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# Understanding Elementary Students' Argumentation Skills through Discrepant Event "Marbles in the Jar"

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**Abstract**

Teachers are increasingly faced with questions that enhance students' argumentation and critical thinking skills. The purpose of this case study is to investigate how middle school students utilize argumentation and critical thinking skills, which have an increasing popularity and importance in science education. A total of 41 8th grade students were purposefully selected. The argumentation process and abilities of forty-one eighth grade students related to a scientific problem are investigated using descriptive research method. In this study, the aim was to investigate students' argumentation and critical thinking abilities about a discrepant science problem. The problem involved two different sizes of marbles and two identical cups. The findings revealed that most students do not possess adequate levels of argumentation and critical thinking skills. Among them, teachers' comprehension and ability to apply such higher-order thinking skills were found to be the main most issue.

**Keywords**: Scientific argumentation, Critical thinking, Discrepant science events.

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## INTRODUCTION

In the history of science education, there exist several methods of instruction believed to enhance students' science process skills such as observing, analyzing, synthesizing, experimenting, data selecting and problem solving (Padilla, 1990; Clarke, 2010). The main aim of developing instructional approaches in science teaching is to improve such skills because they are needed for real life problems that students face in the future. Originally, the discovery-learning approach by Jerome Bruner was a major influence in teaching science concepts. Beyond that, derivations, of this approach have been developed since then in science education: these include the learning cycle, discussion, inquiry, argumentation and critical thinking (Yerrick, 2000). According to the constructivist learning theory that is widely used nowadays, individuals actively configure the information, think critically and solve the problems from different angles (Kıngır el al., 2011). At the problem solving and critical thinking stage, argumentation is required (Cho & Jonassen, 2002; Duschl & Osborne, 2002; Zohar & Nemet, 2002).

Argumentation has been examined extensively for decades in science education. It has been widely accepted as a fundamental pillar of science teaching (Pontecorvo & Girardet, 1993; Yerrick, 2000; Duschl & Osborne, 2002; Zohar & Nemet, 2002; Osborne et al., 2004; Erduran & Jimenez, 2007; Sadler, 2006; Duschl, 2008; Bricker & Bell, 2008; Kuhn, 2009, 2010) pointed out the importance of argumentation has been described as follows, "Argumentation is a form of discourse that needs to be appropriated by students and explicitly taught through instruction, task structuring and modeling". Moreover, early researchers (Stephen, 1958; Kuhn, 1991) described argumentation as the ability of informal reasoning to make claims and to ensure evidence in supporting these claims, in solving problems or in making decisions.

### Scientific Argumentation

Stephen (1958) proposed a layout containing six interrelated components for analyzing arguments: claim, data, warrant, backing, rebuttal, and qualifier. The above steps are known as Toulmin's Argument Pattern (TAP) which is used for the analysis of arguments (Erduran et al., 2004; Pontecorvo & Girardet, 1993). Thisargumentation model which is primarily based on Toulmin's theory helps learners to make an argument and to support this argument with data or evidence, then to connect these data or evidence with correct and relevant sources, and finally to assess the constraints of their solutions (Erduran, et al., 2004). Already, when applied to an educational environment, the argumentation model of Toulmin encourages both teachers and students to discuss their ideas thereby verbalizing their standpoint and deciding on different ideas because of the interactivity involved (Hewson & Ogunniyi, 2011).

Essentially the basis of the scientific argumentation model, defined as the examination of different viewpoints so as to reach a shared understanding of observed phenomena, is seen as discussion by scientists and it is based on the argument which learners put forward by providing proof (Harlow & Otero, 2004; Okumus, 2012). Because proofs and justifications support students' thinking in the process of scientific debate, their arguments, which are supported with evidence, will effectively develop their argumentation skills (Okumuş, 2012). In this regard, this process is vital to the development of scientific knowledge, namely scientific argumentation in the classroom not only aids students in their acquisition of science knowledge and but also increases students' understanding of the social nature of scientific knowledge (Driver et al., 2000). To sum up, as justified by the goals of science education in [AAAS]/Project 2061 and [NRC]/1996, argumentation could be highly beneficial to students and plays a critical role in science classrooms in learning how to describe and judge scientific arguments (Bell and Bricker, 2008). Considering that teaching with argumentation differs basically from the traditional instructional approaches that still exist in many schools worldwide, argumentation mirrors scientific practice most importantly. Because ideas are proposed and contradicted in this scientific application, students find the chance to develop argumentation skills (Hewson & Ogunniyi, 2011).

Recent articles explored different ways to enhance argumentation abilities or willingness to initiate an argument in science contents. Sampson and his friends (2010) aimed to increase students' participation in scientific argumentation and the quality of the scientific arguments. The authors utilized a series of laboratory activities designed using an instructional model Argument-Driven Inquiry (ADI) and investigated its influences. Nineteen 10th grade students were selected for that purpose. The participants were engaged in 15 different laboratory experiments in groups. The results of their study revealed that the students had better engagement and produced better arguments after the intervention.

In a similar study, researchers (Ryu & Sandoval, 2012) assessed whether an instructional model could improve children's understandings and applications of epistemic criteria for argumentation. The study took place in a class with 3rd/4th grade students. Students' ages ranged between 8 and 10. The researchers designed a "science time" corner during a regular academic year curriculum. In conclusion, students achieved an understanding of argumentation and the ability not only to construct but also to evaluate scientific arguments. The above-mentioned experimental studies focus on improving students' argumentation skills or their ability to evaluate arguments. Some other studies in the literature aim to enhance such skills.

**Critical Thinking Skills in Science**

Because of more information being available in the current century, the science and education environment is experiencing the era of technology and information is subject to rapid change. Goh (2008) states that according to educators', knowledge may become outdated more quickly than in the past. Due to this statement, the development of knowledge acquisition skills is required. This development equips student with the opportunity to acquire knowledge that may not exist now and to solve problems they have not encountered before (Pithers & Soden, 2000). Dealing with the sudden changes also requires students to engage in active critical thinking processes including higher-order thinking (Halpern, 1999).

Because the argumentation not only becomes the focal point of critical thinking (Ingram, 2008) but also the realization of critical thinking processes, it is of the utmost importance that primarily the concept of critical thinking should be understood fully. Since 1900, many definitions have been made of critical thinking in different disciplines. First, as cited in German (2008), according to Meyers (1986), John Dewey defined the term critical thinking in 1910 as suspended judgment involving active, persistent and careful consideration of any belief or supposed form of knowledge in light of the evidence (German, 2008). Later, Dewey (1916) described the essence of critical thinking as suspended judgment to determine the nature of the problem before trying to solve it and suggested that analysis and synthesis of the problem were necessary components of critical thinking (Becker, 2007). According to Paul's (1990) definition, critical thinking is disciplined, self-directed thinking appropriate to a particular mode or domain of thought. In the late 1990s, the Delphi Project, which was conducted as two-year multi-faceted research project, devised a definition of critical thinking, which was intended for instruction and educational assessment (Burns, 2009). Facione in Derwin (2008) suggested that the Delphi report lists six skills related to critical thinking, which are interpretation, analysis, evaluation, inference, explanation, and self-regulation. In a Delphi study conducted by the American Philosophical Association (APA) critical thinking was described as the process of purposeful, self-regulatory judgment and an interactive, reflective reasoning process (Becker, 2007). Moreover, Halpern (1999) also described critical thinking as purposeful and logical, and aimed at the use of cognitive skills and strategies. He stated that critical thinking is related to our thought processes of how good a decision is or how well a problem is solved (Halpern, 1999).

The consensus that emerges from this and similar definitions is that critical thinking is not only a contextual or subject related skill, but also extends beyond a set of skills (Byrne & Johnstone, 1987; Ingram, 2008). In this process, thinking critically requires knowledge and an understanding of the content, skills and processes of the subjects under consideration (Byrne and Johnstone, 1987). Also in this connection, critical thinking involves going through certain processes, for example, analyzing the issue, gathering, evaluating the data and synthesizing the information (Bailin, 2002). To Ingram (2008), critical thinking is a reflective process, from which the outcome may be more thinking, and involves the application of the above-mentioned skills in a logical and rational manner.

Developing critical thinking is one of the goals of science education. For example, the National Science Education Standards (1996) include critical thinking among their numerous topics (Bailin, 2002). As it is, science education has the potential for improving students' critical-thinking skill because of the nature of science. Namely, science gives the critical thinker the opportunity to make discoveries, which are pure science, and to make practical use of new knowledge, which is applied science (Alexander, 2004). Given the Next Generation Science Standards, it is important to understand by assimilating that the scientific practices include the critical thinking skills. Three active learning strategies are proposed as supportive mechanisms to enhance student critical thinking: small-group learning with authentic tasks, scaffolding, and individual writing (Kim et al., 2012). "Here we need to heighten students' awareness of and practice in these strategies" (Paul, 1990). According to Van Erp (2008), though it is difficult to foster critical thinking skills, it is not impossible.

The recent literature suggests that critical thinking skills can be developed if educators facilitate processes requiring students' experience and inquiry and test their ways of thinking (Erduran & Jimenez, 2007; Sadler, 2006; Osborne et al., 2004). In this process, though encouraging educators to utilize strategies promoting critical thinking skills is a rigid step, this issue needs to be considered more globally as well and, most importantly, critical thinking itself should be the mission of an educational institution (Van Erp, 2008). However, obstacles still exist in the teaching of critical thinking though standards mandate instruction in higher-order thinking (Thurman, 2009). Studies in the literature indicate that the lack of instruction for teachers in regard to critical thinking is a problem if they are expected to teach the skills with any degree of proficiency (Burns, 2009). In the same way, few introductory science courses provide students with learning environments where they engage in tasks which encourage their critical thinking skills (McConnell, 2005). As cited in Burns (2009), Moreno (1999) asserted that the other barriers facing teachers in regard to teaching, the lack of background and pedagogical knowledge can hinder the teaching of critical thinking skills and critical thinking; these include a lack of teacher training opportunities for both pre-service and practicing teachers. The other deficiency in this issue is assessment of critical thinking skills. Many educators do not feel that written tests can appropriately measure the students' higher-order thinking skills (Burns, 2009**).**Consequently, in spite of these, This is an education reform movement should be initiated to eliminate the gap related to the development of critical thinking skills because critical thinking skills will not only prepare students for postsecondary education and close the gap in college preparedness but also equip them with a 21st century skill necessary to compete in our global society thinking (Thurman, 2009).

The above-mentioned studies on argumentation and critical thinking skills generally investigated these two topics separately and experimentally. Few studies, however, focus on how students reflect their argumentation and critical thinking skills in discrepant science problems. In this paper, we report the preliminary findings on levels of elementary students' argumentation skills in a proposed science activity.

## Objectives

Given this gap in the literature, the current study examined two important aspects of ability that pertain to argumentation and critical thinking on science concepts. In this respect, we investigated and compared the individual and group responses of students. Critical thinking and argumentation skills were investigated. Secondly, the students also commented on the discrepant problem and discussed it from different perspectives. Finally, the participants evaluated their responses, and their thinking skills extensively.

## Research Questions

The literature reviewed indicates that although argumentation and critical thinking abilities have been investigated separately in mostly experimental studies, few studies attempted to focus on both concepts together. This study was therefore designed to address the following research questions:

- What critical thinking and argumentation strategies do students use when a discrepant science problem is presented?
- Do students' individual responses differ when they are in groups?
- What do students think about the discrepant science question?

## METHODS

### Research Design

As a method, a descriptive study carried out in the form of a case study was utilized. Structured and focus group interviews were conducted as data collection tools using a scientific problem of a discrepant event.

The discrepant event (Figure 1) in this study can be described as follows: "We have two identical glass containers and two different sizes of marble sets. Small marbles have around 0,4 cm and bigger marbles with 0,8 cm in radius. We filled each container to the top with marbles (up to its maximum capacity). We asked them "What can you say about the spaces between the marbles in each glass container?" "Are they equal or are some of them greater?" Later, they are asked to give support their ideas, indicate how sure they are and how to prove their ideas. Afterwards, they were asked to form groups and answer same questions with group members".

Figure I. Picture of the discrepant event question

To assess students' argumentation and critical thinking skills, the participants in this study were asked to complete a task that required them to engage in argumentation to explain a discrepant problem and discuss possible responses that makes sense. This task, which is called *the Marbles in the Jar* problem, required students to first determine which explanation, of three plausible alternatives, was the most valid way to explain their observations using the available data. Once the participants had determined which explanation best explained the phenomena, they started to explain their ideas in writing and drawing with appropriate reasoning and arguments. The participants in this study, who were enrolled in the $8^{th}$ grade, were randomly assigned to this study.

Following students' individual explanations, critical thinking and argumentation about the problem, five groups were randomly formed. Each group consisted of 8 students with the exception of the last group, which had 9students. The focus group interview took around 60 minutes for the investigation.

The groups were asked the same question and to come up with their group responses and explanations. Group members were engaged in intense discussions, arguments and a brain storming process as they produced their group answers and explanations. They were allowed to raise their voices to group discussion levels as they discussed the explanation.

Lastly, the groups returned to their own seats. They were finally asked to think thoroughly about the discrepant event and list their ideas regarding it. Initially, it was expected that students in groups would respond to questions with higher levels of critical thinking and argumentation.

### The Discrepant Event

We generated a new type of event followed by a question that entails students' reasoning, argumentation and critical thinking skills. The *Marbles in the Jar* problem focuses on density, volume, geometry and imagination. This scientific question requires students to generate a scientific argument that explains why two jars can hold an equal amount of water although they are filled with different sizes of marbles ($radius_1$ = 0,4 cm; $radius_2$ = 0,8 cm).This question has a basic explanation: two jars filled with different sizes of marbles would have an equal amount of space left among them. This could be explained as generating arguments such as comparing the densities of the different marbles and also the jars. Since the jars are identical, the densities of the marbles are the only variables that could make a difference. However, when students investigate each marble in both jars carefully, they would notice that the number of big marbles in the jar is extremely much lower the other that filled with smaller marbles. Also, when they examine them closely, imagining the situation in a two-dimensional picture, they would also observe that it does not matter how many circles are drawn in a square, the final spacing between the marbles and the jar stays the same.

### Participants and Procedure

Forty-one students participated in this study. These students were all enrolled in the 8$^{th}$ grade science course at a small local private school located in the Mid-Eastern region of Turkey. Of them, 66% were male and 34% were female. The students ranged in age from 13 to 14 years. The school has a total of 184 students in grades 5-8. Their teachers described them as candidates for the top high schools.

The students who participated in this study participated in a 3-hour demonstration of the event, discussion of the event and potential reasonable responses and explanation session. The participants were informed about the process at the beginning of the event. The session took place in the conference room at the same school. Data were collected during the second semester of the2012-13 academic year. In order not to reveal participants' identity, they were coded as S1 toS41 respectively.

The participants were introduced to the discrepant event "the Marbles in the Jar" following the introduction and information step. Students assigned to the individual argumentation step completed this task on their own. Later each student worked in groups in the second step with other group members. Students were required to describe their opinions about the proposed question and to emphasize their responses as well as their evidence to support them. To identify codes, themes and groups explicitly the researchers analyzed descriptively all of the evidence students gave to support their answers. Students were required to describe their opinions about the proposed question.

## RESULTS AND DISCUSSION

The presentation of the results is divided into three subsections by the research question. Each subsection includes a brief overview of the analysis, the result of the analysis and a discussion of the findings.

### Critical Thinking and Argumentation Strategies the Students Usefora Discrepant Science Problem

To compare individual and group performance, individual scores on the Marbles in the Jar problem were calculated and compared with group scores. When students are asked to answer the first question about the problem, they mostly agree that the jar with big marbles has more spaces among them (Table 1).

Table 1: Students' responses to the first question (Which jar has more spaces between the marbles?)

| Students | Jar w/ small marbles (N) | Jar w/ big marbles (N) | Same (N) | No Info (N) |
|---|---|---|---|---|
| S1-4,6-17,19,20,22-34, 36-38,41 | | 35 | | |
| S40 | 1 | | | |
| S35 | | | 1 | |
| S5, 18, 21,39 | | | | 4 |
| **Total (%)** | 2.44 | 85.37 | 2.44 | 9.76 |

As shown in the table, at the beginning of the process, the majority of students (85%) indicated that big marbles would leave more spaces between them. This approach looks very easy as they can see the jars (Figure 1) clearly. In the second part of the first research question, the students specified their reasoning to support their opinions. Two tools were utilized for data analysis of this section: 1) Observation of the students during the data collection process and 2) Response sheets filled in by the students individually and in groups. Codes and themes were structured by using qualitative data analysis process.

During the observation process, the participants were carefully observed and recorded by a video camera. The data collection process took place in the conference room in the school basement. The seats were very comfortable and that probably affected students' attentiveness. Secondly, the person who posed the questions and asked for further responses was a foreigner and for that reason the local researcher translated everything he and the students said. On the other hand, since students could understand English well, no translational effects appeared in the study. In addition, seats were held in a position and so students had to turn to the side and around to talk to group members in group sessions.

Furthermore, based on the observational data, students seemed very relaxed about the questions; however, they were very curious. As the jars were shown and the question was asked, the students immediately started to raise their hands to answer the question. It was assumed that most of the students firmly believed that it was an easy question. When the researcher asked students what evidence they had to support their "arguments" or opinions, they were a bit frustrated, possibly because they thought there might be a catch in the problem. As they discussed the questions in their groups, they talked and argued about what they believe about the questions and tried to convince their group members. Some students drew pictures of the problem and explained why they thought as they did.

In the second part of the data analysis of the individual responses, the students' responses were coded and a few themes about the situation emerged. Emerging major codes included "Big marbles, easy question, difficult questions, simple, it is obvious". The majority of students thought that as they implied "Big marbles. There are more small marbles in the other cup." Or "Big marbles. Because they are big and can't take up all the space". These responses indicate that students thought the jar with big marbles would have more spaces between the marbles (Table 1). Therefore they supported their argument by specifying that "jar would hold fewer big marbles than small marbles" and for this reason there would be more spaces between the big marbles. Also, they used arguments such as "suggesting putting water in the jars" or "using the analogy of putting sands in a jar". In the first step of the process, the researchers did not show them the water bottles so it is very important that some students suggested beforehand the use of the water to prove they were right.

Twelve students suggested pouring water into the containers and measuring the volume of them. Interestingly, out of these students, only one of them considered that small marbles would have more spaces between them.
Students were asked about how sure they were about their answers. Only 11 of the students were very sure about their answers (80% or above); some of the students (N=12) were fairly sure (50% or above).

## Comparison of Individual and Group Performances

As individual and group responses were compared, it was found that some students changed their minds when they joined a group. As illustrated in Table 2, all five groups indicated that big marbles would leave more spaces between them. However, only two groups specified that opinion (G1, G3). Although other groups did not expressly state which jars would have more spaces, based on their arguments, they clearly favored big marbles. All of the arguments developed by the groups expressed that "Pouring water in both jars and measuring the amount of water in each jar will show us which jar has more spaces" (G1).
Another significant finding is the groups' arguments supporting their opinions (G1 and G3). They said that big marbles are like big particles and matter such as solid contains a larger number of particles so there should be more spaces in that. Groups 2,4, and 5 made an analogy of the spaces with sands and stones. They thought that smaller particles wouldfill up less space and for this reason leave more spaces. This shows that although they did not indicate that small marbles leave more spaces, their arguments still support that previous opinion.

Table 2: Groups' Responses to the Problem

| Groups | Jar w/ big marbles | Not specified | Arguments |
|---|---|---|---|
| G1, G3 | X | | Put water into the jars. Big marbles have big spaces between them.<br>Big marbles have more particles. Greater number of particles means that more spaces e.g. solids. |
| G2, G4, G5 | | X | Put water in the containers and measure their volume with measuring cups.<br>Melt the marbles and measure their volumes.<br>Analogy with sands and stones. |
| **Total (%)** | 40 | 60 | |

## Students' Opinions about the Problem

Table 3: Students' opinions about the problem and how sure about their answers

| Students | Difficult (N) | Easy (N) | Sureness (%) | No Info(N) |
|---|---|---|---|---|
| **S.4,6-7,13-15,17,30,37** | 9 | | Less (4), 50 (3), very sure (75%, 2) | |
| **S.1-3,8-12,16,19-20,25-29,31-34,38,40** | | 24 | Very sure (100%; N= 16), less sure (50%-65%; N= 9) | |
| **S.5,18,21-23,35,39,41** | | | | 8 |
| **Total (%)** | 22 | 56 | | 20 |

Table 3 shows that most students found the problem easy (56%), which means that initially it looked very easy. Interestingly, although some of them believed that it was easy some of them were not very sure about their answers and argumentation.

Each of the five groups supported the same thesis about pouring water into each jar and measuring that water to prove or find out which jar had more spaces. This result indicates that students were influenced by each other when in groups. Other group members convinced students to change their minds who originally believed that the jar with small marbles had more spaces between them. However, Groups 2, 4 and 5 did not specifically indicate their opinions as a group. This might be due to their disagreement about the situation. They probably did not reach agreement with their group members but none of the groups supported the view that the jar with small marble shade more spaces. This indicates that students supporting this opinion changed their minds in group discussions.

In the second part of the study, students were asked to write their opinions about the problem and how sure they are about their answers. Although 24% of the students (N=24) indicated that it was an easy question, some of them (N=9) were not very sure about their responses. Their arguments about it being easy were as follows: "It is easy because I saw a similar question", "We can see it" and "It looks like easy". Above arguments shows that students' arguments were generally based on visual observation.

## CONCLUSION

This study aimed to investigate about students' argumentation skills and opinions about a scientific problem. The result of the study revealed that most students do not hold scientific argumentation skills. In order to increase scientific argumentation skills of students, educators should pose more such questions in the classroom. However, the biggest barrier for this is the standards and the curriculum. To sum up, students' argumentation skills should be investigated in depth with observations, interviews and archival documents.

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