MEHMET AYDENIZ, AYBUKE PABUCCU, PINAR SEDA CETIN and EBRU KAYA

ARGUMENTATION AND STUDENTS' CONCEPTUAL UNDERSTANDING OF PROPERTIES AND BEHAVIORS OF GASES

Received: 14 December 2011; Accepted: 2 March 2012

ABSTRACT. The purpose of this study was to explore the impact of argumentation-based pedagogy on college students' conceptual understanding of properties and behaviors of gases. The sample consists of 108 students (52 in the control group and 56 in the intervention group) drawn from 2 general chemistry college courses taught by the same instructor. Data were collected through pre- and post-tests. The results of the study show that the intervention group students performed significantly better than the control group students on the post-test. The intervention group students also showed significant increase in their test scores between pre- and post-test. While at least 80 % of the students in the intervention group abandoned their initial ideas on all of the 17 alternative conceptions that were identified by the authors but one, the percent of student abandoning their initial ideas in the control group was less than 50. The discussion focuses on the implications of these results for addressing students' alternative conceptions, promoting the argumentation–pedagogy in college science courses and the challenges associated with the use of argumentation in college science classrooms.

KEY WORDS: alternative misconceptions, argumentation, college science, gases

Argumentation is a fundamental discourse of science, a part of the practice of science for developing, evaluating, and refining scientific theories about the natural world (Duschl & Grandy, 2008; Osborne, Erduran & Simon, 2004). Scientists argue over the questions they pose, the methods of investigations they use, the nature and source of evidence they use, and the conclusions they arrive at (Kuhn, 1993; Latour & Woolgar, 1986). In spite of its centrality to the process of science, argumentation is rarely used in the teaching and learning of science (Driver, Newton & Osborne, 2000; Erduran & Jimenez-Aleixandre, 2008; Erduran, Ardac & Yakmaci-Guzel, 2006; Kuhn, 2010).

Argumentation is a reform-based pedagogy, consistent with the epistemological assumptions of cognitive approaches such as social constructivism (Vygotsky, 1978) that describe the process of learning (Anderson, 2007). Social constructivism assumes that learning takes place through a social and communicative process, whereby learners share knowledge and construct understandings in a social context through dialogue, conflict and negotiation (Aldridge, Fraser & Taylor, 2000; Mercer, Jordan & Miller, 1996; Vygotsky, 1978). Students are challenged and helped to construct knowledge by engaging in such activities as

International Journal of Science and Mathematics Education (2012) 10: 1303–1324

sharing of information, responding to the questions posed by members of the community and challenging the validity of responses to those questions collectively, and backing claims to knowledge with evidence (Bricker & Bell, 2008; Kuhn, 1993; 2010).

Science educators and learning scientists that promote the use of argumentation in formal educational settings emphasize several benefits of argumentation. First, they argue that argumentation enhances the quality of student learning because it engages students in the public exercise of reasoning (Bricker & Bell, 2008; Erduran & Jimenez-Aleixandre, 2008). The argument holds that because learners are challenged to externalize their reasoning, they are more likely to notice the inconsistencies in their reasoning, and with the help of their peers and their teacher, they are more able to develop reasons that pass the test of rationality than if they were to learn science through traditional methods (i.e. listening to a teacher lecture) (Bricker & Bell, 2008; Kuhn, 1993, 2010). This is because argumentation engages students in dialogical reasoning and makes learning a social as well as a cognitive activity (Baker, 1999; Bricker & Bell, 2008; Venville & Dawson, 2010). In such a dialogical learning environment, students support each other in construction of evidence-based scientific explanations that pass the test of rationality and consistency (Erduran & Jimenez-Aleixandre, 2008). Although these theoretical assumptions point out the benefits of argumentation, teaching science through argumentation has proved to be a challenging task for many teachers (McNeill & Knight, 2011; Sampson, 2009). In addition, previous empirical studies reveal mix results about the effectiveness of argumentation on students' learning. We provide a review of these studies next.

Empirical Studies on Argumentation

Several empirical studies (Cross, Taasoobshirazi, Hendricks & Hickey, 2008; Venville & Dawson, 2010; Zohar & Nemet, 2002) have reported the positive impact of argumentation on students' conceptual understanding of key scientific ideas and processes. Other studies have reported the positive impact of argumentation on students' epistemic engagement with learning (Kelly & Takao, 2002) and the quality of learning achieved by students (Shemwell & Furtak, 2010; von Aufschnaiter, Erduran, Osborne & Simon, 2008).

Cross et al. (2008) conducted a study with a sample of middle and high school students. They used argumentation to teach the targeted science concepts over a 2-week period. The results of their study led them to conclude that engaging students in argumentation results in "more secure understanding of pre-existing concepts," exposes them to new ideas, helps "extend their prior knowledge," and "possibly eliminating their misconceptions" (p. 842).

Venville & Dawson (2010) conducted a study with 10th grade Australian students in a genetics classroom in which they looked at the impact of argumentation on students' conceptual understanding of genetics concepts among other outcomes. They subjected one group of students (n = 46) to argumentation-based pedagogy during three of the 50-min lessons on genetics topics while the comparison group students (two classes; n = 46) conducted library research on genetic engineering, genetic diseases, and cloning. The results of their study show that both groups of students improved their conceptual understanding of the genetics topics covered during the intervention in significant ways. However, the results of their analyses show that the experimental group students performed significantly better than the control group students on the post-test that measured students' conceptual understanding of the targeted genetics topics.

The authors attribute these reported gains in students' conceptual understanding in argumentation group to several factors. First, they argue that the "process of participating in and listening to rational and sophisticated arguments modeled and encouraged by the teacher" may have positively impacted students' knowledge of genetics (p. 970). Second, they state that engagement in argument construction may have encouraged students to make meaningful "connections between isolated facts and concepts" and thus resulting in an improved understanding of the topics under investigation (p. 970). Third, they argue that argumentation might have given students a chance to "consolidate and elaborate" on their existing ideas related to genetics. Additionally, they state that students might have developed increased understanding because they were able to apply their knowledge of genetics to meaningful or "practical" contexts. Finally, the authors argue that the scaffolding of student thinking during argumentation may have contributed to the reported learning gains in students' conceptual understanding of genetics topics. These results tell us that when argumentation is used effectively, it can result in significant learning gains for students.

Although most argumentation research reports positive impact of argumentation on students' learning, argumentation has not always resulted in such significant learning gains for students. For instance, Walker, Sampson, Grooms, Anderson & Zimmerman (2010) conducted an argumentation study with a group of community college students

($n = 372$) in the USA. They exposed students ($n = 372$) to argumentation-drive inquiry (ADI) during the lab sections of a chemistry course. Then, they compared the learning gains of the ADI group to a control group. The results of their study indicate that while the ADI group students did not significantly perform better than the control group students on a test that measured their conceptual understanding of key chemistry concepts, they performed better at a reasoning and the use of evidence task that was also administered to the participants after they had gone through a traditional thermochemistry laboratory. One of the limitations of this study is that while the control group students completed 11 laboratory experiments, the ADI group completed six investigations. Exposure to fewer investigations might have resulted in mastery of fewer science concepts by the ADI group students.

Taken together, these results indicate that argumentation may not have a significantly positive impact on students' learning of key scientific concepts in every context. Therefore, it is important for science educators to explore the impact of argumentation on scientific concepts that have been proven to be "hard to learn" for students. In an attempt to make contribution to the existing literature, we designed this study to explore the impact of argumentation-based pedagogy on college students' conceptual understanding of the properties and behaviors of gases. The topic of gases was chosen because previous research indicates that students at all ladders of education hold alternative conceptions related to the properties and behaviors of gases (Kautz, Heron, Loverude & McDermott, 2005a; Madden, Jones & Rahm, 2011). We provide a review of these alternative conceptions in the following section.

Students' Alternative Conceptions Related to Properties and Behavior of Gases

Research studies show that a significant number of college and high school students hold alternative conceptions related to gas properties and gas behaviors (Beall, 1994; Kautz, Heron, Shaffer & McDermott, 2005b; Liu, 2006; Wiebe & Stinner, 2010). Beall (1994) conducted a study with college freshmen where he lectured his students on the ideal gas laws. He found that 89 % of the students were not able to correctly predict the effect that opening a cylinder of compressed gas would have on the temperature of the gas after the instruction. Kautz et al. (2005a) found that college students in chemistry and physics have limited understanding of the macroscopic properties of the ideal gas law. In a second study, Kautz et al. (2005b) found that many undergraduate science and engineering majors have "flawed microscopic models for the pressure and temperature in an ideal gas" (p. 1). Bonder (1991) investigated the first year chemistry graduate students' ideas about some chemistry ideas and found that about 20 % of the participants believed that the bubbles in the boiling water consisted of oxygen, hydrogen, and air.

Benson, Wittrock & Baur (1993) investigated learner constructed concepts related to the nature of gases. They asked the participants to draw the sketches of the air in a flask. Their analyses of students' drawings revealed the following alternative conceptions: (1) Air is a continuous (nonparticulate) substance, (2) the behavior of gases is similar to the behavior of the liquids, and (3) there is a relatively little space between gas particles. Griffiths & Preston (1992) conducted a similar study with 12th grade Canadian students and found that grade 12 students think that the size of molecules changes across different phase changes. The students also thought that the water molecules in the gaseous state are the smallest and therefore the lightest.

Although science educators have invested a significant amount of effort into identifying students' alternative conceptions, there are only few studies that focus on interventions to remedy these alternative conceptions (see Liu, 2006; Şenocak, Taşkesenligil & Sözbilir, 2007; Hwang & Chiu, 2004; Cetin, Kaya & Geban, 2009). However, none of these studies has used argumentation pedagogy to promote students' conceptual understanding of the concept of gases. In this study, we fill this gap by testing the effectiveness of argumentation-based instruction on students' conceptual understanding of the properties and behaviors of gases. The research question guiding this inquiry is: What effect does argumentation-based instruction has on college students' conceptual understanding of the properties and behavior of gases?

Methods

Context and Participants

This study took place at a university in central Turkey with a population of 16,624 students, of which 3,968 are in the college of education. The sample consists of 108 students (52 in the control group and 56 in the experimental group) drawn from two general chemistry college courses taught by the same instructor. Control group consists of 13 males and 39 females. Experimental group consists of seven males and 49 females. The participants' ages range from 19 to 22. All students have taken a chemistry course at high school and have seen extensive tutoring in general chemistry in high school as the majority of students have to attend tutoring schools for at least 1 year in preparation for the university entrance exam in Turkey.

Instruction in the Control Group Classroom

The course professor spent 6 h lecturing the control group students about the gas laws and the properties and behaviors of gases over 2-week period of time. This is the same amount of time she spent lecturing the experimental group students prior to argumentation sessions. After 6 h of lecturing, the professor spent two additional hours with the control group students solving chemistry problems in preparation for the post-test. This is the same amount of time she spent on teaching argumentation to the experimental group students. Students worked in groups of four to solve the problem set provided by the course professor (see sample questions in "Appendix 2"). Students gave each other feedback on possible solutions to the problems during this problem-solving activity. Students sought help from the members of the neighboring groups or the course professor when they could not find a solution to a problem. Finally, the course professor solved and discussed solutions to the problems that were considered to be emphasizing the most important ideas on the board. In sum, the learning environment for the control group was very interactive.

Instruction in the Experimental Group Classroom

After the course professor taught the gas laws, properties, and behaviors of gases through lectures by spending 6 h of instruction over 2-week period of time, she modeled the act of argumentation with the participants with the help of the third coauthor. The course professor used Toulmin's (1958) model of argumentation in her modeling of argumentation for her students. The students developed written arguments and were coached on how to back up their findings with credible evidence, how to establish linkages between ideas, and how to substantiate their claims by using rational causal, inductive, and deductive reasoning strategies. It was hoped that by emulating the act of argumentation students would learn to successfully engage in epistemic practices, such as elaboration, reflection, and reasoning with evidence as part of their participation in scientific argument construction and evaluation activities (Bell & Linn, 2000; Newton, Driver & Osborne, 1999).

The intervention focused on students' conceptual understanding of the properties and behaviors of gases. We chose this topic for several reasons.

First, previous studies show that many students hold alternative conceptions related to properties and behaviors of gases (Liu, 2006; Kautz et al., 2005a; Wiebe & Stinner, 2010). It was hoped that by engaging in argumentation students would overcome some of their alternative conceptions related to the properties and behaviors of gases. Second, there are multiple variables that students need to take into account in order to solve a problem related to the properties and behaviors of gases. Choosing the topic of gases thus enabled us to develop cases that lent themselves to argumentation.

The argumentation took place in two phases. The first phase of the implementation required the participants to develop written arguments to justify their responses to a five-question two-tiered test related to the properties and behaviors of gases for 1 h. The participants were required to engage in verbal argumentation based on the five-question two-tiered test in groups of three for 1 h during the second phase of the intervention.

Development of Written Arguments. After the orientation session that lasted for 1 h, the participants were presented with five questions with multiple claims and asked to develop written arguments for each question. The students were challenged to evaluate the validity of those claims by using their knowledge of the properties and behaviors of gases and norms of scientific argumentation modeled for them in the classroom. They were explicitly instructed to make sure that their arguments are persuasive and based on evidence. The students were given 1 h to complete the assignment.

Verbal Argument Development. After the participants completed their written arguments, they were placed in groups of three and were challenged to engage in collective argument evaluation and construction using the same questions. They were challenged to evaluate the validity of each claim, support their agreements or disagreements of the claims with rational justifications and credible evidence. The participants' engagement in verbal argumentation lasted for 1 h as well.

Data, Data Collection, and Instruments

Data consist of students' pre- and post-test scores and students' responses to the post-argumentation reflection questionnaire. The pre- and post-tests consisted of 10 questions (see "Appendix 1" for sample questions from the tests) that were designed to measure students' conceptual understanding of the properties and behaviors of gases. The content validity of these tests was established through the expert panel methodology. All of the researchers who constructed the questions hold a chemistry degree in addition to an advanced degree (Ph.D.) in science education. They all taught chemistry at the college level and have extensive experience in test formation, evaluation, and administration. In addition, all four authors have conducted research in chemical education previously. The authors developed and evaluated the content validity of the two-tiered questions iteratively until the consensus was established about the validity of the test items, the difficulty level of each question, and the ease of language used in the questions. The authors have been teaching similar student populations for more than 3 years arrived at the conclusion that the questions were not too difficult or too easy for the students to answer.

The post-argumentation questionnaire looked at the perceived impact of argumentation on students' conceptual understanding of the behavior and properties of gases. The post-argumentation reflection questionnaire consisted of 14 items in five-point Likert scale (strongly agree, agree, undecided, disagree, strongly disagree). It was designed by the researchers to elicit how argumentation may have helped the participants in a variety of ways and the perceived impact of argumentation on their learning of the concepts related to properties and behaviors of gases.

Data Analysis

In order to test our hypothesis (i.e. argumentation has a significantly positive impact on college students' conceptual understanding of properties and behavior of gases), we ran several statistical tests: an independent samples *t* test to compare the control and experimental group students' conceptual understanding of gases prior to the intervention, an independent samples *t* test to compare the two groups' conceptual understanding after the intervention ended, and a paired samples *t* test to explore the significance level of the difference between students' conceptual understanding of the properties and behaviors of gases between pre- and post-tests. In addition to the tests of significance, we conducted between and within group comparisons between pre- and post-tests using descriptive statistics. In running the independent samples *t* test for checking the difference in achievement between the control and the experimental group students, we grouped the data in the following manner: The control group pre-test was assigned a group which was given a value of "1," and the experimental group pre-test was assigned a group which was assigned a value of "2." The same procedure was followed in running the independent samples *t* test for the post-test. We also compared the frequency of alternative conceptions revealed in both groups of students' responses to the pre- and post-tests. Finally, we analyzed students' responses to the post-argumentation reflection questionnaire to justify the reported impact of argumentation on students' conceptual understanding of the properties and behaviors of gases. In our analyses, we calculated the mean for each statement and reported the means as a way of measuring the perceived impact of argumentation on students' learning.

Results

Results are reported in the following order: the results of the pre- and post-test data, within group comparisons between pre- and post-tests, comparison of the changes in frequencies of students' alternative conceptions between pre- and post-tests, and the results of the post-argumentation reflection questionnaire.

Results of Pre-test Data

Our analyses of students' performance on pre-test indicate that both groups started off at the same level of conceptual understanding. The results of an independent samples *t* test on participants' pre-test scores indicated that there was not a significant difference ($p = 0.499$) between the control and experimental group students' conceptual understanding of the behavior and properties of gases covered by the pre-test. In spite of the differences in the achievement of the two groups of students in three questions out of 10, there was not a significant difference between the overall achievement scores of the two groups on the pre-test.

Results of Post-test Data

Post-test data analyses show that the experimental group students performed significantly better ($^*p = 0.002$) than their peers in the control group. Further analysis of group comparisons for the post-test indicates that the experimental group students outperformed the control group students on all questions but Q2 and Q6. While both group of students performed very poorly on Q6, the control group students outperformed the experimental group students on Q2. Q2 focuses on students' understanding of the behavior of a gas in a closed container with a movable piston, and Q6 focuses on students' understanding of the

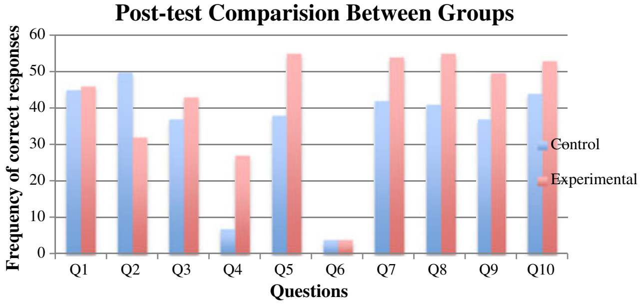


Figure 1. Post-test comparison between groups

relationship between the temperature and pressure of a gas inside a closed container. The details of post-test analyses are summarized in Figure 1.

Examining Participants' Progress from Pre-test to Post-test

Control Group. We compared the frequency of students that correctly answered each question between pre- and post-test to understand students' progress between pre- and post-test. The results show that while the control group students made improvements on all questions, they did not make any improvements on Q4, Q5, and Q6, between pre-test and post-test. However, students had the most difficulty with Q4 and Q6 both pre- and post-instruction. Q4 focused on students' understanding of partial and total pressures inside a closed container, Q5 focused on diffusion rate of the gas molecules, and Q6 focused on students' understanding of the relationship between temperature, pressure, and volume of a gas in a closed container. However, the traditional instruction had a positive impact on students' conceptual understanding of the concepts tested by Q1, Q2, Q3, Q7, Q8, Q9, and Q10. These details are summarized in Figure 2.

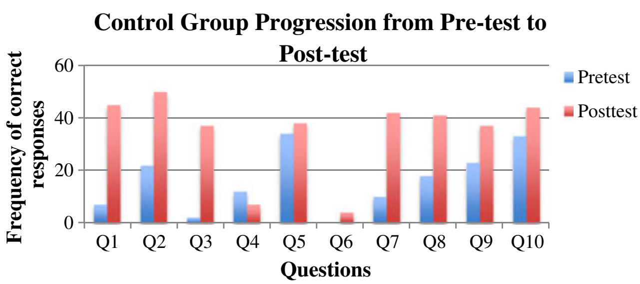


Figure 2. Control group progression from pre-test to post-test

Experimental Group. The results show that the experimental group students made improvements on all questions but Q6 between pre-test and post-test. However, students had the most difficulty with Q6 both pre- and post-instruction. These results show that argumentation-based pedagogy had a significantly positive impact on students' conceptual understanding of the concepts measured by all questions but Q6, which focuses on the relationship between the temperature, pressure, and volume of a gas in a closed container. The details of the experimental group students' progression from pre-test to post-test are summarized in Figure 3.

Group Mean Comparisons Between Pre- and Post-tests

The comparison of the two groups of students' test score means indicate that both groups of students made progress between pre- and post-test. However, the experimental group students made larger gains between pre- and post-test. While the experimental group students made a 126.73 % gain between pre- and post-test, the control group students made a 90.57 % gain between pre- and post-test. These statistics are summarized in Table 1.

Change in the Frequency of Alternative Conceptions Held by Students

In-depth analyses of students' written responses to the test questions indicate that students in the intervention group held fewer alternative conceptions after the intervention than their peers in the control group. These statistics are summarized in Table 2.

The results of this analysis indicate that the control group students did worse on three alternative conceptions on the post-test compared to the pre-test. These alternative conceptions are solid molecules of the same substance weigh heavier than its gas molecules (0 on pre-test, 3 on post-test), gases have no weight (3 on pre-test, 7 on post-test), and an increase in the temperature of a gas in a closed container increases the system's

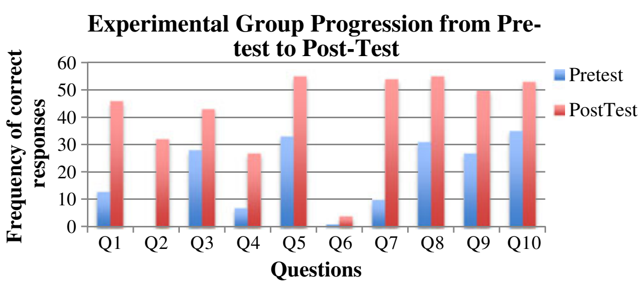


Figure 3. Progression from pre-test to post-test

TABLE 1

Group mean comparisons between pre- and post-test scores

Groups	*Pre-test score mean*	*Standard deviation*	*Standard error mean*	*Post-test score mean*	*Standard deviation*	*Standard error mean*	*Percent gain*
Experimental (n = 56)	33.00	14.3	0.192	74.82	14.89	0.199	126.73
Control (n = 52)	34.81	12.6	0.174	66.34	11.88	0.164	90.57

Each student could receive 10 points for each correct answer, thus a maximum of 100 points

pressure and volume (8 on pre-test, 15 on post-test). The frequency of alternative conceptions held by the control group students that did not change or changed slightly in spite of instruction includes temperature is a necessary entity for calculating a gas' partial pressure (12 on pre-test, 12 on post-test); volume is a necessary entity for calculating a gas' partial pressure (7 on pre-test, 7 on post-test), as the number of gas particles inside a closed container with a movable piston increase so does its volume and pressure (12 on pre-test, 10 on post-test); when the air is compressed, all the air particles are pushed to the end of syringe (15 on pre-test, 8 on post-test); and gas particles expand as the temperature increases (6 on pre-test, 6 on post-test). These findings suggest that traditional instruction was ineffective at eliminating or decreasing eight alternative conceptions out of the 17 that we had identified.

The experimental group students made a significant progress in terms of abandoning their alternative conceptions between pre- and post-test. The only exception to this finding is the alternative conception related to the relationship between the temperature of a gas in a closed container, its volume, and pressure (10 on pre-test, 14 on post-test). A large number of students from the control group (n = 15) also held the same alternative conception on the post-test. Students may have had a hard time abandoning this alternative conception due to the increasing variables that needed to be taken into consideration in thinking about the relationships.

However, taken together, these results tell us that the argumentation-based pedagogy had a more positive impact on students' conceptual understanding of the behavior and properties of gases than the traditional instruction did. However, in order to attribute this reported gain primarily to the argumentation-based instruction, we solicited students' perceptions of the effectiveness of argumentation on their learning through a Likert-scale questionnaire (see "Appendix 4"). We report the results below.

TABLE 2

Change in frequency of alternative conceptions held by students over time

Alternative conception type	*Control pre-test frequency*	*Control post-test frequency*	*Experimental pre-test frequency*	*Experimental post-test frequency*
1. The gas particles are unevenly scattered in any enclosed space.	12	1	10	2
2. Heavy gases occupy more space than the lighter ones.	11	0	4	1
3. The gases that move faster occupy more space than the slower ones.	12	0	10	0
4. In a 2-L closed container gases want to occupy 22.4-L space.	17	3	20	0
5. An increase in the volume of a gas causes an increase in the temperature and pressure of the closed system as well.	15	2	12	4
6. Solid molecules of a substance are heavier than its gas molecules.	0[a]	3	7	1
7. Gases have no weight.	3[a]	7	13	1
8. Temperature is necessary to calculate a gas' partial pressure.	12[a]	12	14	2
9. Volume is a necessary entity for calculating a gas' partial pressure.	7[a]	7	14	1
10. The diffusion rate of a gas is directly related to its molecular weight.	3	2	5	1
11. The diffusion rate of a gas is higher under high-pressure conditions.	4	0	7	0
12. As the temperature of a gas in a closed container increases, so does its volume and pressure.[a]	8[a]	15	10[a]	14
13. Gases behave ideally at low-temperature and high-pressure conditions.	24	1	18	1
14. As the number of particles increase the pressure of gases in a closed container with movable piston also increases.	12	10	11	0
15. When the air is compressed, the air particles are all pushed to the end of the syringe.	15	8	9	0
16. The attraction force between gas particles increases with an increase in the temperature.	3	1	5	1
17. Gas particles expand as the temperature increases.	6[a]	6	8	0

[a]Indicates the frequency of alternative conceptions that either stayed the same or increased in spite of instruction

Perceived Impact of Argumentation on Students' Conceptual Understanding of Gases

The results of our analysis of the post-argumentation questionnaire data show that argumentation helped students in variety ways: helped the participants to become aware of their knowledge deficiencies in the topic of gases ($\overline{X} = 4.09$), helped them to address their misconceptions related to the topic of gases ($\overline{X} = 3.8$), gave them a chance to repeat the topics related to the lesson ($\overline{X} = 4.00$), helped them to develop a better understanding of the topic ($\overline{X} = 4.11$), and helped them to become more confident in their knowledge of gases ($\overline{X} = 3.67$). We also wanted to understand what types of specific learning activities within argumentation brought about such perceived outcomes. The results of our analyses show that these results became possible partly because argumentation made learning an enjoyable experience ($\overline{X} = 3.74$), increased students' active participation in learning ($\overline{X} = 3.70$), gave students a chance to repeat what they already knew about the topic of gases ($\overline{X} = 4.00$), argumentation gave the students the opportunity to ask clarifying questions to their peers ($\overline{X} = 3.76$), the opportunity to exchange ideas with their peers ($\overline{X} = 4.00$), and challenged them to support their claims with credible evidence and rational reasoning ($\overline{X} = 3.96$).

The participants also stated that learning about the properties and behaviors of gases through argumentation increased their interest in the topic ($\overline{X} == 3.67$), learning through argumentation helped them to learn new things about the topic ($\overline{X} == 3.85$), and verbal argumentations helped them to become aware of deficiencies in their knowledge ($\overline{X} == 3.87$). Finally, participants stated that their ideas about the topic changed ($\overline{X} == 3.03$) as a result of verbal argumentation session. These results support the results of our quantitative analyses, which point to the positive impact of argumentation on student learning.

Discussion

The results of our analyses and the reported perceptions of students about argumentation-based learning led us to conclude that argumentation-based learning had a positive impact on students' conceptual understanding of the properties and behaviors of gases. This result is consistent with some previous studies that report the positive impact of argumentation on student learning in other contexts (e.g. Jimenez-Aleixandre, Bugallo-Rodriguez & Duschl, 2000; Jimenex-Aleixandre

& Pereiro-Munoz, 2002; Leach, 1999; Mason, 1996; Zohar & Nemet, 2002). Although we cannot attribute these significant gains achieved by the participants solely to argumentation-based pedagogy, we believe that argumentation played a major role in bringing about these improvements in students' learning.

Several factors contributed to this positive outcome. First, because of their previous exposure to the topic of gases, students already held some unstable conceptions about the behavior and properties of gases. Argumentation created a context for the learners to elaborate on their pre-existing ideas in a social context and a chance for their peers to evaluate the rationality and accuracy of their ideas and provide feedback to the learners. Second, argumentation in general and written argumentation particularly engages students in reflective metacognitive thinking. When students develop written arguments, they have to organize the information they already know and communicate their knowledge to the teacher in the most convincing and coherent way possible (Kelly & Chen, 1999; Keys, 1999; Prain, 2006). Moreover, such reflective activity may have helped the students to become aware of the gaps in their knowledge. Engaging students in verbal argumentation after they had developed their written arguments may have helped the students to address the gaps in their knowledge by listening to their peers' ideas and asking questions to clarify their understandings. Students' comments about the perceived impact of argumentation on their learning support these interpretations.

Third, we believe that argumentation-based pedagogy contributed to such positive results partly because the course professor understood the epistemological and pedagogical foundations of argumentation, had experience with learning science through argumentation, and had previously conducted research on argumentation-based learning. Her understanding of the epistemological and pedagogical assumptions of argumentation may have helped her to better scaffold argumentation tasks and the discourse. Such scaffolding may have helped the students to more effectively participate in the act of argumentation and argument development.

Although these results are limited, they have implications for the role of argumentation in bringing about conceptual change in students' alternative conceptions. Recent research on conceptual change suggests the use of instructional strategies that can stimulate a restructuring of students' understanding of scientific concepts. These include strategies aiming to increase students' metacognitive awareness (Beeth, 1998), fostering collaboration, and promoting dialogue among the students (Vosniadou, Ioannides, Dimitrakopoulou & Papademetriou, 2001). It has been argued that such strategies result in higher levels of thinking, recognition of the gaps in one's knowledge, and articulation of the relationships between various variables associated with a particular science concept and thus increase the plausibility and intelligibility of scientifically correct ideas. These are the cognitive processes facilitated when students engage in argument construction and evaluation (Bricker & Bell, 2008).

Another benefit of argumentation is that it forces students to challenge their peers through questioning to substantiate their claims to knowledge. Questioning is a key inquiry practice that encourages elaboration, expansion, and interpretation (Lustick, 2010) and thus driving the students to a deeper understanding of the concepts under investigation. In addition, argumentation has been proven to enhance the quality of student learning as it engages students in epistemic thinking (Kelly & Takao, 2002), increased abstraction of knowledge (von Aufschnaiter et al., 2008), and in-depth investigation of scientific ideas (Shemwell & Furtak, 2010). It follows that argumentation may be one of the most effective tools for bringing about conceptual change in students' conceptual understanding of "hard to learn" science concepts such as the properties and behaviors of gases. Therefore, science educators should invest their efforts into researching the impact of argumentation on students' conceptual understanding of "hard to learn" science topics.

Limitations

As is the case with most educational studies, there are few limitations to this study that we would like to mention. First, this study was conducted with a sample size of 108, which may not represent students of all ability levels. Second, the argumentation-based instruction was used to promote students' conceptual understanding of the properties and behaviors of gases; therefore, it may not be as effective in bringing about positive improvements in students' conceptual understanding of other science topics. Finally, we cannot attribute these positive results to argumentation-based pedagogy only. Other factors that were not controlled for may have contributed to these results as well. For instance, it may be the case that the experimental group students invested more time and effort into studying for the post-test than the control group students did. However, we did not monitor students' study time. We would like our readers to keep these limitations in mind as they consider the implications of these results for their particular contexts.

Appendix 1: Sample Questions from Conceptual Test: Gazlar Kavram Testi

1. 1 mole of oxygen gas and 1 mole of helium gas are kept in two separate 2L containers at the room temperature. Which of the following statement(s) hold true about these gases under these conditions.

I. The volume of both 1 mole of oxygen and I mole of helium is 2L.
II. II. The volume of 1 mole of oxygen will be different from that of 1 mole of helium.

Which of the following explanations would you use to justify your answer:

a. Since gas molecules homogeneously spread across the containers they are in, 1 mole of each gas will occupy a volume of 1L.
b. Oxygen will occupy more space because its molar mass is larger than the molar mass of Helium.
c. Under normal conditions, I mole of an ideal gas occupies a volume of *22.4L, therefore, each gas will occupy the same 22.4 L of volume*.
d. Since gas molecules homogeneously spread across the containers they are in both gases will occupy 2L volume of space.
e. Because helium diffuses 4 times faster than oxygen, helium will occupy 4 times more space than oxygen.

2. If we slowly add more He gas to a closed container with a piston that already has He gas in it, which of the following will hold true about the pressure inside the container.

I. Increase II. Decrease III. No change

Which of the following explanations would you use to justify your answer:

a. Pressure will increase as the number of molecules per unit area increase.
b. As the amount of He inside the container increase, so will the temperature and therefore the pressure.
c. As the volume of He gas at constant temperature increases, the pressure will stay the same.
d. As the volume of He gas at constant temperature increases, the pressure will decrease.
e. As the average kinetic energy of the He gas increases so will the pressure inside the container.

3. Which of the following properties of a chemical substance will change as as result of going through phase changes: from solid state to the liquid state and from liquid state to the gas state?

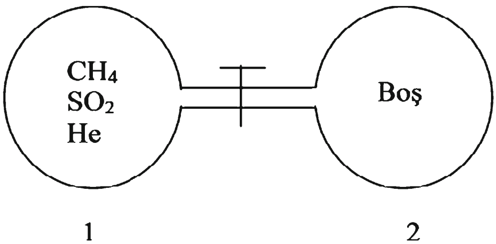
I. Kinetik energy II. Size of molecules III. The distance between molecules.

Which of the following explanations would you use to justify your answer:

a. Because the absorbed energy that is used during state changes is used to facilitate the process of phase change, there will be a decrease in the kinetic energy of the molecules.
b. As the matter moves from solid state to the gas state molecules bump into each other more frequently therefore, the size of gas molecules will decrease.
c. Because the gas molecules absorb energy and expand the distance between molecules will shrink.
d. Because the gas molecules take the shape of the containers they are in, the shape and size of the molcules will change.
e. As the kinetic energy of the gas molecules increase because of the absorbed energy during phase change, they will move faster. Therefore, the distance between the molecules will increase.

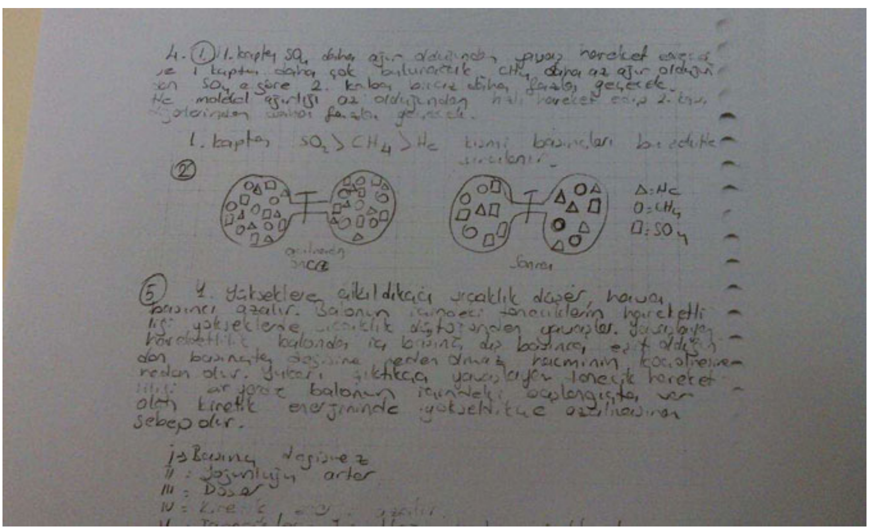
Appendix 2: Sample Questions from the Problem-Solving Session

1. The temperature of a closed system has been increased from 27°C to 127°C by adding 8 grams of CH_4 to 8 gr of H_2 in a closed cylinder with a constant volume. If the final pressure of the system is 9 atm, what was the pressure of the system before 8 grams of CH_4 was added to the system. (C: 12, H: 1)
2. Equal amount (in moles) of the three gases CH_4, SO_2 and He are placed in container I on the left. If we lift the block between the two containers for a while, which of the following will hold true about this system.



I. The number of SO_2 molecules in container II will be the highest of all three gases.
II. The mass of He has in container I will be the highest.
III. The relationship between the magnitude of these gases' pressures can be described as $P_{He} < P_{CH4} < P_{SO2}$.

Appendix 3: Exemplary Written Argument



Appendix 4: Post-argumentation Questionnaire

Statement	*Mean*
1. Learning the topic of gases through argumentation helped me become aware of the gaps in my knowledge related to gas properties and behaviors.	4.09
2. Learning the topic of gases through argumentation helped me to correct my misunderstandings related to the properties and behavior of gases.	3.8
3. Learning the topic of gases through argumentation helped me to revisit what I had already known about the topic.	4.00
4. Learning the topic of gases through argumentation exposed me to new ideas about gases.	3.85
5. Learning the topic of gases through argumentation helped me to develop a better understanding.	4.11
6. Learning the topic of gases through argumentation increased my confidence in my knowledge of gas properties and behaviors.	3.67
7. Learning the topic of gases through argumentation made learning of the topic more fun.	3.74
8. Learning the topic of gases through argumentation ensured my active participation in learning.	3.70
9. Learning the topic of gases through argumentation increased my interest in the topic.	3.67
10. Verbal argumentation gave me a chance to ask my peers questions related to gases that I would not have been able to ask otherwise.	3.76
11. I become aware of the gaps in my knowledge during verbal argumentations.	3.87
12. I become aware of the importance of justifying my ideas because of my participation in verbal argumentation.	3.96
13. I exchanged ideas with my peers during verbal argumentations.	4.00
14. Verbal argumentations changed some of my ideas that I initially held about the topic.	3.03

References

Aldridge, J. M., Fraser, B. J., Taylor, P. C. & Chen, C. C. (2000). Constructivist learning environments in a cross-national study in Taiwan and Australia. *International Journal of Science Education, 22*, 37–55.

Anderson, C. (2007). Perspectives on science learning. In S. K. Abell & N. Lederman (Eds.), *Handbook of research in science education* (pp. 3–30). Mahwah, NJ: Lawrence Erlbaum Associates.

Baker, M. J. (1999). Argumentation and constructive interactions. In P. Coirer & J. Andriessen (Eds.), *Foundations of argumentative text processing* (pp. 179–202). Amsterdam, the Netherlands: University of Amsterdam Press.

Beall, H. (1994). Probing student misconceptions in thermodynamics with in-class writing. *Journal of Chemical Education, 71*(12), 1056–1057.

Beeth, M. E. (1998). Teaching for conceptual change: Using status as a metacognitive tool. *Science Education, 82*, 343–356.

Bell, P. & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education, 22*(8), 797–817.

Benson, D. L., Wittrock, M. & Baur, M. E. (1993). Students' preconceptions of the nature of gases. *Journal of Research in Science Teaching, 30*, 558–597.

Bonder, G. M. (1991). I have found you an argument. *Journal of Chemical Education, 68*, 385–388.

Bricker, L. & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education, 92*(3), 473–498.

Cetin, P., Kaya, E. & Geban, O. (2009). Facilitating conceptual change in gases concepts. *Journal of Science Education and Technology, 18*, 130–137.

Cross, D., Taasoobshirazi, G., Hendricks, S. & Hickey, D. T. (2008). Argumentation: A strategy for improving achievement and revealing scientific identities. *International Journal of Science Education, 30*(6), 837–861.

Driver, R., Newton, P. & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287–312.

Duschl, R. & Grandy, R. (Eds.). (2008). *Teaching scientific inquiry: Recommendations for research and implementation*. Rotterdam, the Netherlands: Sense.

Erduran, S., Ardac, D. & Yakmaci-Guzel, B. (2006). Learning to teach argumentation: Case studies of pre-service secondary science teachers. *Eurasia Journal of Mathematics, Science and Technology Education, 2*(2), 1–14.

Erduran, S. & Jimenez-Aleixandre, M. P. (Eds.). (2008). *Argumentation in science education: Perspectives from classroom-based research*. Dordrecht, the Netherlands: Springer.

Griffiths, A. K. & Preston, K. R. (1992). Grade 12 students' alternative conceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching, 29*(6), 611–628.

Hwang, B., & Chiu, S. (2004). The effect of a computer instructional model in bringing about a conceptual change in students' understanding of particulate concepts of gas. In *Paper presented in Informing Science and IT Education Joint Conference*, Rockhampton, Australia.

Jimenex-Aleixandre, M. P. & Pereiro-Munoz, C. (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International Journal of Science Education, 24*, 1171–1190.

Jimenez-Aleixandre, M. P., Bugallo-Rodriguez, A. & Duschl, R. A. (2000). 'Doing the lesson' or 'doing science': Argument in high school genetics. *Science Education, 84*(6), 757–792.

Kautz, C. H., Heron, P. R. L., Loverude, M. E. & McDermott, L. C. (2005a). Student understanding of the ideal gas law, part I: A macroscopic perspective. *American Journal of Physics, 73*, 1055–1063.

Kautz, C. H., Heron, P. R. L., Shaffer, P. S. & McDermott, L. C. (2005b). Student understanding of the ideal gas law, part II: A microscopic perspective. *American Journal of Physics, 73*, 1064–1071.

Kelly, G. & Chen, C. (1999). *The sound of music*: Constructing science as sociocultural practices through oral and written discourse. *Journal of Research in Science Teaching, 36*(8), 883–915.

Kelly, G. & Takao, A. (2002). Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Science Education, 86*(3), 314–342.

Keys, C. W. (1999). Language as an indicator of meaning generation: An analysis of middle school students' written discourse about scientific investigations. *Journal of Research in Science Teaching, 36*(9), 1044–1106.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*(3), 319–337.

Kuhn, D. (2010). Teaching and learning science as argument. *Science Education, 94*(5), 810–824.

Latour, B. & Woolgar, S. (1986). *Laboratory life: The construction of scientific facts*. Princeton, NJ: Princeton University Press.

Leach, J. (1999). Students' understanding of the co-ordination of theory and evidence in science. *International Journal of Science Education, 21*(8), 789–806.

Liu, X. (2006). Effects of combined hands-on laboratory and computer modeling on student learning of gas laws: A quasi-experimental study. *Journal of Science Education and Technology, 15*(1), 89–100.

Lustick, D. (2010). The priority of the question: Focus questions for sustained reasoning in science. *Journal of Science Teacher Education, 21*(5), 495–511.

Madden, S. P., Jones, L. L. & Rahm, J. (2011). The role of multiple representations in the understanding of ideal gas problems. *Chemistry Education Research and Practice, 12*, 283–293.

Mason, L. (1996). An analysis of children's construction of new knowledge through their use of reasoning and arguing in classroom discussions. *Qualitative Studies in Education, 9*(4), 411–433.

McNeill, K. L., & Knight, A. M. (2011). The effect of professional development on teachers' beliefs and pedagogical content knowledge for scientific argumentation. In *Paper presented at the annual meeting of the National Association for Research in Science Teaching*, Orlando, FL.

Mercer, C. D., Jordan, L. & Miller, S. P. (1996). Constructivistic math instruction for diverse learners. *Learning Disabilities Research and Practice, 11*, 147–156.

Newton, P., Driver, R. & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education, 21*, 553–576.

Osborne, J., Erduran, S. & Simon, S. (2004). Enhancing the quality of argument in school science. *Journal of Research in Science Teaching, 41*, 994–1020.

Prain, V. (2006). Learning from writing in secondary science: Some theoretical and practical implications. *International Journal of Science Education, 28*(2), 179–201.

Sampson, V. (2009). Science teachers and scientific argumentation: Trends in practice and beliefs. In *Paper presented at the Annual International Conference of the National Association of Research in Science Teaching (NARST)*, Garden Grove, CA.

Şenocak, E., Taşkesenligil, Y. & Sözbilir, M. (2007). A study on teaching gases to prospective primary science teachers through problem-based learning. *Research in Science Education, 37*, 279–290.

Shemwell, J. T. & Furtak, E. M. (2010). Science classroom discussion as scientific argumentation: A study of conceptually rich (and poor) student talk. *Educational Assessment, 15*(3–4), 222–250.

Toulmin, S. (1958). The uses of argument. Cambridge, England: Cambridge University Press.

Venville, G. J. & Dawson, V. M. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. *Journal of Research in Science Teaching, 47*, 952–977. doi:10.1002/tea.20358.

von Aufschnaiter, C., Erduran, S., Osborne, J. & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*(1), 101–131.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A. & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction, 11*, 381–419.

Vygotsky, L. S. (1978). *Mind and society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Walker, J., Sampson, V., Grooms, J., Anderson, B., & Zimmerman, C. (2010). Argument-driven inquiry: An instructional model for use in undergraduate chemistry labs. In *Paper presented at the 2010 Annual International Conference of the National Association of Research in Science Teaching (NARST)*, Philadelphia, PA.

Wiebe, R. & Stinner, A. (2010). Using story to help students' understanding of gas behavior. *Interchange, 41*(4), 347–361.

Zohar, A. & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62.

Mehmet Aydeniz

The University of Tennessee
A 408 Jane & David Bailey Education Complex, 1122 Volunteer Blvd, Knoxville, TN 37996-3442, USA
E-mail: maydeniz@utk.edu

Aybuke Pabuccu and Pinar Seda Cetin

Abant Izzet Baysal University
Bolu, Turkey

Ebru Kaya

Selcuk University
Konya, Turkey