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A Qualitative Inquiry about Students' Conceptualizations of Force Concept in terms of Ontological Categories

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ABSTRACT

The purpose of this study was to inquire about students' conceptualizations of the force concept in terms of ontological categories. Although some of the literature have been providing supporting evidences about the fruitfulness of ontological categories for explaining the nature of students' alternative conceptions, some others provide strong arguments against it. To tap the controversial issues in the literature, an inquiry was conducted in a classroom context with students who were seeking a degree to become physics teachers. The data consist of four students' written responses to physics problems, reflections about their own conceptualizations from the theoretical perspective of ontological categories, and video recordings of classroom discussions. The analysis of data showed that a theory-driven interpretation (ontological categories) about students' conceptualizations of the force concept did not match with the students' own interpretations about their conceptualizations. Furthermore, the students did not consider ontological category shift a fruitful instructional strategy because of the possible problems they projected for the implementation. The major problem emerged as the difficulty of situating every physics concept into the distinct ontological categories.

Keywords: Alternative Conceptions; Force Concept; Teaching and Learning Physics; Ontological Categories.

INTRODUCTION

An extensive body of research, conducted during the 1960s through the 1990s, explicitly revealed that students' pre-instructional ideas do not always match with scientifically accepted conceptions and they influence further learning (Driver, 1989). In this period of time, several labels were generated to refer to these ideas, such as "pre-conceptions," "misconceptions," "alternative conceptions," and "intuitive knowledge." The key result of these studies, alternative conceptions influence further learning, initiated a significant argument against a well-established belief among numerous cognitive and educational researchers concerning students' failure to understand physics. According to these theorists, the Piagetian developmental stage of formal operational thinking is the prerequisite of learning physics and students' failure in this domain is due to their under attainment of these stages (White, 1993).

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In the early 1980s, the psychological and philosophical base of a new paradigm had already begun to emerge among the community of science educators to explore students' difficulties in learning some basic scientific concepts. It was recognized that alternative conceptions were one of the main problems in students' understanding science and this opened a new window to explore students' failure in learning science. This realization stimulated many researchers to develop new learning models to effectively deal with alternative conceptions. Among others, Conceptual Change Model (CCM) received special interest from the educational community. Furthermore, the CCM has become synonymous with constructivism in science education (Mortimer, 1995). The basic idea behind the CCM is that learning is a rational activity and when students' central concepts are inadequate to explain new phenomena successfully, students must replace or reorganize their central concepts (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). However, in the following years, it was realized that what was supposed to be replaced or reorganized was ambiguous (Wittmann, 2002). The ambiguity is not due to the lack of research on identification of alternative conceptions hold by students but the lack of theoretical arguments about the nature of these conceptions. In the following years, several researchers shifted the emphasis on their research program from "identification" to "understanding the nature" of students' alternative conceptions. However, these affords could not readily provide a coherent and consistent framework. Different researchers generated different interpretations about the nature of alternative conceptions and, as a result, different theoretical frameworks emerged in the literature. Chi and her colleagues' (Chi, 1992; Chi, 2005; Chi & Slotta, 1993; Slotta & Chi, 2006) proposal in terms of ontological categories, diSessa's (1988, 1993) phenomenological primitives, Minstrell's (1992) facets of knowledge, Hammer's (2004) cognitive resources, and Vosniadou's (1994) interpretations in terms of naïve theories and mental models are some examples of these frameworks. The focus of attention in these new frameworks is to understand the cognitive, epistemological, and/or ontological resources used by novices while they are reasoning about physical phenomena, rather than solely identifying students' misconceptions.

In this study, I will focus on one of the frameworks generated for the nature of alternative conceptions, namely ontological categories, and delimit the content area to the force concept. The purpose of the study is to provide a qualitative analysis about students' conceptualizations of the force concept from the perspective of ontological categories. Before formulating specific research questions, I will first provide a theoretical framework for ontological categories in the following section.

Ontological Categories

Based on Keil's (1979) interpretations on conceptual development in terms of ontological categories, Chi and Slotta (1993) proposed a theory about the nature of students' alternative conceptions. The major supposition behind the theory is that all the entities in the world belong to different ontological categories and individuals' learn about these entities by implicitly or explicitly situating them into a specific category. While making these suppositions, Chi and Slotta considered three general ontological categories which were referred to as "matter," "processes," and "mental states." There are also subcategories for each of these general categories such as direct and emergent processes under the category of processes, which all together form a tree. The theory claims that these categories are stable and constraining, which means that an individual's conceptualization of a concept fall into one distinct ontological category and changing it to another category requires an extraordinary change process.

According to this interpretation, the nature of many physics concepts falls into the processes category. Gravitational force, electrical current, heat, and light are provided as examples of physical concepts belonging to this category. Chi, Slotta, & Leeuw (1994) identify several ontological attributes of this category such as no beginning and end, no progression, acausal, uniform in magnitude, simultaneous, static, and on-going. Based on ontological categories, Chi et al. interpret the nature of students' alternative conceptions as misclassification of physics concepts according to their ontological characteristics. Several studies (Reiner, Chi, & Resnick, 1988; Reiner, Slotta, Chi, & Resnick, 2000) assert that students tend to consider many of the physics concepts within the matter category in spite of their process specific nature. It was claimed that students interpret these concepts either as material substances or properties of a material substance. Reiner, Slotta, Chi, & Resnick (2000) define several properties of substance based schema such as *pushable* (able to push and be pushed), *containable* (able to be contained by something), *consumable* (able to be "used up"), *additive* (can be combined to increase mass and volume), *locational* (have a definite location), and *transitional* (able to move or be moved).

Chi et al. (1994) argue that robustness of some alternative conceptions is due to ontological differences between novice and expert's conceptualizations of some physical concepts and the difficulty of shifting a specific conceptualization from one ontological category to another. Based on these interpretations, Chi and her colleagues hypothesized that conceptual change can be facilitated by making students be aware of different ontological categories and the true ontological category of a scientific conception.

Slotta and Chi (2006) tested this hypothesis with pre-test post-test control group design by providing experimental group with direct instruction about process ontology. The study was conducted with 24 undergraduate students about electricity. The qualitative and quantitative analysis of the students' responses showed that ontological training helped students gain an appropriate ontological status for the electricity concepts. Another empirical test was conducted by Lee and Law (2001) with students from a secondary school in Hong Kong. Their results also showed that students' conceptions on electric circuits were substance based and supported the claim that instructional strategies enriched with ontological training helped students change their robust alternative conceptions related to electricity. Similar results were also reported in other domains such as genetics (Tsui & Treagust, 2004; Venville & Treagust, 1998), evolution (Ferrari & Chi, 1998), thermodynamics (Clark, 2006), chemical bonds (Harrison & Treagust, 2000), and management (Rooke, Koskela, & Seymour, 2006).

In addition to these empirical studies, Chen's (2007) interpretation of scientific revolutions in the history of science can be considered as an attempt to make a bridge between ontogenetic and phylogenetic development of scientific ideas in terms of ontological categories. Chen provides several cases from the history of science exemplifying the substance bias in the development of several scientific conceptualizations such as heat and motion which were considered identical to substance based conceptualizations of novices. Further evidences about ontological shifts experienced throughout the history of science provided by Chi and Hausmann (2008). Electricity, dinosaur extinction, theories about the causes of some diseases such as epilepsy are some examples of ontological shifts.

In spite of the numerous studies supporting the theory of ontological categories, several researchers provided strong arguments against it. The first opposition came from diSessa (1993b) who tried to show the implausibility of making direct ontological distinctions among physics concept by providing examples from experts' use of several concepts such as entropy, quantum field, and relativity. In recent years, the major arguments were provided against context independent conceptualizations of ontological categories. For example, Teichert, Tien, Anthony, & Rickey (2008) demonstrated students' context dependent conceptualizations of molecular concepts. Gupta, Hammer, & Redish (2010) also emphasized the importance of contextual factors on thinking about specific physics concepts. They provided several examples from both experts and novices illustrating their transitions from one ontological category to another in different contexts.

According to the perspective of ontological categories, the robustness of some misconceptions were due to students' ontological biases towards a substance based conceptualization and within this framework, ontological attributes used by students provide information about the specific ontological category of a concept hold by students. Based on these arguments, students' use of adjectives and predicates related to a concept were taken as a base to make interpretations about students' conceptualizations. The purpose of this study is to understand students' conceptualizations of the force concept in terms of ontological categories. For this inquiry, the "force" concept was chosen because it is a fundamental concept of Newtonian mechanics and provides a baseline for understanding a broad range of physical phenomena. I first analyzed students' conceptualizations of the force concept from the theoretical perspective of ontological categories by following the same procedure recommended by Chi and Slotta (1993). Then, I focused on the students' own interpretations about their conceptualizations. The available data also made it possible to investigate other related issues such as the change process of students' conceptualization of the force concept and their interpretations about ontological categories. The specific research questions were formulated as follows:

1) How do students conceptualize the force concept according to ontological category perspective?
2) How do students change their conceptualizations of the force concept during classroom discussions?
3) How do students interpret their own conceptualizations of the force concept from the perspective of ontological categories?

METHODOLOGY

In this study, two qualitative methodologies were used, case study (Yin, 2003) and cooperative inquiry (Reason, 2003). The case study was used in a way that each individual student considered as a case and their conceptual reasoning about the physics problems was analyzed by using the theoretical framework of ontological categories. These analyses basically consisted of the researcher's search of the available data for the students' substance based attributions to the force concept.

Cooperative inquiry was used as an instructional tool to help students understand and analyze ontological categories as a theoretical framework. In this inquiry, the role of being researcher was distributed among the whole class by engaging them in reading the related literature, analyzing the exemplary cases, and doing retrospective analysis about their own conceptual difficulties related to the force concept. The data emerging from this inquiry were used to analyze students' own interpretations about their conceptualization of the force concept. In the following sections, participants, classroom setting, and data sources were detailed.

a) Participants and Setting

This study was conducted with 29 undergraduate students (19 females and 10 males) in an "instructional method" course designed for students who were seeking a degree to become physics teachers. The major objective of the course was to help students understand the nature of alternative conceptions and gain basic knowledge and skills on the implementation of several instructional strategies in physics classrooms, such as cognitive conflict, anchoring/bridging analogies, extreme case reasoning, ontological category shift, and learning cycle. The data were collected in two consecutive semesters (2007-2008 autumn and spring semesters). All the students attending the course had already taken the core physics courses (mechanics, electromagnetism, electronics, optics and waves) and they were taking education-related courses during the period of data collection. Students' ages ranged from 19 to 28 with a mean of approximately 22 years. Although the students took the "instructional method" course after they completed core physics courses, they still had conceptual difficulties. Therefore, a considerable amount of time was usually spent on students' own understanding of physics concepts by posing different types of conceptual physics problems at the high school level. In response to these questions, students were requested to describe their own reasoning, to discuss it with class, to reflect on their difficulties, and to find appropriate solutions. Finally, the instructor stimulated them to come up with appropriate instructional strategies to overcome the experienced difficulties. Students were also provided with lectures about different interpretations about the nature of alternative conceptions and instructional strategies, and they were required to read assigned papers selected from the literature. In short, this course was designed to increase students' pedagogical content knowledge by engaging them into an inquiry. Students were evaluated mostly based on their contributions to the classroom discussions and competency on the applications of specific instructional strategies covered in the course.

b) Data Sources

The data set used in this study was extracted from different types of activities conducted with students. The data consist of students' written documents and video recordings of the classroom activities. To respond to the research questions the available data sources were categorized as follows which also shows the sequence of the data collection process

Written responses to the problems. At the beginning of the course, students were provided with a set of problems related to mechanics. The problems were open-ended, mostly counterintuitive, and conceptual. Many of the problems were adopted from the force concept inventory (Hestenes, Wells, & Swackhamer, 1992) and the others were developed by the author and his colleagues. There were 10 problems in total and students completed their responses approximately in 45 minutes.

Classroom discussions about the problems. After students written responses were analyzed by the researcher, different predictions generated for each problem were categorized. In the classroom session, each prediction was written on the board and students were requested to give more details about their predictions by explaining their reasoning. Before students begin discussion, they first had a chance to hear the arguments behind each prediction. All the discussions were video recorded for further analysis.

Reflection papers on ontological categories. After the problems were discussed in the classroom session, students were introduced with Chi and her colleagues' interpretations about the nature of alternative conceptions in terms of ontological categories. In an hour lesson, the findings in the literature about students' use of substance based conceptions exemplified and ontological training as an instructional strategy was explained with specific examples. After these explanations students were requested to read the assigned papers about ontological categories and write a reflection paper about ontological categories. Students were also requested to make interpretations about their own conceptualizations of the force concept and make connections with the theory.

Classroom discussions on ontological categories. To help students detail their arguments about ontological categories, a classroom discussion was conducted after they handed in their reflection papers. During these discussions, students were stimulated to reflect on their own conceptual problems experienced during the problem solving and make connections with the theory, especially the students whose conceptualizations of the force concept coded as substance based by the researcher. All the discussion session was video recorded for further analysis.

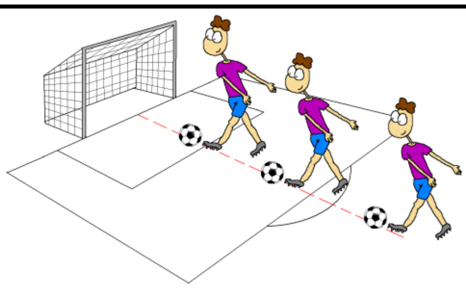
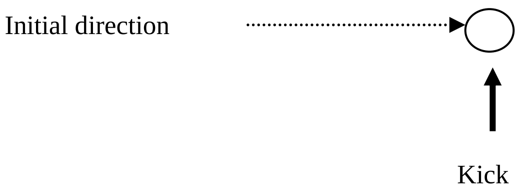
FINDINGS and RESULTS

The data were analyzed separately for each research question. For the first research question (substance based conceptualizations), a straightforward analysis procedure was followed. Based on the theoretical framework of ontological categories, students' written responses and classroom discussions about the problems were analyzed; specific cases where students attributed a substance based characteristics to the force concept was searched and coded accordingly. For the second research question (change process), the data emerging from the students' discussions about the problems were analyzed. In this process, specific attention was given to the particular changes on the students' conceptualization of the force concept during the discussions. These analyses consisted of the researcher's interpretations on the students' use of the force concept from the theoretical perspective of ontological categories. However, for the third research question (students' reflections), students' inquiry and reflections were taken as a base for the analysis.

Students' Substance Based Conceptualization of the Force Concept

The analysis of the students' written responses and classroom discussions about the problems showed that students still had conceptual difficulties related to force and motion after they completed core physics courses. However, only 4 (out of 29) students' difficulties was directly related to substance based conceptualization of the force concept when the available data were analyzed from the perspective of ontological categories. According to this perspective, ontological attributes used by the students provide information about the specific ontological category of the concept hold by the students. The four students' specific attributions to the force concept seemed to be matching with two properties of substance based schema, namely *containable* and *transitional*. The specific attributions to the force concept used by the students were identified as "given," "imparted," and "provided."

Table 1. *The problems on which the students used substance based conceptualization.*

Problem 1		A soccer player is kicking the ball from three different positions as shown on the picture. If you assume that the player is kicking the ball the exact same way in each position, how do you compare the speeds of the ball for each kick when the ball enters the goal?
Problem 2		While a hockey puck is moving in the given direction, it receives a kick. What would be the path of the hockey puck after the kick?

Students' substance based attributions were explicitly observed on two problems which were given on Table 1. Before moving any further, it would be better to talk little bit about these problems. The common characteristic of these problems was that the problem situations included simultaneous and temporary act of forces such as kicking at an object. In addition to the attributions of substance based characteristics, the most explicit form of substance based conceptualization emerged as students' assumption on the existence of the force on an object when there was not actually any force acting on the object. Substance based conceptualization of the force concept did not reveal itself easily if there is a continuing force on objects such as gravitation or continuously pushing or pulling an object. In these situations, it was not easy to distinguish whether students have substance based attributions or not because in both cases there was a force acting on objects.

The four students' substance based conceptualization of the force concept was almost identical in both problems. In both problems, the students thought that there was still a force acting on the object after the kick. The students seemed to be thinking that the temporary force applied by the players during the kick was transferred to the ball. The responses of the four students to the first problem were almost the same. They thought that the ball would enter the goal when the player kicks the ball from a distant position. Below is a student's written response to the first problem.

> "If we ignore the friction, the ball will enter the goal with the highest velocity when the player kicks the ball out of the penalty area. This is because, the ball accelerates with the force *given* by the kick. In a small distance the ball would not accelerate much. But, when the distance was increased, the ball had a chance to increase its velocity on the way to the goal."

According to Newtonian physics, there is no force acting on the ball after the kick – the force is simultaneous and when the kick is over, there is no force acting on the ball anymore. However, the students' conceptualization seemed to be that the force was transferred to the ball after the kick. Therefore, they thought that the force was still acting after the kick and the ball was accelerating. Another interesting point in the students' reasoning was their use of Newton's second law (force causes acceleration). Although students correctly stated Newton's second law, their inappropriate conceptualization of the force concept made this statement meaningless. This is like saying "sugar makes tea sweet" but conceptualizing sugar as something else, like salt. Although the literal statement of the law is correct the actual meaning is completely destroyed.

The following examples describe the four students' reasoning about the second problem. The problem was asking the path of a hockey puck when it receives a kick while moving in a straight line with a constant speed. There were two different responses to this problem. Nevertheless, in both cases the students' conceptualization of the force concept was the same: they thought that the force applied by the player transferred to the puck. One of the students thought that the puck would go straight on the direction of the kick. His argument was quite interesting. He claimed,

> "Objects move in the direction of the net force acting on it. In this problem, the only force acting on the puck is the force *provided* by the kick. Therefore, the puck will move in the direction of the kick. There is no other way."

This student was quite sure with his answer. In actuality, objects do not necessarily move in the direction of the net force acting on the object. Probably he generalized a principle specific to the forces acting on static objects or acting on the same direction with the velocity. He thought that the force was imparted to the puck after the kick. Therefore, he thought that the force was still acting after the kick. Other three students' responses were similar to that of the first problem; they stated a correct physical principle. However, the operation of the principle did not work well because of the students' misconceptualization of the force concept. They thought that the puck would follow a curvy path. Actually, their reasoning can be easily predicted by thinking as if there were continuing force acting on the puck (like gravitation). Below is one of the students' written explanations.

> "The puck would follow the path as shown on the picture above (he drew a curve)… There is only one force acting on the puck which is the force *given* by the kick. The puck is moving under the influence of initial velocity and this force. Therefore, the puck would be distracted continuously from its initial direction and follow a curvy path."

Actually these students' reasoning could be correct if there was a continuing force acting on the puck (such in the case of projectile motion – continuous act of gravitation on a horizontally moving object). However, in this situation there is no continuous force. The force due to kick is simultaneous and there is no force after the kick. Again, we see that although students correctly stated a physical law, their misconceptualization of the force concept led them to an incorrect conclusion.

The Change of Substance Based Conceptualization

In this section, I will describe how the students who were holding a substance based conceptualization (according to ontological category perspective) changed it through classroom discussions and then make speculations about this change process. To describe this process, I will present a considerably long episode from the classroom discussions. In this episode, the students were discussing about the soccer problem. During the discussions, there were 15 students in the class and two of them (Meltem and Defne) were holding a substance based conceptualization.

Instructor:	Okay, here is the problem. In your papers there were two different answers… Let's hear first from the ones who thought that the farther the ball is from the goal, the faster it gets…
Meltem:	I thought that when we increase the distance, the ball would gain more acceleration and enter the goal with greater speed.
Instructor:	Can you explain more why do you think the ball gain more acceleration with the distance?
Meltem:	Actually, I was thinking about the time. If there is more time, the ball will gain more speed. Because there is acceleration all along this time, the speed of the ball will increase.
Instructor:	Then you are saying increase in speed, not the acceleration.
Meltem:	Yes, the speed, not the acceleration. Acceleration will be constant which increases the speed…
Std2:	I could not understand why there is acceleration all along?
Defne:	Because of the kick. Kick is the net force here, which causes acceleration.
	...
Std4:	Then, if we kick the ball from the other goal area, does it enter the goal with more speed?
Std7:	Good question! What if we increase the distance to say a thousand kilometers? There is no way of increasing the velocity.
Meltem:	There is air friction [pause] and eventually the ball will fall…
Std6:	What if there is no friction and gravitation?
Meltem:	I know, it sounds strange but according to the Newton's second low [F=m.a]. The speed must increase…
Std2:	According to the law, if there is no force there is no change in the velocity. The ball's speed does not change all along the way...
Defne:	But there is a force.

Std11: No, there is not.

Defne: What about the kick? The kick is a force, isn't it?

Std2: Yes, but there is no force after the kick…

Std10: It is like a spring; when the objects leave the spring there is no force after…

Std7: If there were force after the kick, everything should be speeding up. It would not be a problem to reach the velocity of light in space and we could send spaceships to other galaxies easily.

Meltem: I understand what you are saying. I did not think about it before. Let me think about it for a while.

Instructor: Defne, what do you think about this?

Defne: I am confused. I always thought there was a force after the kick. But, it is correct if there is always force everything should be speeding up. I did not think about it before either.

Std8: You thought force like energy I guess…

[We took a break after this comment. During the break I believe students kept discussing about the force concept; however, because they left the class these discussions could not be recorded. When we returned, the discussions continued as follows]

Defne: I thought about it and it makes sense. If we think force like that we can never get a constant velocity. The force is there while we are pushing or pulling; when it is over, there is no force.

In this episode, we see Defne and Meltem's dissatisfaction with their prediction by the arguments provided by other students. At the beginning of these arguments, other students did not use physics concepts or principles but they tried to falsify the substance based prediction by common sense beliefs supported with extreme cases. Later on, Newton' second law brought into discussion which made the students realize the conceptual discrepancies among them related to the force concept. Throughout the discussions Meltem and Defne realized that Newton' second law did not make sense by using the force concept as they used to think. Through the end of the discussions they seemed to be changing their conceptualization of the force concept.

The following quotations extracted from the students' discussions on the second problem provided more evidence that the students have changed their conceptualization. In this episode, we immediately see that the students who used substance based conceptualization before were changing their arguments on the second problem (hockey).

Defne: I made the same mistake in this problem. I solved the problem as if there were force acting on the puck after the kick. Therefore my answer was a curved path.

Instructor: What do you think now?

Defne: Okay. Let me think. I previously thought it like a projectile motion. But it is not possible. I know if there is no force, objects must go straight or do not move. The kick is simultaneous and the puck gains a velocity in the direction of the kick. It would move in the direction of the kick but the puck was moving before the kick. Well. [Pause] Okay, there is no force after the kick, and then it has to move in a straight line. If there is no force it can't make a curve, it must be straight. We should add up the velocities then… It must be between the kick and the initial velocity.

Instructor: Meltem, what about you? How do you think about the problem?

Meltem: I agree.

Instructor: But you did not think this way before.

Meltem: Yes, I thought there was force acting on the puck after the kick.

Instructor:	What makes you think, now, that there is no force after the kick?
Meltem:	Because force is not defined that way. There is force when there is an there is something between the things like pushing or pulling. After that, it is over.
Instructor:	Tell us more how did you think about the force before?
Meltem:	I do not know exactly. I did not think about the force with details before. I solved tons of problems while I was getting prepared for the university entrance exam and none of them required me to figure out whether there was a force or not. The force was always given. But, in some cases, I assumed that there was no force; for example, if the problem was saying the speed was constant, I immediately assumed that there was no force.

What can we say about this change process? According to the theoretical framework of ontological categories, these students have shifted their conceptualization of the force concept from one ontological category (matter) to another (the process). The theory claims that "once an ontological commitment is made with respect to a concept, it is difficult through any stages of mental transformation to change one's fundamental conception from a *substance* to a *process* (Chi & Roscoe, 2002). Thus, ontologically misattributed concepts would require an extraordinary process of conceptual change" (Slotta & Chi, 2006, p. 263). However, this shift was not as problematic as it was projected by the theory. From Meltem and Defne's statements, we can understand that they did not have a strong ontological commitment to the force concept although their initial reasoning about the problems showed that they attributed substance based characteristics.

Although I could exemplify only Defne and Meltem's case because of the limited space, other two students also changed their conceptualization of the force concept in a short time. The easiness of these students' conceptual change seemed to be due to students' familiarity about the process nature of the force concept. One source of this familiarity might be coming from the students' experiences with springs as one of the students explanation pointed out; "It is like a spring; when the objects leave the spring, there is no force after…"

Students' Reflections on Ontological Categories and Their Own Conceptualizations

The major pattern emerging from students reflections about ontological categories was that they conceptualized ontological categories as a complex issue. Almost all of the students claimed that ontological categories could not make it easier to understand concepts, but make it more complicated and confusing for both teachers and students. The following script extracted from one of the students' reflections is a typical response provided by many of the students:

> "I think ontological categories might explain some of the roots of misconceptions. However, it doesn't seem possible to make students be aware of different types of ontological categories and stimulate them to shift from one category to another. This process might confuse them because even I am not sure about the ontological status of every physical concept. For example momentum, I do not know its ontological status. I know what momentum is and what is not but I cannot tell students about its ontological category."

Only two students (out of 29) provided supporting arguments for ontological categories without a substantial critique. These students arguments were based on a claim that knowing a concept requires being aware of its ontological status. The following quotation was extracted from one of these students' reflections.

> "I think we can help students understand physics concept by teaching them about different ontological categories. To know something with details require knowing its ontological status. For example, if we need to know about whales we have to know that it is a mammal not a fish. Similarly, when students learn about the force concept they have to learn that it is a process not a matter."

The students' reflections whose conceptualization of the force concept was coded as substance was interesting because they did not interpret their conceptualization substance based. Without an exemption, all four students argued that their conceptualization of the force concept was similar to energy or momentum. They explained their conceptual difficulties in terms of failure to totally comprehend an individual concept. Below is one of the four students' reflections.

> "I do not think that ontological categories are an appropriate way of describing the roots of misconceptions. While I was solving the soccer problem, I thought there was a force after the kick. Actually, I did not think about the force something like matter or substance. I realize now that I thought force more like energy or momentum. I guess we need to know exactly what is force, energy, current, momentum etc. Our instructors did not explicitly provide lectures about the details of these concepts; therefore, we did not completely understand these concepts. I guess the problem is simple: we do not know about the concepts. Ontological categories are difficult to grasp and do not seem to be necessary for students to know. We need to help students wholly understand each concept. We can help them by providing different types of examples for these concepts. For example for the force concept we should explicitly show students when there is a force and there is not with broad range of examples."

During the classroom discussions, students restated their opinions they wrote on their reflection papers. The major argument immerging from the discussions was the difficulty of situating all the physics concepts into the distinct ontological categories. Although they did not explicitly stated, they seemed to be thinking that all the physics concepts should be categorized explicitly according to their ontological categories to be used for instructional practices. The discussion began with the following question asked by one of the students.

> "I could not find an ontological category for the momentum. Is there any map or table showing the ontological categories of all the physics concepts?"

Unfortunately we could not find a distinct category for the momentum throughout the discussions and then the discussions shifted to other concepts such as energy, volume, density, and even mass (which should be considered as a form of energy from the relativistic perspective). Although finding a category for the concepts studied in the literature such as heat and electric current was rather easy, the classroom discussion showed that finding an ontological category for every concept encountered in physics is not an easy task. I think the following comment made by one of the students summarizes the general attitude of the students toward ontological categories.

> "I don't think categories are important as long as we know exactly what a specific concept is all about. I remember our discussions in elementary school about whether a watermelon is fruit or vegetable. As long as I know how it tastes, smells, and look like it does not matter which category I am putting them in."

DISCUSSION and CONCLUSION

The literature on ontological categories has been providing very convincing results about students' biases towards substance based conceptualizations and the effectiveness of ontological training on students' understanding of true nature of scientific concepts. However, this research line has been taking an outsider perspective and put little attention on students' own interpretations about their conceptualizations. In this study, when the available data were analyzed from the same perspective, similar conclusions were reached that some students' conceptualization of the force concept seemed to be substance based. However, these students' retrospective analysis about their own conceptualizations showed that they did not consider their conceptualization of the force concept substance based. They did not make an ontological distinction between their previous and new conceptualizations of the force concept. They argued that they experienced difficulty with the force concept because they did not have explicit knowledge about force. They attributed their conceptual problems to the instructional practices ignoring the conceptual aspects and heavily relying on laws and formulas. Students' classroom discussions about the problems also provided supporting evidence that they could easily adopt a scientific conceptualization when they were explicitly informed about the actual meaning of the concept by their classmates.

Most of the students also believed that ontological interpretations on physical concepts make it more complicated to understand. Classroom discussions also supported this belief; when the questions about ontological status of different types of physical concepts were raised, all class including the instructor realized that it is not an easy task. Even for the simplest concepts, like "mass," the categorization process turn out to be a complicated issue. Although we consider mass concept as matter, in the advanced level it is also energy (Einstein's well-known proposition $E=m.c^2$). Should we put it in the matter category or process; or should we adopt a context dependent ontological schema (which was rejected by the theory)? Another similar concept is "momentum;" how should we define its ontological status? Because in the simplest form, momentum is mass times velocity, which includes both matter and process characteristics. The number of examples can be increased but finding a context independent ontological category for every concept does not seem possible.

In spite of these critiques, there was a consensus among students that traditional instruction did not support gaining an explicit knowledge about the physics concepts. In this respect, what the students are arguing against and the theory match with each other. Both argue that without special treatments demonstrating the explicit forms of a concept, it is difficult to construct an appropriate conceptualization. However, the students strongly rejected the idea of conceptualizing the physic concepts in terms of ontologically distinct categories because of the difficulty they experienced in their attempts to locate physics concepts into the distinct ontological categories.

The implications of this study are twofold. The first one is methodological – specific attributions used by individuals and ontological categories do not necessarily match with each other. Therefore, alternative methodologies should be employed to understand students' ontological orientations toward a specific concept. The second one is theoretical. The question is; can every physics concepts be located into context independent distinct ontological categories? In this classroom, we failed to do that. The researchers who are in favor of the theory should provide more evidence with broad range of examples that every physics concept can be located into distinct ontological categories.

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