' inquiry about their knowledge, we saw that "satisfaction" with this knowledge was also important. Among the 15 students who examined their own learning, eight were satisfied with their knowledge. In comparison with the percentage of the model usage of related with the awareness of knowledge, the percentage of model usage of students who were both aware of and satisfied with their knowledge was 30.6%, and it indicates an increase in the percentage of displayed models (from 26.7% to 30.6%). The final issue about metacognitive

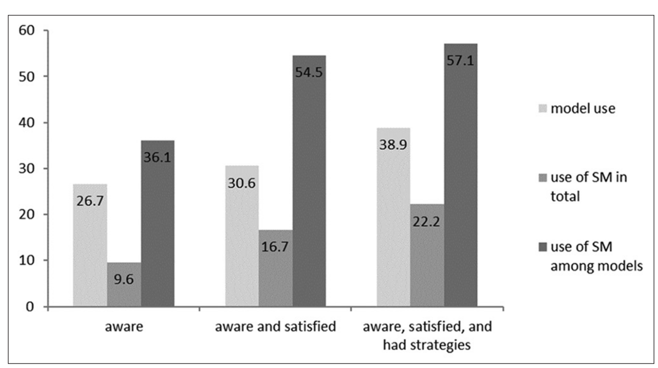

Figure 1: Percentages of students' use of mental model, use of scientific model in total instances, and among models due to their metacognitive behaviors which students satisfied with their knowledge

behavior is "strategy selection," which can be defined as the "strategies for one's own cognitive process." Individuals analyze the elements influencing their learning and control their cognitive activities to reach their goals. After examining the students' awareness of and satisfaction with their knowledge of the quantization of physical observables, we examined their approach to the analysis of the elements influencing their cognition and the selection of their own strategies. The results showed that six students, who were aware of and satisfied with their knowledge, had some methodologies for their learning. When examining knowledge organization across contexts, the percentage of model usage was 38.9%. By comparison, when examining the percentages of model usage of the students who were only aware of their knowledge (26.7%) and who were aware of and satisfied with their knowledge (30.6%), there was an increase in students' model use. The use of the SM among other models increased from 36.1% (for aware students) to 54.5% (for aware and satisfied) and then to 57.1% (for aware, satisfied, and had strategies). In addition, when the total instances (use of any kind of knowledge structures) were considered for each group, students' use of the SMs increased from 9.6% (for aware students) to 16.7% (for aware and satisfied), and then to 22.2% (for aware, satisfied, and had strategies). Table 3 presents the models of these six students who have their own strategies across contexts.

The following excerpts are from the students with three basic metacognitive behaviors (aware, satisfied, and had strategies). St2 displaying PSM and SM explained his strategies as follows:

> *St2: I got it. Actually, I know I had a style to study. In the first exam, I studied modern physics topics every day. I increased to study step-by-step until the exam date. I studied the whole day in the library just before the exam day. I can say that if I have enough time to study, I feel relaxed. I really give importance to "understanding" concepts. Just 1-2 hours of practice every day is very helpful. It also gives pleasure. For this reason, I study regularly by taking pleasure. That means, for this course, I study like that.*

St7 was a student who tried to understand the nature of the concepts and spent a lot of time on this issue. She also stated that she was aware of her knowledge, cognitive process, etc. She had the PSM and SM about the quantization phenomenon. She explained her metacognitive control with these words:

> *St7: I have a characteristic valid for my daily life. I must learn the "reasons" of something. I must understand it well. If I cannot understand the reasons well, I cannot go forward. Then I cannot construct the other concepts. I cannot learn the whole of the topic… I must imagine it. I wonder about the reasons for events too much. However, sometimes I think the opposite such as "scientists constructed the knowledge for long years. I cannot learn the reasons for everything in a short time; it is not easy, and my expectation about learning the reasons for everything is wrong. It is wrong to try to understand everything. Then, I try to understand how the scientists thought about things as possible. It seems so interesting to me. I wonder "how" they thought, explained and then I learn.*

During the interview, these students also indicated their interest - enjoyment in the activities - in learning the quantization phenomena:

> *St2: I really feel that I learn modern physics not to get good grades, but I just want to learn because I enjoy it. The topics are so interesting and the instructor explains them very well. I really enjoy myself while learning; that means I come to the classes not for the attendance requirement.*

> *St7: The concepts of modern physics are very interesting. I like modern physics very much. I also like the instructor's teaching methodology, then I enjoy. That's all.*

Figure 2 displays the decrease in the diversity of used mental models when students were satisfied with their knowledge.

PSM, ShM, AM, and EM were unscientific mental models. When students' mental models were examined, the diversity in unscientific model decreased and the percentage of use of SM among models increased as shown in Figure 2. To summarize, the increase in model usage indicates that satisfaction of knowledge may facilitate knowledge organization. In addition, the increase in the use of the SMs (both among models and other knowledge structures) indicates an iterative relationship between satisfaction and scientific knowledge. This relation can be interpreted; thus, when students are satisfied, they construct scientific knowledge; and when they scientifically organize their knowledge, they are satisfied with their knowledge.

On the other hand, in addition to positive feelings about learning quantum theory concepts, which is satisfaction of

Table 3: Models of students who are aware, satisfied, and had strategies for their learning

Code	Gender	Department	Context 1	Context 2	Context 3	Context 4	Context 5	Context 6 a1	Context 6 a2	Context 6 b1	Context 6 b2
St2	M	PHED	PSM	NM	PSM	SM	NM	NM	SM	NM	SM
St3	M	PHYS	PSM	PSM	NM	SM	NM	SM	SM	NM	NM
St6	M	PHYS	NM	NM	SM	SM	NM	NM	NM	NM	NM
St7	F	PHYS	PSM	NM	PSM	SM	NM	SM	NM	SM	NM
St29	F	PHYS	ShM	NE	ShM	ShM	NA	NE	NE	NE	NE
St31	M	PHYS	NM	NE	SM	NM	NM	NM	NM	NM	NM

F: Female, M: Male, PHYS: Physics student, PHED: Physics education student, NA: No answer, NE: No element, NM: No model. SM: Scientific model, PSM: Primitive scientific model, ShM: Shredding model. Contexts: (1) Photoelectric effect, (2) Blackbody radiation and ultraviolet catastrophe, (3) Energy levels and atomic spectra, (4) Particle in a box, (5) Harmonic oscillator, (6a) Bohr atom, and (6b) the quantum mechanical model of atom knowledge, we also examined how dissatisfaction shaped students' knowledge organizations. As similar to Figure 1, Figure 3 presents students' use of models and their use of SM among all models and in all instances due to their metacognitive behaviors for students who were dissatisfied with their knowledge.

In contrast to Figure 1, there is a sharp decrease in students' model use and their use of SM in all knowledge structures and among models after their awareness of their knowledge. For example, when examining the percentages of model usage of the students who were only aware of their knowledge (26.7%) and the students who were aware of and dissatisfied (7 students) with their knowledge (22.2%), there was a decrease in students' model use. This decrease also occurs in the use of SM among total instances (from 9.6% to 1.6%) and other models (from 36.1% to 7.1%). We interpreted "satisfaction with knowledge" as a breaking point that students needed to reorganize their knowledge after this. We identified an increase in students' model use, use of SM in all knowledge structures, and among models after they were dissatisfied but had strategies (4 students). Model use increased from 22.2% to 25%, use of SM in all knowledge structures increased from 1.6% to 2.8%, and use of SM among models increased from 7.1% to 11.1% for students who were aware, dissatisfied, and had strategies for their learning of quantization phenomena. The diversity in the students' models is presented in Figure 4.

Similar to Figure 2, we observed a decrease in the diversity of models when students presented control in their cognition with the use of own strategies although they are unsatisfied with knowledge. The students who were aware of and dissatisfied with their knowledge and not having strategies displayed mainly unscientific mental models. For example, St21, having EM and AM, also was not satisfied with his understanding. He explained it by stating his displeasure while making explanations:

> *St21: I could not give good answers to your questions. I guess I have a problem with my learning, or I forget what I learned.*

The excerpt below belongs to St30, who had the ShM, and indicated her dissatisfaction with her knowledge:

> *St30: I think my understanding is not enough because, I understand the concrete concepts better. However, it is so abstract, and I cannot visualize quantization in my mind much.*

As a very brief summary of the sources influence students' mental models, in the interview, the instructor indicated the importance of metacognitive issues and explained some sources of the students' understanding from his perspective:

> *Instructor: At the beginning of the semester, I always advise my students about learning modern physics: "You should learn to learn." Students should not write everything that the instructor writes (on the board), they should be selective and take notes briefly. This contributes to learning. We can mention other things about learning. For example, students should use extra books to learn in addition to the textbooks. They should link the concepts learned in the past to the present. I would like to say previous learning makes a great contribution to students' new learning. If students care about these issues, they will affect success positively.*

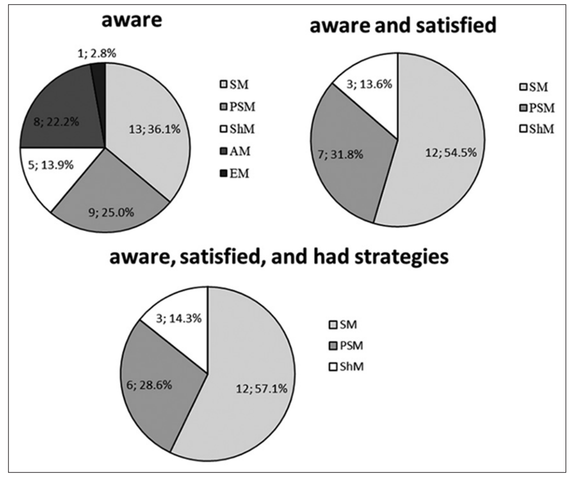

Figure 2: Percentage of each mental model used by students, who were satisfied with their knowledge, due to their metacognitive awareness

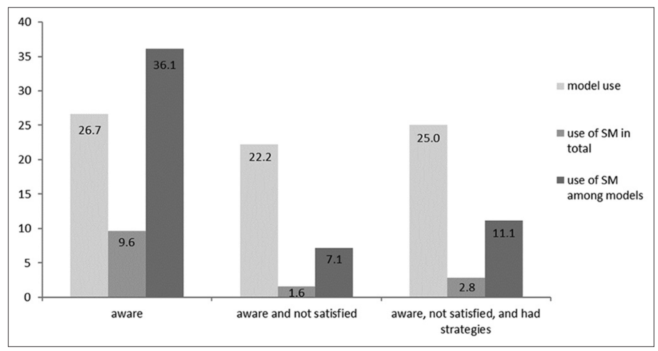

Figure 3: Percentages of students' use of mental model, use of scientific model in total instances, and among models due to their metacognitive behaviors which students dissatisfied with their knowledge

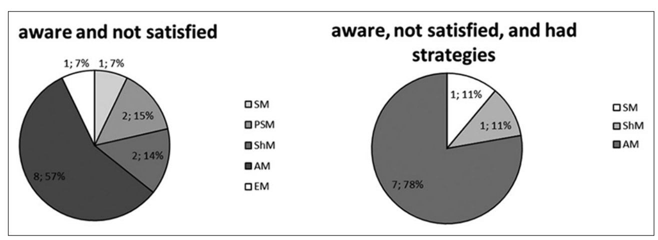

Figure 4: Percentage of each mental model used by students, who were dissatisfied with their knowledge, due to their metacognitive awareness

CONCLUSIONS, DISCUSSION, AND IMPLICATIONS

This research differs from the previous research examining students' mental models about the concepts of quantum theory

(Bao, 1999; Didiş et al., 2014; Didiş et al., 2016; Özcan, 2015; Park and Light, 2009) by considering students' metacognitive behaviors in the construction and use of mental models. Two fundamental conclusions of this study are important to explain students' construction of physics knowledge by considering their metacognitive behaviors.

Conclusion 1: Students presenting more metacognitive behaviors constructed more coherent and scientific knowledge structures than the others. By comparing the percentages of students' use of mental models, use of SM in total instances, and use of SM among all models, we observed an increase from being only aware of knowledge to be aware and satisfied and also to be aware, satisfied, and having strategies. This increase indicates that students used more coherent knowledge structures (mental models) when they were aware, satisfied, and had strategies for their learning. In literature, it is explained that metacognitively aware learners are better in learning than others because awareness allows them to monitor the learning process, which directly improves their performance (Schraw and Dennison, 1994).

Conclusion 2: The satisfaction with knowledge is a breaking point for students' reorganization of their knowledge. The finding about students presenting enjoyment when they are satisfied with their knowledge might indicate the relation of metacognitive experiences to effective elements (Efklides, 2006), which was our interest in this study. On the other hand, Flavell (1979) explained that metacognitive experiences might affect the metacognitive knowledge base by "adding to it, deleting from it, or revising it" like Piaget's explanation of "assimilation" and "accommodation." Similarly, the organization of knowledge - change in mental models - was explained by Vosniadou (1994) as enrichment and revision. In contrast to aware and satisfied students, we recognized that aware and dissatisfied students also had some strategies to promote their learning. However, we identified that the use of models, including the use of SM among all models and all instances, decreased with dissatisfaction, and then, we observed that they increased for the students who had strategies. At this point, we interpret satisfaction with knowledge as a breaking point at which students need to reorganize their knowledge as a kind of conceptual change with "revision" of knowledge Vosniadou (1994).

In addition, regardless of whether students were satisfied or dissatisfied, the diversity of unscientific mental models decreased and the percentage of SM increased for the students who had their own strategies to learn quantization phenomena. This can be evidence for metacognition as a role on conceptual learning because the satisfaction of knowledge promoted scientific understanding.

We have two different profiles of students: Future' physicists and physics teachers. Among the six students, who were aware and satisfied with their knowledge and had strategies for their cognition, only one student was from the physics education department, and the rest were physics students. This may be related to the finding of Didiş (2015) that pre-service physics teachers were slightly reluctant to learn the concepts of quantum theory by considering its future utility (i.e., when they get a job).

To summarize, metacognitive elements influence the development of mental models. Metacognitive strategies may enhance learning (Gredler, 2001). The students who were aware of and satisfied with their knowledge and had strategies mainly presented models and these models were mainly SMs. Although students might not consciously use their mental models (Wittmann et al., 1999), dis/satisfaction of knowledge provides some feedback to students to revise their knowledge. Simultaneously having these three elements of metacognition is important for developing SMs and explanations mainly with models across contexts. As a final statement, these findings indicate the importance of metacognitive issues to students' knowledge organization. By considering the influence of metacognition on students' mental models, the following issues should be considered:

1. The application of metacognition in classes is beneficial for teaching (Zohar and Barzilai, 2013), so teachers should support metacognition in their instructions (Beeth, 1998). Teachers should have theoretical knowledge of metacognition and the ability to encourage metacognitive thinking practice in class (Zohar and Barzilai, 2013). Some activities showing students' affective status should be followed by instructors. These activities might be done at the beginning of the semester by examining these issues. Then, the instruction might be redesigned in light of the findings about the students. For example, short reports reflecting students' ideas during the semester might be included in the instruction. By this way, not only the course might be reshaped with students' reflections but also students learn more about themselves. If students know their own strengths and weaknesses, they can adjust their own cognition and thinking, and then they may facilitate their learning (Pintrich, 2002).
2. Metacognition can be considered an internal source, which means that students can control their learning if they learn metacognitive thinking and inquiry. A student's metacognitive inquiry is important for both organizing knowledge by having any kind of model and having SMs. Students should ask themselves about their learning, and they should develop easier ways of understanding quantum concepts by regulating their learning. Instructions focusing on improving metacognitive knowledge should be explicit (Pintrich, 2002).

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APPENDIX

Appendix 1: Operational definitions of mental models

Mental model
Scientific model (SM):
"The quantization of physical observables such as energy and angular momentum is seen when a particle is confined in a region
The values of physical observables are restricted. The physical observables can have only discrete values, and these values are only certain (allowed) values
This is natural for the atomic systems." (Didiş et al., 2014)
Primitive scientific model (PSM):
"The values of physical observables are restricted. The physical observables can have only discrete values, and these values are only certain (allowed) values
The quantization of physical observables is observed for all atomic particles and not for only bound particles
This is natural for atomic systems" (Didiş et al., 2014)
Shredding model (ShM):
The physical observables are divided into quanta and have discrete values, just like dividing them into little particles
The values of the physical observables are not restricted, and quanta can take any value, just as you can take any size slice of cake
The quantization of physical observables is seen in all atomic particles, not for only bound particles
Quantization is not a natural characteristic of atomic systems but rather an external manipulation of the values of the physical observables" (Didiş et al., 2014)
Alternating model (AM):
Quantization occurs like any kind of change. It is like a spontaneous change of values
There is no restriction for the values of the physical observables and so they can have any values
This is observed for all atomic particles, not only for bound particles
It is a natural characteristic of atomic systems" (Didiş et al., 2014)
Integrative model (IM):
Quantization is an integration process done to make the values of the physical observables continuous
Quantization of physical observables is observed for all atomic particles, not only for bound particles
Quantization is not a natural characteristic for atomic systems but rather an external manipulation of the values of the physical observables" (Didiş et al., 2014)
Evolution model (EM):
"Quantization is a phenomenon of Einstein's theory of relativity
It occurs like any kind of change
The quantization of physical observables is observed for all atomic particles, not only for bound particles
It is not a natural characteristic of atomic systems but rather an external manipulation of the values of the physical observables" (Didiş et al., 2014)

Appendix 2: Code list for the data analysis

Dimension	Code Abbreviation	Definition of the codes
Metacognition	IS-(MC)	Act of thinking about students' own mental process
1. Awareness	IS-(MC) A	Being aware of what the individual knows and does not know how s/he thinks, etc
2. Satisfaction	IS-(MC) S	Feeling frustration or satisfaction of own knowledge
3. Strategy selection	IS-(MC) STR	Strategies for own cognitive process