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Obstacles to Reasoning about Inertia in Different Contexts

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Abstract

The present study investigated the underlying reasons for difficulties faced by students when they applied the concept of inertia across varying contexts. The participants of the study included five high school students. Data obtained from interviews were interpreted from the perspectives of the coordination class and epistemological framing theories. Analysis indicated that students demonstrated different reasoning patterns across the varying situations. Students' performances were influenced by their epistemological framings about problem solving and previous experiences related to learning physics. Students also revealed a lack of metacognitive awareness about their reasoning in related situations. The results also demonstrated that learning inertia is not a simple task as assumed. The study provides methodological and instructional implications for assessing and teaching inertia.

Keywords: Contextualized-learning, coordination class, epistemological framing, transfer, understandings of inertia

Introduction

Different theoretical frameworks have been proposed to explain the underlying reasons behind difficulties individuals face when reasoning in diverse contexts (diSessa, Elby, & Hammer, 2002; diSessa &Wagner, 2005; Hammer, Elby, Scherr, & Redish, 2005). Working a concept across varying contexts is generally situated in transfer research. The traditional view of transfer has associated the problems of individuals in transfer with not having enough abstract knowledge structures applicable to diverse contexts (diSessa &Wagner, 2005). On the other hand, diSessa and Wagner (2005) have approached transfer from a more contextualized perspective. They used the coordination class theory introduced by diSessa and Sherin (1998) to explain problems encountered during transfer tasks, indicating that difficulties are related to not having a concept projection, which is defined as "the particular set of strategies and cognitive operations that are used by an individual in applying his or her concept in a particular situation" (p. 128). Moreover, some researchers (e.g., diSessa et al., 2002; Hammer et al., 2005) have attributed obstacles in transfer to inappropriate activations of cognitive and epistemological resources. Hammer et al. (2005) have argued that students' epistemological framings, or expectations about how knowledge is constructed and acquired, affect their approaches to learning tasks.

The present study applies the coordination class and epistemological framing theories jointly to discuss underlying reasons for difficulties students faced when applying the inertia concept in different contexts. Applying these theories to the same data set enables us to examine the relationship between them. Inertia was chosen since it is often neglected by physics education researchers compared to other Newtonian concepts such as force or gravity, and little is known concerning students' understandings of inertia.

Theoretical Framework

Coordination Class Theory

Coordination class theory is a model of having a concept and of conceptual change (Levrini & diSessa, 2008). A coordination class is a systematic collection of strategies employed to determine a category of information from real-world situations (diSessa & Sherin, 1998). For example, this information can determine the forces affecting a book on a table. Physics concepts such as force, acceleration, and proper time are examples of coordination classes (diSessa & Wagner, 2005).

According to diSessa and Wagner (2005), the contexts in which a particular coordination class can be applied are diverse. For example, recognizing the forces at work on a car when it is at rest, when it is moving steadily, and when it is accelerating requires different strategies, knowledge, and concept projections for each situation. Applying a theoretical concept to different situations raises two major problems. diSessa and Wagner (2005) identified these problems as span and alignment. Span refers to having sufficient resources to apply a concept to a particular situation, otherwise known as concept projection. Span requires adequate accumulation of concept projections. The problem of alignment refers to being able to determine the same information across different contexts or manipulating projections in different situations to produce the same information (diSessa & Wagner, 2005; Levrini & diSessa, 2008).

According to coordination class theory, having a concept requires being able to see concept characteristic information in various relevant contexts (Levrini & diSessa, 2008). Several researchers have provided evidence to support this theory (Levrini & diSessa, 2008; Ozdemir, 2013; Thaden-Koch, Dufresne, & Mestre, 2006; Wagner, 2006; Wittmann, 2002). For example, Thaden-Koch et al. (2006) applied coordination theory to explain students' conceptual reasoning about the realism of computer animations featuring metal balls moving on a pair of metal tracks. First, students were asked to reason about the reality of the animated motions as a single ball rolled on two tracks. Then, they were asked to judge the animated motion as a second ball was added and the two balls rolled on the tracks together. Students provided different judgments concerning the reality of the animated motions for both situations. They employed drastically different strategies to assess realistic motion in the two contexts.

Difficulties reasoning in different contexts can be explained by coordination class theory, which emphasizes the importance of having sufficient concept projections to work a concept across varied situations. Because different contexts may require different concept projections to determine a related class of information, a narrow span may be responsible for failure to apply a concept across multiple situations.

Epistemological Framing

Based on Tannen's original notions (1993), Hammer et al. (2005) have defined framing as "phenomenologically, a set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she thinks to act" (p. 98). In terms of framing, an individual draws from previously acquired abstract knowledge to make sense of what is happening in situations they view to be similar (Hutchison & Hammer, 2010).

Epistemological framing is related to knowledge and knowing or learning. An individual's responses to "How will I learn/build new knowledge here?" and "What counts as knowledge here?" can form an epistemological frame (Redish, 2004). When students encounter new learning situations, they may apply similar past experiences to deal with those situations. Differences in epistemological framings influence students' actions in a particular learning or problem-solving situation. Elements such as instructors' statements, physical environment, and the words or context of problems can also influence an individual's activation of epistemological frames (Redish, 2004).

Methodology

Participants

Five tenth grade high school students (two female, three male) in a public high school in Ankara, the capital of the Turkey participated in the study. The school accepts students succeeding high school entrance exam. Students' ages ranged from 15 to 17. They formed a heterogeneous group representing low, medium, and high achievement levels determined with their ninth grade physics GPA. All students had been exposed to the concept of inertia in various grade levels since primary school. In their high school education, students took a two-hour physics course at ninth grade and they were taught inertia concept in force and motion unit. During data collection period, they were taking a two-hour physics course and they completed the properties of matter unit. The physics curriculum they were exposed was named as a contextualized physics curriculum in which the physics concepts were introduced using contextualized real-life examples. The high school physics curriculum had also spiraling feature to revisit the same concepts at more advanced levels. Thus, the tenth grade physics curriculum also included inertia concept in force and motion unit. The learning environment in which the participants were taught was generally teacher-oriented.

Data Collection and Analysis

Students were individually interviewed for about half an hour before they were instructed on the inertia concept as indicated in the tenth grade physics curriculum. The following five interview questions were developed by the researcher based on coordination class theory's claim that having a concept requires working that concept across different contexts.

1. Can you define inertia?
2. Does a stationary car have inertia?
3. Does a steadily moving car have inertia?
4. Does an accelerated car have inertia?
5. Can you compare the inertia of two cars if one is moving at **V** velocity and the other is moving at **2V** velocity?

The researcher asked the first questions to probe students' context free abstract knowledge about inertia. The rest of interview questions in the protocol were developed to investigate students' contextualized understandings. Specifically, the aim of these questions was to probe whether students activated proper concept projections to work inertia in different contexts and knowing abstract definition of inertia was enough to apply inertia in different contexts.

Transcripts of audiotaped for each student's interview were used for data analysis. An interpretivist qualitative methodology was employed to investigate underlying reasons behind the difficulties students faced when they applied their understanding of inertia in varying contexts (Creswell, 2007). First, the data obtained from interviews were interpreted from the perspective of coordination class theory. Then, it was observed that some difficulties for activating suitable concept projections could be related to students' epistemological understandings. Finally epistemological framing was employed to explain students' problems of working inertia in different contexts.

Results

Context-free Conceptions of Inertia

The first question in the interview probed students' abstract knowledge of inertia without relying on specific context. Students' definitions of inertia are summarized in Table 1. Except for Student 3 and Student 5, the students provided nearly complete explanations. Student 5's definition was not completely incorrect, as he identified the motion that happens as result of inertia as inertia.

Table 1. *Descriptions of inertia*

Students	Description of inertia
Student 1	Inertia is the tendency of a body to keep its state of motion.
Student 2	Inertia is the tendency of an object to keep its position.
Student 3	Inertia is a thing that we do not exert intentionally but that leads an object to have velocity or force.
Student 4	Inertia is the tendency of an object at rest to keep its position.
Student 5	Inertia is when an object moves unintentionally under a force,

On the other hand, is having an abstract definition of a concept adequate to apply that concept in various contexts, or, using coordination class terminology, is knowing the simple definition of a concept enough to have that concept? To answer this question, students were asked contextualized questions during the interviews.

Inertia at Rest for Car Context

After defining inertia, students were asked to think about it in the particular context of a car in different states of motion. Table 2 presents students' conceptions about whether a stationary car has inertia. Analysis indicated that most students thought objects at rest did not have inertia.

Table 2. *Inertia at rest*

Students	Conceptions
Student 1	There is no inertia at rest.
Student 2	*The context of the question did not make sense to her, so she did not answer*[1].
Student 3	There is no inertia at rest.
Student 4	There is inertia at rest for certain objects.
Student 5	There is no inertia at rest.

[1] Student 2 denied answering the rest of contextualized questions in the interview by saying speaking inertia in situations different from the contexts include passengers in vehicles. Therefore, we have the data for Student 2 in only the first question in the interview protocol.

Knowing an abstract, context-free definition of inertia did not help the students perform accurate reasoning. Responses to the first question showed that most of students had at least partly factual information about inertia; however, they did not apply this information when answering the second question. For example, according to Student 1, "Inertia is the tendency of a body to keep its state of motion." After this response, Student 1 was expected to say that a stationary car had inertia, but he did not. Such inconsistencies can be explained by coordination class theory. The students did not have the proper concept projections of a stationary car's context to see or interpret its inertia. As seen in the table, to determine inertia in this context, students focused on the state of "resting," which led them to bridge unreliable information.

Students' difficulties in working a concept in different contexts can be explained in terms of epistemological framings as well, which might hinder them from producing or activating suitable concept projections. For example, one student's behavior indicated the effects of epistemological framing on her problem solving approach. Student 2 stopped answering the rest of questions in the interview because the car context did not make sense to her. The following excerpt is from her interview:

Researcher: Does a stationary car have inertia?
Student 2: Does a car have inertia? It can't.
Researcher: Does a car not have inertia?
Student 2: Maybe, but the inertia of a car is nonsense to me.
Researcher: Why is it nonsense?
Student 2: That a car has inertia does not make sense to me. Before a car starts to move, they [people] speed up. Maybe, that time it has inertia, But again my response would be no.
To prompt Student 2 to consider the inertia of stationary objects, the researcher changed the context.
Researcher: Okay. Then, let's change the car to a ball. Does a stationary ball have inertia?
Student 2: Um... I do not know. I can't think. A ball (pause) but I get the ball to move. According to my definition of inertia, it tends to keep its position. Does the ball go back? It is not possible. I do not know, I cannot reason.
Researcher: Ok let's continue. When the stationary car starts to move, how does its inertia change?
Student 2: Again, the same. How does the car even have inertia?
Researcher: Okay, let's change the car to the ball.
Student 2: No, No! (laughing) The ball is more complex.
Researcher: Then, let's speak about the passenger in the car. You used that example when you defined inertia.
Student 2: Yes, for me, inertia is valid for a passenger (laughing).
Researcher: Why do you always consider the same example?
Student 2: Because the same examples have been given [by teachers].
Researcher: Based on your previous experiences, did you answer?
Student 2: Yes. Since I was in seventh grade, I have learned inertia through this example. Nobody has ever asked me about the inertia of a car. Given examples: Balls tied to the ceiling of a moving car or a passenger in the car. The ball goes left or right but it is always inside something moving. For example, if the ball you asked about was in a moving thing, then speaking about the inertia of the ball makes sense to me. But the ball is at rest, then we are pushing it, that's how its inertia changes. Nobody has said anything about it.

Student 2's problem seems to be epistemological. Her previous experiences with problem solving might lead her to frame activities that are different from those her teachers or textbooks provided or discussed as hard to reason out or impossible to solve. This framing caused Student 2 to reject the production of concept projections that would allow her to apply inertia in the car context.

> *The idea of the inertia of a car did not make sense to Student 4, either. Her approach can also be explained with epistemological framing, as seen in this interview extract:*
> *Researcher: Does a stationary car have inertia?*
> *Student 4: How? (puzzled)*
> *Researcher: Does a car have inertia?*
> *Student 4: It can't. For example, as I said before, when the bus driver puts on the brake, someone in a bus goes forward if he does not hold something, but he tends to keep his position. That is, something acts on an object. But noting acts on a car.*
> *Researcher: Then, let's say like this. Does a ball have inertia?*
> *Student 4: Yes, it does. We exerted a force on a ball from outside, but it is not possible to have such thing for a car.*
> *Researcher: What gets a car to move?*
> *Student 4: We do, but the structure of a car is different. It has its own equipment inside. It can move or stop.*

According to Student 4, the car context was atypical, with different working physics principles than those seen in classrooms or textbooks. Thus, inertia could not be applied. She seems to frame that physics principles are not applicable for all objects' motion, only certain objects' motion. Similar to Student 2's, Student 4's framing prevented from her applying the inertia concept to the car. However, unlike Student 2's, Student 4's framing did not preclude her from seeing inertia in the ball context. Although not so overt, Student 4's framing might also is a result of her learning experiences. In classroom learning and textbook examples, physics principles are generally taught in idealized situations, ignoring other rules such as friction to simplify situations. Such experiences might have lead Student 4 to frame that physics principles are not valid in complex real life situations.

Inertia during Constant Motion

The third question asked students whether a car with constant velocity had inertia. According to Student 1 and Student 5, it did not, while Student 3 reported that it did. Student 4 considered a ball in constant motion instead and indicated that the ball did have inertia (see Table 3). Student 3 and Student 4 focusing on movement allowed for a concept projection to see inertia in that context. However, Student 1 and Student 5 paid attention to the non-change in state of motion and provided similar justifications for their answers. They expressed that constant motion implied no change in state of motion, so there was no inertia. Student 1 and Student 5 focusing on "constant, changeless state of motion" hindered their production of concept projection. In addition, Student 5 referenced inactive and active inertia and demonstrated another epistemological issue: he thought that physics concepts could work differently in different situations, which influenced his response. According to Student 5, "If we consider the car in constant motion, it has inertia, but this inertia is not active. To activate the inertia, there should be a sudden force, sudden acceleration, or stop."

Table 3. *Inertia during constant motion*

Students	Conceptions
Student 1	There is no inertia during constant motion.
Student 2	*The context of the question did not make sense to her, so she did not answer.*
Student 3	There is inertia during constant motion.
Student 4	There is inertia during constant motion.
Student 5	There is no inertia during constant motion.

Inertia during Accelerated Motion

Except for Student 2, who refused to respond to car questions, all students accepted that an accelerated object has inertia. This finding implied that it was easy for students to consider inertia during a change in motion. In other words, focusing on change in motion helps students to produce concept projections to specify inertia in that context.

Table 4. *Inertia at accelerated motion*

Students	Conceptions
Student 1	There is inertia during accelerated motion.
Student 2	*The context of the question did not make sense to her, so she did not answer.*
Student 3	There is inertia during accelerated motion.
Student 4	There is inertia during accelerated motion.*
Student 5	There is inertia during accelerated motion.

* Student 4 continued to apply the ball context.

Dependence of Inertia on Amount of Velocity

Students' understandings regarding whether an object's inertia depends on the magnitude of its velocity are given in Table 5. All students activated unreliable concept projections to produce reliable information, but no students contradicted their reasoning from Question 3. According to Student 1 and Student 5, since objects moving with constant velocity do not have inertia, neither object has inertia. On the other hand, Student 3 and Student 4 argued that the car's velocity influenced its inertia by focusing on differences in magnitudes; the faster car had more inertia. Student 4 justified her reasoning: "To stop the ball having 2V velocity, I exert a force, but as it has more velocity, it wants to continue its motion and tends to keep his position more. That's why its inertia would be greater."

Table 5. *Students' conceptions related to dependence of inertia to magnitude of velocity*

Students	Conceptions
Student 1	Equal inertia (zero) since they are in constant motion.
Student 2	*The context of the question did not make sense to her, so she did not answer.*
Student 3	The faster car has more inertia.
Student 4	The faster objects have more inertia.
Student 5	Equal inertia (zero) since they are in constant motion.

Conclusion and Discussion

This study discussed students' performances when applying the inertia concept to varying contexts from the perspective of coordination class and epistemological framing. The analysis of the students' reasoning indicated that they generally employed varying concept projections to determine related information about inertia across contexts. Students activated proper concept projection to apply inertia during accelerated motion, as all students except for Student 2 applied it correctly in that situation.

In terms of coordination class theory, this study provides rich implications about learning, teaching, and research. To have a concept, an individual should determine concept-related information from diverse contexts (Levrini & diSessa, 2008). Based on the students' performance in this study, it can be said that none of them fully understood the inertia concept, since they produced inconsistent reasoning across the situations. Students did not have problems providing an abstract definition of inertia, and they were able to recognize inertia during accelerated motion, but they could not appropriately apply inertia to resting and constant motion situations. Acquiring and recognizing reliable concept characteristic information from diverse contexts requires a wide span, which means adequate accumulation of concept projections, as well as appropriate alignment. A wide span can be accomplished with significant situation-specific knowledge. Thus, using multiple contexts promotes reasoning across diverse situations, since new contexts promote different concept projections, which are useful for knowledge transfer (diSessa & Wagner, 2005).

The findings of this study support the importance of contextualized learning. Participants easily activated suitable concept projections to apply inertia in an accelerated motion context. The underlying reasons for the students' successes can be inferred from their examples and Student 2's explicit statements. Almost all students mentioned the context of a passenger in a car or bus suddenly stopping or speeding up. That is, inertia was introduced and taught to them in situations featuring acceleration. If they had been exposed to more resting or constant motion situations, they might have adequate collections of concept projection.

Metacognitive deficiencies in students' reasoning were also observed in this study. Students did not monitor for and were not aware of inconsistency between their answers to the series of questions. Lack of metacognitive awareness of reasoning demonstrated in varying contexts is related to alignment, whether students recognize that concept projections used in different situations should produce the same information. The students in the present study had alignment problems with the inertia concept as well. To overcome alignment problems, metacognitive instruction can be employed. Explicit exposure to and the relation of multiple classes of concept projections can promote students' metacognitive awareness that different projections of a concept in different contexts can generate the same information (Levrini & diSessa, 2008). Georghiades (2006) has provided evidence that metacognitive instruction can increase students' performance in different contexts.

In addition, analysis indicated that students' epistemological framings influenced their reasoning across varied contexts. Inappropriate activations of epistemological resources hindered students in producing concept projections to apply inertia in a particular context. This finding parallels diSessa et al. (2002). Redish (2004) has further recommended that teachers should develop students' epistemological frameworks with both overt and covert messages. For example, teachers can probe students' epistemological framings related to learning and then address those framings explicitly with activities such as small group discussions. That students are frequently exposed to multiple contexts when learning a concept, including complex and unfamiliar real life situations can promote their epistemological framings. In addition, teachers should task students to solve challenging questions and scaffold them into problem solving sessions. This study also offered implications for the assessment of conceptual understanding. Students demonstrated context-dependency in their answers. Thus, to ensure whether students have mastered a particular concept, they should be assessed using questions with multiple contexts.

The results of the study have implications on teaching inertia for instructors, textbook writers, and curriculum developers. A short review of the famous physics textbooks (e.g. Giancoli, 2000, Griffith, 2001) and a current high school textbook (Ministry of Education Board, 2014) used in Turkey clearly indicated that inertia has not received adequate attention. Textbook writers generally give little focus under Newton's laws of motion or mass sections without discussing it in a separate detailed section. The findings of this study indicate that understanding inertia is not as simple as assumed. Instructors and textbook writers should change their methods of presenting and teaching inertia. Students focused on states of motion when trying to determine inertia in different situations, which caused them to produce improper concept projections. Students' inclinations might have originated from textbook definitions, such as the following examples:

- *The tendency of a body to keep moving once it is set in motion results from a property called inertia… The tendency of a body at rest to remain at rest is also due to inertia. (Young & Freedman, 2008, p. 112)*
- *The tendency of a body to maintain its state of rest or of uniform motion in a straight line called inertia. (Giancoli, 2000, p. 79)*
- *Mass is a measure of an object's inertia, the property that causes it to resist a change in its motion. (Griffith, 2001, p. 59)*

The commonality among the definitions is an emphasis of state of motion. Inertia depends only on the mass of a body and is independent of state of motion, yet only one definition above addressed mass. It can be speculated that if the definition included mass, it might help guide the activation of suitable concept projections. The following working definition is recommended considering the difficulties presented in the current study: Inertia is the intrinsic tendency of a body to maintain its state of motion, whether at rest or in constant or accelerated motion, due to its mass.

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