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Consistency of Students' Ideas about the Concept of Rate across Different Contexts

Öğrencilerin Hız Kavramı Hakkındaki Düşüncelerinin Farklı Bağlamlardaki Tutarlılığı

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Abstract

This study investigates consistency of 11th grade students' ideas about the concept of rate across different contexts namely velocity of an object in physics and rate of reaction in chemistry. The subjects of the study were 200 11th grade high school students in three schools. Data were collected after formal teaching on reaction rates and kinematics. Data sources included students' responses to six diagnostic questions and interviews. The results suggest that consistency of students' ideas about rate concept across different contexts and domains are limited. The results revealed that students' ideas about the concept of rate depend to some extent on the format and contextual features of the questions presented. It is observed that students are more likely to give a correct answer when data are presented on a table rather than on a graph. There is very little evidence showing that students coherently apply their ideas about rate concept across a wide range of contexts. Implications for designing instruction that would provide students with opportunities to develop metacognitive skills are suggested. In this respect, teachers from different disciplines can cooperate with each other when they teach closely related concepts in biology, chemistry, physics or mathematics.

Keywords: consistency, concept of rate, velocity, misconceptions

Öz

Bu çalışma, 11. sınıf öğrencilerinin hız kavramı hakkındaki düşüncelerinin tutarlılığını, bir cismin hızı ile kimyada reaksiyon hızı kavramları için araştırmaktadır. Çalışmaya üç farklı okuldaki 11. sınıf öğrencilerinden toplam 200 kişi katılmıştır. Veriler, reaksiyon hızı ve kinematik konuları anlatıldıktan sonra toplanmıştır. Bu çalışmadaki veriler, öğrencilerin tanısal altı soruya verdikleri cevapları ve öğrencilerle yapılan görüşmeleri içermektedir. Sonuçlar, öğrencilerin hız kavramı hakkındaki düşüncelerinin tutarlılığının değişik içerik ve alanlar arasında sınırlı olduğunu göstermiştir. Sonuçlar, öğrencilerin hız kavramı hakkındaki düşüncelerinin tutarlılığının soruların format ve içeriğine bağlı olduğunu göstermiştir. Veri tablosu verilip öğrencilerin bu verinin grafiğini çizmeleri istendiğinde, öğrencilerin doğru cevabı vermeye daha yatkın olduğu gözlemlenmiştir. Öğrencilerin hız kavramı konusundaki düşüncelerini çok geniş bir alana sahip bir içerikte uyumlu olarak uyguladıklarını gösteren çok az veri vardır. Öğretim programlarını tasarlarken öğrencilerin bilişötesi beceri geliştirmelerini sağlayacak stratejiler önerilmiştir. Bu bakımdan farklı branşlardaki öğretmenler fizik, kimya, biyoloji veya matematikte bağlantılı kavramları öğretirken birbirleriyle işbirliği yapabilirler.

Anahtar Sözcükler: Tutarlılık, hız kavramı, hız, kavram yanılgıları.

Introduction

It is important to understand the meaning of science concepts within and across disciplines.

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Students usually learn a concept within one discipline; however, they usually fail to understand the same concept when they face it in another discipline. For example, they learn the slope concept in mathematics but they usually fail to use it correctly in physics, chemistry or biology. Thompson (1994) noted that speed is usually taught as distance divided by time, but not as a ratio, so that is an obstacle for student to understand the speed as a rate.

There are many concepts in science that are not isolated and specified for one specific discipline. One of these concepts is the concept of rate which has a broad use in many areas in science and mathematics. The term "rate" is often used to describe the change in a quantity that occurs per unit of time. Basically, both in physics and chemistry the meaning of rate is similar but the use and the terminology of this concept is different for each domain. For instance, in chemistry, the rate of a reaction can be defined as the change in concentration of a particular reactant or product per unit of time. On the other hand, in physics, the term "velocity" is used for the amount of displacement in a certain time period, which also refers to the "rate" concept. Therefore, in this paper the terms "rate" and "velocity" are sometimes used interchangeably. One of the objectives of the Turkish secondary science (biology, chemistry and physics) curriculum is to establish links between physics, chemistry and other science fields in terms of key science concepts (MEB, 1998; 2007). Therefore, it does not seem unreasonable to expect students to have coherent conceptions of rate in chemistry and physics. Accordingly, this study aims to investigate consistency of students' ideas about the concept of rate namely velocity in physics and rate of reaction in chemistry. By consistency we mean the common application of a conceptualization or framework to explain a number of related contexts, thus, from an educational point of view demonstrating a conceptual understanding of the underlying scientific ideas (Kwen, 1996). Rodrigues and Bell (1995) state that in the literature, the word "context" can mean a variety of things, such as the classroom, the learning environment, or the relevance of an activity. However, in this paper by "context" we mean a task (or a situation) in different settings in which different cueing is given. In other words, "context" refers simply to the situational settings of tasks.

Students' Common Conceptual Difficulties Regarding Rate of Reaction

Research on students' understanding of rate of reaction documented following conceptual difficulties: inability to define the rate of reaction (e.g. defining reaction rate as reaction time), difficulties in explaining how reaction rate changes as the reaction progresses (Cakmakci, Leach & Donnelly., 2006; Calik, Kolomoc & Karagolge, 2010), misunderstandings of the relationships between temperature change and the rate of reaction (Calik et al. 2010; Justi, 2002; Quilez & Solaz, 1995; Van Driel, 2002), misunderstandings of the relationships between concentration change and the rate of reaction (Cachapuz & Maskill, 1987; Cakmakci et al., 2006; Sozbilir, Pinarbasi & Canpolat, 2010), misunderstandings of the effect of a catalyst on the rate of reaction and on the mechanism of the reaction (Cakmakci, 2009; Hackling & Garnett, 1985; Tastan, Yalcinkaya & Boz, 2010), and having conceptual difficulties in interpreting empirical data and graphical representation (Cakmakci et al., 2006).

Students' Common Conceptual Difficulties Regarding Velocity in Kinematics

The concept of velocity is one of the demanding concepts in physics and usually confused with the concept of "speed". Speed is a scalar quantity and describes how fast an object moves. On the other hand, velocity is a vector quantity which explains the rate of an objects displacement. Here is an example to explain the distinction between these two concepts: A car moves from city A to city B and then back to city A. There is a certain amount of speed for that car, but the velocity is zero since the displacement equals to zero.

Students learn a concept in a course, but they usually fail to use correctly that concept in different domains. Beichner (1994) conducted a study with 895 high school and college level students. All students had already been taught kinematics by using traditional instruction in which the teacher is the speaker and the students are the listeners. The Test of Understanding

Graphs-Kinematics (TUG-K) was used to test students' kinematics graph interpretation abilities. Beichner realized that students confuse the slope and area in kinematics graphs. He noted that students were able to find the distance by using the distance formula ($d=v_*t$), but they had difficulty in realizing that the area under the curve of a v-t graph also represents the distance. Students learn how to calculate the area under a curve in mathematics, but as can be seen from Beichner's study they usually fail to apply that in physics.

Researchers reported some common misconceptions related to the concept of velocity such as that velocity has to be positive (McDermott, Rosenquist & van Zee, 1987), same positions means same speed (Trowbridge & McDermott, 1980), leading object moves faster (Trowbridge & McDermott, 1980), same velocity means same acceleration (Trowbridge & McDermott, 1981), larger (smaller) velocity means larger (smaller) acceleration (Trowbridge & McDermott, 1981), positive slope for a negative velocity means the object is speeding up (Goldberg & Anderson, 1989), students plot position and velocity graphs as the path of the particle (McDermott et al., 1987) and zero velocity means zero acceleration (Trowbridge & McDermott, 1981). In addition, since graphs are commonly used in kinematics, students usually have some difficulties related to the use of kinematics graphs. The most common difficulties that students experience are as follows: graph as picture error (Brasell & Rowe, 1993; Kozhevnikov, Hegarty & Mayer, 1999), transforming knowledge of graphs that they have learned in mathematics (Beichner, 1990), interpretation of kinematics graphs (Adams & Shrum, 1990; Beichner, 1994), and construction of kinematics graphs (Berg & Phillips, 1994).

Theoretical Foundations

There is continuing debate about what best characterizes the nature of students' ideas in science (Ozdemir & Clark, 2007). On the one hand, there is a view that students' ideas in science are coherent, stable and theory-like (McCloskey, 1983). In some cases, it has been claimed that students' preconceptions resemble earlier theories in the history of science (McCloskey, 1983). For example, McCloskey (1983) proposed that in the domain of mechanics many students hold systematic alternative conceptions that appear to be grounded in a systematic, intuitive theory of motion that is consistent with fundamental principles of Newtonian mechanics, resemblance a pre-Newtonian theory known as the impetus theory discussed by the French philosopher Buridan in the fourteenth century. On the other hand, there is a contrasting view that students' ideas in science are not theory-like, but instead are fragmented collection of ideas, loosely connected, unsystematic, and context depended (diSessa, 1988). diSessa (2002) views students' preconceptions consist of coordination classes and certain phenomenological primitives (p-prims), which are simple abstractions from everyday experiences. Some examples of p-prims cited are "force as a mover" (an abstraction of a push or toss), "dying away" (to correspond to dissipating forces) and "violent force" (to correspond to throwing an object). Nonetheless, there is another view among researchers which suggests that students may simultaneously have several alternative explanatory schemes, each of which is persistent over time and applied coherently across a wide range of overlapping contexts (Nakhleh, 2001; Taber, 2000). These cognitive structures may include representations at varying grain sizes and with different degrees of coherence, integration and commitments (Taber, 2000).

The Research Aim and Significance of the Study

Bearing these points in mind, this study aims to investigate consistency of students' ideas about the concept of rate across different contexts namely velocity in physics and rate of reaction in chemistry. The aim of the study is addressed through the following research questions:

(i) What kind of conceptual difficulties do students experience in the concept of rate in chemistry and physics?

(ii) How well do students use the concept of rate in a range of contexts in chemistry and physics?

The concept of rate was selected as the focus of this study because it has received minimal attention in the literature dealing with students' conceptual understanding of rate across different domains. As discussed earlier many researchers who focused on rate concept only considered chemistry or physics domains. None of these studies assessed students' ideas about rate concept across chemistry and physics. Knowing a concept in the abstract within a context and domain, and using it appropriately across different contexts and domains are two different things. Therefore, it is a necessity to investigate whether students' generalize their conception of the rate across different contexts and domains. These results can be used to help students develop meaningful understanding of the concept of rate.

Methodology

The sample of this study included 200 11^{th} grade (aged 16-17) high school students from three public high schools in Turkey one of which was Anatolian high school. Data were collected after formal teaching on reaction rates and kinematics. The study was undertaken in the spring semester of the 2009–2010 academic year. Data sources included students' responses to six diagnostic questions along with interview questions. Three diagnostic questions about reaction rates and three questions about kinematics were used as a data collection instrument. Chemistry questions were previously used and validated in our previous studies (Cakmakci et al., 2006; Cakmakci, 2010; Cakmakci & Aydogdu, 2011). In addition, chemistry and physics questions were piloted on 194 grade-11 high school students in the 2008–2009 academic year. Each question was first reviewed by the researchers, who commented on its suitability with regard to scientific content, format and language. In addition, before the first pilot study one secondary school chemistry and physics teachers served as judge on the content validity of the questions against the curriculum. In the light of the pilot study, any required modifications were made on the questions. The diagnostic questions were in two parts similar to two-tier questions (Treagust, 1988). However, the first part has five multiple choices and the second part asks students to explain their answers. An English version of all six questions can be accessed in Bektasli and Cakmakci (2011). The questions were intended to reflect the use of knowledge rather than merely possessing knowledge. The questions were designed to allow the investigation of students' ideas in different contexts in chemistry and physics. For instance, as shown in questions 3 and 5, students' ideas about the concept of rate were addressed in two different questions. These two questions are relevant to each other from a scientist's point of view (i.e., the underlying science and reasoning are similar in both cases). In the questions, different kind of data was presented to students; they had to assess the data and find out how the rate/velocity changes with time. Students were asked to describe both textually and graphically, how the rate changes during time. After the administration of the diagnostic questions, a surface analysis of responses was conducted and possible interviewees were selected. A subsample of the participants was selected to represent diversity in responses to the written questions and to probe their understanding of the concept of rate in more depth. Six students in the main study (and eight students in the pilot study) were interviewed based on their performance on the test. In the main study, two high, two middle and two low level students were selected for interviews. Students were asked to explain their answers in details, and challenged by some questions to find out how they think when they solve the questions. The interviews lasted 10-20 minutes, were tape-recorded and transcribed for analysis.

Data Analysis

Initially each question was analyzed and three main categories of responses were identified and used in the reporting results: (1) responses including mainly scientifically incorrect ideas about the topic, (2) responses including mainly scientifically accepted ideas about the topic, (3) all other responses (no response or incomprehensible responses). Students' responses to the questions were entered into SPSS (Statistical Package for Social Sciences) and analyzed accordingly. An example of the outcome of the analysis is shown in tables 1 and 2. In order to explore how students were reasoning, individual students' responses to the questions testing the same ideas were cross-tabulated (see table 4). If students' reasoning is based on underlying reasoning patterns, consistent responses might be expected to the questions testing the same ideas. The patterns of individual students' responses to questions testing the same basic idea in chemistry and physics are shown in table 2-4.

So as to explore the nature of students' explanations and difficulties, a more detailed analysis was conducted. The main aims of interviews were to obtain further information regarding students' ideas about the concept of rate and to check for appropriate interpretation of the written responses. Students' interviews were transcribed to search for consistency as well as inconsistency of student ideas about the concept of rate within and across chemistry and physics domains.

Table 1.
Percentage of Students' Answers for the Diagnostic Questions

	Question	(A)	(B)	(C)	(D)	(E)	Other or No Answer	Total
Chemistry	1	7.5	29.5* (4.0)**	30.0	18.5	14.5	-	100
	2	28.0	32.5	10.5	16.5* (2.5)**	15.5	-	100
	3	*37.5*	11.6	9.5	35. 9* (11.7)**	5.1	1.0	100
Physics	4	48.5* (10)**	5.5	6.5	22.5	16.5	0.5	100
	5	31.5	2.5	58.5* (4.0)**	3.0	4.0	0.5	100
	6	27.5	1.5	60.0* (7.0)**	5.5	4.5	1.0	100

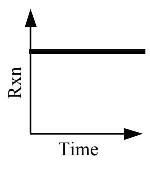
N*otes: * Symbol shows the percentage of correct answer to the first part of the question*
** Symbol shows the percentage of correct answer to the first part of the question but incorrect reasoning is given in the second part of the question

Results

Students' Responses to Questions Related to Chemical Reaction Rates

Question 1

While 25.5% (29.5-4=25.5%) of the students gave a scientifically correct answer for this question, 74.5% of them used conceptions not consistent with scientific perspectives and had conceptual difficulties in explaining how reaction rate changes as reaction progresses (see table 1). The idea that "reaction rate increases as the reaction progresses," "reaction rate is constant," "reaction rate increases up to a maximum value, and remains constant at this value" and "the rate of a reaction was constant" were quite common among students. Here is an example:

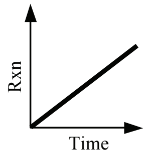


Decrease of the concentration of W [reactant] *shows that the reaction occurs. However, since there isn't any external factor (e.g., temperature, pressure etc.) that affects reaction rate, the rate of the reaction would remain constant.* [Student-58]

As presented in this quotation, many students assumed that as long as certain factors (e.g. temperature, concentration or catalysts) were not altered, the reaction rate would remain constant or remain the same during a reaction. However, they state that "*If* the temperature or concentration is changed, *then* the reaction rate would change, otherwise the reaction rate is constant during a reaction." This evidence suggests that students have superficial understanding of reaction rate.

Question 2

This question was particularly difficult for the students. Only 14% (16.5-2.5=14%) of the students provided a scientifically correct answer, while the rest of them had an incorrect answer. Here is an example:

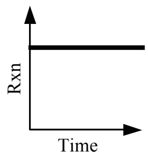


Catalyst is used in this reaction which means the amount of the substance will not change but the reaction rate will increase ….. The amount of [NO] decreases during time and since catalyst is used, it will decrease more rapidly. [Student-150, interview]

As evident in this quote, students simply memorize some pieces of knowledge without understanding the ideas behind them and without considering other data in the given task. In addition, students appeared to have difficulties in moving within and across different representational forms. For instance, while they provided appropriate explanation for the relationship between reaction rate and time in written or oral form, they failed to construct a symbolic representation for this relationship–e.g. by representing it on a graph (Cakmakci et al., 2006).

Question 3

In questions 1 and 2, data were presented on a graph, however this time, question 3 presented students with data in a table. The students had to assess the data and find out how the reaction rate changes with time. The results indicated that while 24.2% (35.9-11.7=24.2%) of the students provided a correct answer, the majority of the students (74.8%) had a scientifically incorrect answer for the question.



Concentration of G [product] *is increasing during time. However, all of these chemicals are in liquid phase and the reaction rate wouldn't change. Because the concentrations of liquids are constant.* [Student-50]

Consistency of Students' Ideas about Reaction Rate across Different Contexts in Chemistry

Table 2 shows the pattern of individual students' responses to questions 2 and 3. In question 2, 28 students (14%) gave a correct answer; for question 3 the figure was 48 (24%). However, only 18 students (9%) answered both questions correctly. Inspecting table 2, it becomes evident that context plays a significant role in students' preference for the usage of their scientific knowledge.

Table 2.
The Pattern of Students' Responses to the Questions Testing the Same Basic Ideas in Chemistry

		Question 3		Total
		Correct	*Incorrect*	
Question 2	*Correct*	18 (9%)	10 (5%)	28 (14%)
	Incorrect	30 (15%)	140 (70%)	170 (85%)
Total		48 (24%)	150 (75%)	198 (99%)

** Both questions are testing the same basic idea in chemistry*

A Summary of Students' Conceptual Difficulties in Reaction Rate

Despite teaching at secondary school, many students did not provide a scientifically acceptable explanation about the nature of a reaction system. The main common difficulties in these three chemistry questions were as follows:

- The reaction is conceived to start slowly and occurs faster afterwards.
- Confusion between the rate of formation of products and the amount of products (or the rate of consumption of reactants and the amount of reactants) during a reaction. Since the amount of products increases as a reaction progresses, students may also conclude the rate of the reaction increases or since the amount of reactants decreases as a reaction progresses, students may also conclude the rate of the reaction decreases.
- As long as certain factors (e.g. catalysts) were not altered, the reaction rate would remain constant or remain the same during a reaction. Accordingly, students do not take into account the experimental data. For instance, they do not take into account the change in concentration of a particular reactant or product per unit of time.
- Difficulties in using their scientifically correct ideas about reaction rate consistently across different context in chemistry.

Students' Responses to Questions Related to Velocity in Kinematics

Question 4

Results showed that 38.5% (48.5-10=38.5%) of the students gave correct answer for this question. The main difficulty students have with that question was students think if position (x) increases by time (t) then velocity (v) increases at the same ratio. The main reason for that reasoning is $x = v.t$. Students say that if x increases then v increases too. Approximately 22.5% of students decided that v-t graph is exactly the same as x-t graph. Based on that idea student says that x-t and v-t graphs have to be the same (Beichner, 1994). In that question it seems that students do not make correct reasoning because they try to explain x-t graph only with $x = v.t$ formula, but not try to interpret the graph directly. The following is an example for this situation.

… Since the velocity unit is m/s and position vs. time graph is given, velocity can be done according to position and since it is given as m/s, if position increases then velocity increases too. [Student-151, interview]

Student's idea that x-t graph has to be the same as v-t graph is very common among students. This misinterpretation may lead students to one of the most common errors in graph interpretation which is the "graph as picture error".

Question 5

Based on the results 54.5% (58.5-4=54.5%) of students answered this question correctly. Data analyses showed that 31.5% of the students responded that x-t graph is the same as v-t graph. As in question 4 students think that if x increases than v increases too.

…..the increase in position during time in another words if position increases as time passes then velocity increases too since it has a direct proportion. [Student-150, interview]

During equal time intervals position increases as direct proportion. I thought that it is speeding up by time. That is why I marked choice A. [Student-150, interview]

Question 6

The number of correct answers was 61% for this question. On the other hand, approximately 28 % of students have the similar reasoning as in questions 4 and 5. Students think that as time passes position increases so the velocity has to increase too.

In fact it is same in here too; here we have an athlete and there we had a student, the athlete is speeding up here. That is why I marked choice A. [Student-150, interview]

Consistency of Students' Ideas about Velocity across Different Contexts in Physics

Students' responses changes based on the type of data presented in the questions that are testing the same idea. For example, both question 5 and 6 are testing constant velocity. However, in question 5, a data table for position and time is given for a student that moves with a constant velocity; on the other hand, in question 6, a position vs. time graph is given for an athlete that moves with a constant velocity. In both questions, students are asked to find how velocity vs. time graph would be. Table 3 shows the pattern of individual students' responses to questions 5 and 6. In question 5, 109 students (54.5%) and in question 6, 104 students (52%) gave correct answers for these questions. However, only 86 students (43%) answered both questions correctly.

Table 3.
The Pattern of Students' Responses to the Questions Testing the Same Basic Ideas in Physics

		Question 6		Total
		Correct	*Incorrect*	
Question 5	*Correct*	86 (%43)	23 (11.5%)	109 (54.5%)
	Incorrect	18 (9%)	72 (36%)	90 (45%)
Total		104 (52%)	95 (47.5%)	199 (99%)

** Both questions are testing the same basic idea in physics*

A Summary of Students' Conceptual Difficulties in Velocity

Students generally did not give a scientifically correct answer, when they interpret kinematics graphs. It seems that many students have some conceptual difficulties in velocity concept. The followings are the main conceptual difficulties that students came across:

- Students believe that as position increases velocity increases too or vice versa. The main reasoning that students do here is related to direct proportion between variables in kinematics formula ($x=v.t$). Similar reasoning is observed in chemistry questions.
- "Graph as picture error" is observed. Students do not pay attention or know the meaning of the variables in each axis (Bektasli, 2006; Brasell & Rowe, 1993; Kozhevnikov, Hegarty & Mayer, 1999). They say that position vs. time graph will be the same as velocity vs. time graph.
- Students define the velocity as the distance traveled in a certain time period. Many of them do not know that velocity is needed to be explained with displacement instead of the distance traveled.
- Students interpret the data table correctly but fail to present their idea in a graph or vice versa. For instance, by looking to the data table students say that the distance travelled increases by time; however they fail to make the same explanation by looking to the graph.
- Students' responses changes based on the type of data presented in the question that is testing the same idea. For example, both questions 5 and 6 are testing constant velocity. However, in question 5 a data table for position and time is given for an object that moves with a constant velocity; on the other hand in question 6 a position vs. time graph is given for an object that moves with a constant velocity. In both questions students are asked to find how velocity vs. time graph looks like. Table 3 presents the number of students that have that kind of problem.

Students' Ideas about the Concept of Rate across Different Contexts in Chemistry and Physics

As discussed earlier some researchers claim that students may simultaneously have different cognitive structures, which have a manifold nature. These several alternative structures may be stable, coherent and can be applied to a range of contexts (Nakhleh, 2001; Taber, 2000). Our findings partly support this view in that some of our data shows that students apply their ideas coherently in a range of contexts, whereas some other data reflects students' ideas incoherent, fragmentary and closely context-bound. Evidence is provided in the following sections to support both consistent and inconsistent ideas about the concept of rate across different contexts and domains.

Table 4 shows the pattern of individual students' responses to questions, which are testing the same basic idea in chemistry and physics. While in question 1 (chemistry), 50 students (25.1%) gave a scientifically acceptable answer; for question 4 (physics) the figure was 77 (38.7%). However, only 22 students (11.1%) gave a scientifically acceptable answer for both questions. Consistency of scientifically acceptable responses to question 3 and 5 were the highest (18.7%). These results suggest that the type of data presented in a question is significantly important. In question 2 and 6, students were given a graph and asked to produce a rate vs. time graph. However, in question 3 and 5, the data were provided on a table and students were asked to produce a rate vs. time graph. It seems that students are more likely to give a correct answer to questions related to rate, when data are presented on a table rather than on a graph. In addition, students are more likely to give a correct answer to questions within a domain, but not across different domains. Inspecting table 4, it becomes evident that context plays a significant role in students' preference for the usage of the knowledge they have.

Table 4.
The Pattern of Students' Correct Responses to the Questions Testing the Same Basic Ideas in Chemistry and Physics

Questions*	Chemistry	Physics	Consistency (Chemistry and Physics)
1 & 4	50 (25.1%)	77 (38.7%)	22 (11.1%)
2 & 6	28 (14.1%)	104 (52.3%)	22(11.1%)
3 & 5	48 (24.2%)	108(54.5)	37 (18.7%)
Average	42 (21.0%)	96 (48%)	27 (13.5%)

** Both questions are testing the same basic idea in chemistry and physics.*

Consistent Reasoning

Some researchers claim that students' ideas in science are coherent, stable and theory-like (McCloskey, 1983). Therefore, it is expected that students can apply these ideas consistently across different contexts and domains. Our findings support this view to some extent.

Students make observations and have some experiences in their everyday lives. Based on these observations and experiences they develop some cognitive structures. Their reasoning ability is affected from this development. "More is more" or "less is less" is one of the most common reasoning that student use in daily life (Stavy, Tsamir & Tirosh, 2002). For example, more substance means more weight or less people mean less crowded. They also use this type of reasoning very often both in physics and chemistry. As presented in the following quotation, students either look at the relationship between variables in a formula or data to reach to that conclusion. When they look at the formula or data they do not usually make interpretation based on conceptual meaning of rate. Common explanation they make is based on mathematical relationships between variables. Here are some examples:

[By looking at the table on question 3] *Concentration* [of product] *increases during time; in the same way the reaction rate also increases along with the concentration.* [Student-151, Question 3, interview]

[By looking at the table on question 5]… *If position increases during time then velocity increases too because of direct proportion.* [Student-151, Question 5, interview]

In question 3, the student needs to analyze how the concentration of G [product] changes by time; similarly in question 5, the student needs to determine how many meters the position changes for every second. However, as can be seen from the quotes above the student only looks at the increments in the data table. By looking at the increments on the data table in question 3, the student thinks that since concentration of G increases then reaction rate increases too. In a same way, in question 5, the student assumes that since position increases by time then velocity has to increase too. The main reasoning that student does here is the direct proportion between variables (what might be called "*more is more*" reasoning).

Some students' ideas about rate concept are consistent across physics and chemistry. The following student gave correct explanation for the rate concept both in physics and chemistry questions.

Concentration has a direct proportion with velocity. If [NO] decreases at a constant rate with time, then rate has to be constant. [Student 192, Question 2]

If position increases at a constant rate then velocity is constant. [Student 192, Question 6]

This student apparently has a conceptual understanding of rate concept across physics and chemistry. Student understood the basic idea of rate concept, which is the amount of change in a unit time.

Inconsistent Reasoning

From a situated cognition perspective, contexts afford or constrain what learners can do and come to know (Cakmakci et al., 2006; Hennessy, 1993). Research on the consistency of students' ideas in a particular concept showed that students' conceptions depend to some extent on the format and contextual features of the tasks (Cakmakci et al., 2006; diSessa, 1988; Engel Clough & Driver, 1986; Palmer, 1997). In the current study, it is observed that many students' ideas about the concept of rate in chemistry and physics are inconsistent (see table 4). Although many students had scientifically correct explanations about velocity in physics questions; they often failed to make a scientifically correct explanation about reaction rate in chemistry. Here are some exemplary quotes to explain this inconsistency:

There is a regular change in position (2 meters every second), so velocity is constant. [Student 23, Question 5]

The concentration of G increases by time which means the amount of substances M and Z will decrease. Reaction rate will increase at the beginning and slow down as the substances begin to run out. [Student 23, Question 3]

As presented above, the student reasoning about velocity concept in physics is scientifically correct since it is based on the amount of change in position; however, the same student does not make a scientifically correct reasoning for rate concept in chemistry.

Some other inconsistent ideas about the rate concept in physics and chemistry were observed. First of all, student's conceptual understanding of rate is different in each domain. Even some students know that rate is the amount of change in a certain time period; they did not make transition of this knowledge between physics and chemistry. One of the main reasons for that is they think that rate in chemistry is more molecular wise so it cannot be observed whereas velocity in physics usually refers to motion of big objects so it can be observed. Here is a representative quotation for this situation:

Researcher*: We talk about a reaction rate and velocity of a bus, what is the difference between these two?*

Student*: Here* [question 5] *a motion that we made is mentioned, on the other hand there* [question 3] *usually there is no motion.*

Researcher*: There is no motion?*

Student*: There is, but not too much, I mean not as much as can be observed.* [A student from pilot study, interview]

Secondly, variables that determines rate concept are different in physics and chemistry. That is usually an obstacle in understanding rate concept in general. It seems that students do not think the rate concept independently as the amount of change in a certain time period. The following is a quote to explain that situation:

Researcher: .....What are the differences between reaction rate and velocity of a car?

Student*: When it is a reaction rate, there is a reaction so you think based on the concentration here* [question 3]*, on the other hand there* [question 6] *you think velocity of something, but when it is reaction rate you think according to concentration so both are very different things.*

Researcher: What is the difference? That is what I am asking. You say reaction rate in one and velocity of a car in another.

Student*: As a result in third question we have a reaction, reactant, products; temperature is increasing etc, but in a car's velocity what can be effective is just acceleration, distance and time nothing else.* [A student from pilot study, interview]

According to the student, the rate concept in chemistry and physics does not have anything in common and they are different from each other. This suggests that the student tries to explain the rate concept within each domain but not across.

Conclusions and Implications

This study investigated the consistency of students' ideas about the concept of rate across different contexts namely velocity in physics and rate of reaction in chemistry. The results revealed that students' ideas about the rate concept are mostly inconsistent across physics and chemistry; however, the consistency of their ideas about rate concept is limited (see table 4). There is very little evidence showing that students coherently apply their ideas about rate concept across a wide range of contexts. These findings suggested that in many cases students were unable to generalize their conceptions of the rate across different contexts and domains (see tables 2-4). These results suggest that consistency of students' ideas across different contexts and domains are limited. It ought to be underlined that students' performance in chemistry and physics does not represent a natural or necessary pattern; rather it occurs as a result of misapplications of some rules, formulae, principles or variables which are embodied in a task. In addition, it is possible that the nature of the task is not the only contextual factor which influences students' conceptions. Students might have been influenced by their own experience of the context. For instance, a considerable number of students had scientifically incorrect ideas about how the reaction rate changes from the beginning to the end of a reaction. Many students had difficulties in understanding that the reaction had the highest rate at the beginning of the reaction and the lowest rate at the end: rather, they tended to think the opposite. Students' understanding might be constrained by perceptual experiences from their daily lives (e.g., a wood fire burns slowly at the beginning and goes faster thereafter) or from the chemistry laboratory (e.g., the reaction of magnesium with dilute acid) (Garnett, Garnett & Hackling, 1995).

Many students have superficial understanding of reaction rate and velocity. Their understandings do not go beyond algorithmic problem solving. There is a lack of conceptual understanding of concepts associated with reaction rate and velocity. Students tended to use mathematical formulae mechanically when answering the questions. For instance, on several occasions they attempted to answer the questions based on a rate equation; however they did not consider some variables in the rate equation (e.g. the reaction order). The underlying ideas behind students' responses would inform designing teaching to overcome these difficulties. This inconsistency of students' conceptions across specific tasks creates a necessity for research to describe and explain the variation of students' conceptions and ways of reasoning (Palmer, 1997). On the basis of this information, teachers can promote awareness of strategies for generalizing thinking by engaging their students in activities that require reflection. Thus, teachers and curriculum designers would provide students with opportunities to develop metacognitive skills (White & Gunstone, 1992). In this respect, teachers from different disciplines can cooperate with each other when they teach closely related concepts in biology, chemistry, physics or mathematics (Berlin & White, 1994). Especially, science and mathematics teachers use some common terminology. Students learn many concepts in mathematics and use them in science. However, most of the times they fail to see the relationship between the meanings of the concept in two different contexts and fail to see the relevance of their physics lessons during their chemistry classes. Therefore, even students use the same concept; their understanding of the concept remains abstract within each context. For example, when students use $y = mx+b$ (y as a function of x) in mathematics classroom they usually cannot see its relationship with physics when they use $V = at+V_0$ (velocity as a function of time) (see figure 1). In mathematics b is a constant and in physics formula V_0 is the initial velocity which is constant too. Similarly, m is slope in mathematics formula and refers to a (acceleration) in physics formula which equals to the slope of a line in velocity vs. time graph. The teacher's role should be supporting and mediating students' conceptualization of the relationships between these two forms of representations. Scientists jump freely from different forms of representations in a series of mental gymnastics (Johnstone, 1982). The ability to pass confidently between these representations should be an important goal for students. In addition, teachers need some explicit knowledge of the significance of these different modes of representations (Erduran & Duschl, 2004), and require a range of pedagogical strategies in order to make these links explicit in teaching (Pekdağ & Le Maréchal, 2010). Scientists do it tacitly: teachers need to have explicit knowledge to draw upon and to employ this in planning their teaching and their interactions with students.

Figure 1. Representations in Mathematics and Physics

The results also suggest that the setting of a task can affect students' approach to explanations. In many cases, students used a correct scientific explanation in one context, but they did not employ it in others. Thus, in order to assess students' understanding of a specific content area, careful consideration of the task is needed and it is necessary to investigate their ideas in a range of contexts. It would be interesting to investigate consistency of students' ideas about some other science concepts across different contexts and domains.

Although, the questions in this study are testing basic scientific ideas about concept of rate, many students gave incorrect answers. Some of the main reasons for that would be students' level of scientific thinking, or prior experiences related to concept of rate. For instance, for many cases in daily life students usually experience "less is less" and "more is more" situation. Therefore students have some problems when they apply that situation to problem solving in physics or chemistry.

The new Turkish secondary science (physics, chemistry and biology) curriculum is implemented in grade-9 in the 2008-2009 academic year. It would be beneficial to assess the new Turkish secondary science curriculum by applying the same data collection instruments on grade-11 students. That would allow us to see if the new curriculum is effective in terms of consistency of students' ideas about rate. A study that clarifies whether the results of the study are applicable to the other countries curricula would also be needed.

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