THE EFFECT OF WORKING WITH IPAD APPLICATIONS INCLUDING MACROSCOPIC AND SUBMICROSCOPIC LEVEL REPRESENTATIONS IN DIFFERENT ORDERS ON STUDENTS' CONCEPTUAL UNDERSTANDING OF GAS LAWS

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ABSTRACT

THE EFFECT OF WORKING WITH IPAD APPLICATIONS INCLUDING MACROSCOPIC AND SUBMICROSCOPIC LEVEL REPRESENTATIONS IN DIFFERENT ORDERS ON STUDENTS' CONCEPTUAL UNDERSTANDING OF GAS LAWS

The aim of this study was to investigate the effect of implementing macroscopic and submicroscopic level instructional activities in different order on conceptual understanding of Gas Laws in the 9^{th} grade chemistry lesson by using iPads. The participants of the study were 44 ninth grade students studying at a private high school in Istanbul. In the beginning of the study, the participants were divided into two groups: first group (called MaMi, N=22) started with the macroscopic level activities, then continue with the submicroscopic level, whereas the other group (called MiMa, N=22) worked on the same activities in reverse order. The instrument used in this study was Gas Concept Test (GCT), which consisted of questions including only macroscopic, only submicroscopic and both types of representations. The GCT which was found to be valid and reliable (α=.777) was given before and after the implementation. In addition, during the implementation students filled in worksheets, and participated in the semi-structured interviews. The implementation was composed of two classroom activities, including iPad applications, "Gas Laws HD Lite" and "iGasLaw" accompanied with worksheets. The total scores of GCT-Pre and GCT-Posttests were compared by using parametric tests, namely, Independent Samples t-test and Paired Samples t-test. The analysis of results showed that both groups improved significantly (p=.000) from GCT-Pre- to GCT-Post; however no statistically significant difference (p=.243) was found in the total scores of GCT-Post between the groups. When groups' scores in answering macroscopic level questions from GCT-Pre to GCT-Posttest were analyzed by using non-parametric test, Wilcoxon Signed Ranks test, MaMi was found to perform significantly better (p=.003) in this type questions than MiMa did. In the worksheet analysis, no statistically significant (p=.378) difference was found. The findings from the interviews revealed student misconceptions regarding behavior of gas particles such as molecular size differs as temperature changes, and gas molecules stick together when temperature decreases.

ÖZET

GÖZLEMLENEBİLİR VE TANECİK DÜZEYİ GÖSTERİMLER İÇEREN IPAD UYGULAMALARI İLE FARKLI SIRALAMALARLA ÇALIŞMANIN ÖĞRENCİLERİN GAZ YASALARINI KAVRAMALARI ÜZERİNE ETKİSİ

Bu çalışmanın amacı 9. Sınıf kimya dersi gaz yasaları konusunda, gözlemlenebilir ve tanecik düzeylerinde iPad uygulamaları kullanılarak yapılan eğitim faaliyetlerinin farklı sıralarda uygulanmasının öğrencilerin Gaz Yasalarını anlama düzeylerine etkisinin araştırılmasıdır. Çalışmaya İstanbul'da özel bir lisede okuyan 44 öğrenci katılmıştır. Öğrenciler, bu çalışmada iki gruba ayrılmıştır: birinci grup (MaMi, N=22) önce gözlemlenebilir sonra tanecik düzeylerinde; ikinci grup ise (MiMa, N=22) önce tanecik, daha sonra gözlemlenebilir düzey aktivitelerle çalışmıştır. Öğrencilerin gazlarla ilgili kavramları anlama düzeylerini belirlemek için Gaz Kavramları Testi (GKT) her iki gruba ön-test ve son-test olarak uygulanmıştır. İçeriğinde sadece gözlemlenebilir, sadece tanecik ve her iki düzeyden gösterimler içeren sorular barındıran Gaz Kavramları Testinin geçerli ve güvenilir (α=.777) olduğu görülmüştür. Bunun yanında, öğrenciler uygulama sırasında sınıf içi yapılan etkinliklerin çalışma kağıtlarını tamamlamış ve son olarak yarı-yapılandırılmış bireysel görüşmelere katılmıştır. Sınıf içi yapılan etkinlikler "Gas Laws HD Lite" ve "iGasLaw" iPad uygulamaları ile yapılmıştır. GKT-ilk ve GKT-son test analizlerinin sonuçlarına göre, her iki grubun da istatistiksel olarak (p=.000) anlamlı bir şekilde ön-testten son-teste doğru geliştiği gözlenmiştir. Ancak grupların son-testleri arasında istatistiksel olarak (p=.243) anlamlı bir fark bulunmamıştır. Öğrencilerin GKT-ilk ve GKT-son test içerisindeki gözlemlenebilir düzeydeki sorulardan aldıkları puanlar incelendiğinde, MaMi grubunun MiMa'ya göre istatistiksel olarak (p=.003) daha başarılı olduğu bulunmuştur. Sınıf içi yapılan çalışma kağıtları incelendiğinde ise, gruplar arasında anlamlı bir fark (p=.378) olmadığı görülmüştür. Yapılan görüşmeler sonucunda öğrencilerin gaz tanecikleri ile ilgili kavram yanılgılarına (örneğin, sıcaklık değişimlerinin molekülün büyüklüğünü değiştirmesi ya da sıcaklığın azalmasıyla gaz taneciklerinin bir araya toplanması) sahip olduklarına dair bulgular elde edilmiştir.

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df	Degrees of freedom
f	Frequency
M	Mean
N	Number of participants
t	t value

LIST OF ACRONYMS / ABBREVIATIONS

GCT	Gas Concept Test
MaMi	The treatment group, which first received the macroscopic level and then submicroscopic level.
MiMa	The treatment group, which first received the submicroscopic level representation and then macroscopic level representation.
Sig.	Significance
Std. Deviation	Standard Deviation

1. INTRODUCTION

The nature of chemistry includes working with the particles, which are too small to see by naked eye. That is why many students have difficulty in understanding what is happening at the submicroscopic level that affects the macroscopic world. According to Gabel (1999) the reason of using models and analogies in chemistry is to make that abstract subject understandable and teachable. For conceptual understanding in chemistry, Johnstone (1993) proposed a model composed of three levels of representation: the macroscopic level (visible chemistry), the submicroscopic level (level of atoms, molecules, and ions) and symbolic level (representations involving symbols, pictures or algebraic relations). Macroscopic representation is used while describing changes in matter through observation and experimentation. Symbolic level involves chemical equations, and mathematical expressions. On the other hand, the submicroscopic level representation is used to relate what is happening in the macroscopic level with the change in molecules, combination of atoms, and exchange of electrons (Liu, 2006). To improve understanding in chemistry, students need to coordinate various models and be fluent in simultaneously conceptualizing models that are macroscopic (hands-on laboratory experiences), submicroscopic (molecular models, atomic models and electron configuration), and symbolic (chemical formulas and reaction equations) (Liu, 2006). All those experiences should be gained in the chemistry classrooms. Instruction using the particulate nature of matter can improve students' understanding of chemistry, helping them make connections between the three levels of representation (Sanger *et al.*, 2000).

In recent years, information and communication technologies (ICT) have been used for effective learning in chemistry. It is thought that ICT could be helpful to overcome the problems that could not be resolved by the traditional regular classroom teaching (Burke, Greenbowe & Windschitl, 1998; Marcano, Williamson, Ashkenazi, Tasker & Williamson, 2004). Gas laws are one of the subjects in chemistry that students have difficulty with, because it requires understanding the behaviors of particles at the submicroscopic level (Nakhleh, 1993; Chiu, 2001). In subjects like gases, learning is not completed until the students can visualize the molecular dynamics of the phenomenon

(Burke *et al.*, 1998). Visualizations using submicroscopic or particulate/molecular animations are effective ways portraying the phenomena that involve molecules in motion. These visualizations help students overcome the learning barrier to visualize and understand how complex dynamics are involved when chemical processes occur (Sanger and Greenbowe, 1997a, b; Williamson and Abraham, 1995). Furthermore, it was found out that (Yezierski and Birk, 2006) submicroscopic level animations foster submicroscopic level explanations or conceptual understanding. Velazquez-Marcano *et al.* (2004) showed the importance of combining both types of visualizations, however it was not suggested any preferred order in the presentation of representations. Contrary to that study, Williamson *et al.* (2012) suggested that it was much better for students to see a macroscopic representation before a submicroscopic level one. In the present study, the focus was on the order of the macroscopic and submicroscopic level representations. The effect of different orders on the conceptual understanding of gas laws using two freely available iPad applications was researched.

2. LITERATURE REVIEW

2.1. Understanding the Nature of Gases

Understanding the nature of gases, including the ideal gas law and the mathematical relationships that describe the behavior of gases, Charles' Law, Boyle's Law, Gay Lussac's Law and Avogadro's Law, are essential in chemistry. Boyle's Law states that at constant temperature, volume of a given sample of gas is inversely proportional to its pressure. Charles' Law describes the change of the volume of gas at different temperature values at constant pressure. Gay Lussac's Law states that at constant volume, the difference in temperature is directly proportional to its pressure. Lastly, Avogadro's Law states that, for a gas at constant temperature and pressure, the volume is directly proportional to the number of moles particles of a gas. These relations and algorithmic modes of problem solving are generally given more attention compared to conceptual understanding. However; Gabel, Sherwood, and Enochs (1984) noted that if students do not understand a chemical concept qualitatively before it is presented quantitatively, they are likely to conduct only mindless manipulations of mathematical equations. Also research showed that students do not trust their conceptual understanding in chemistry. That is why they try to apply algorithms to solve conceptual problems (Nakhleh & Mitchell, 1993). In this study, instead of mathematical expressions of gas laws, conceptual understanding of the relations among the variables – P, T, V, n – were investigated. Different submicroscopic and macroscopic levels of representations were used to understand behaviors of gas particles at different conditions.

A detailed investigation of high school students' conceptual understanding of the gas laws published by Lin, Cheng and Lawrenz (2000) reports that not only high school students, but also teachers, have difficulty in understanding the ideal gas law and their properties conceptually. The study focused on the understanding of gas laws and the ability to apply this knowledge in different situations rather than mathematical calculations in theoretical situations. In the present study, conceptual understanding of gas behavior refers to understanding the nature of gases both at macroscopic and submicroscopic levels.

Understanding gas particles' behaviors in different conditions is a prerequisite for conceptual understanding of gas laws. Gonzalez (2004) researched gas laws by applying scientific concepts in practical situations, instead of mathematical calculations. It was indicated that high school students have a good grasp of the geometric distribution of gas molecules; and a high percentage of students would associate a decrease in the chamber volume with an increase in pressure and vice versa. Students expressed a belief that a more compact and confined area would give an increase in pressure. In the same study, it is found out via interviews that many of the incorrect responses were due to student difficulties with operational definitions of certain components of the ideal gas law.

The macroscopic and submicroscopic level representations together with the symbolic level are indispensible elements of chemistry. Matter can be observed and studied in macroscopic level; however, observations could be explained with inclusion of submicroscopic level. Third, symbolic level comprises a large variety of pictorial representations, algebraic and computational forms of the submicroscopic representation (Gabel, 1999; Chittleborough and Treagust, 2007). Johnstone (1993) has described the threefold manner of representations, as shown in Figure 2.1.

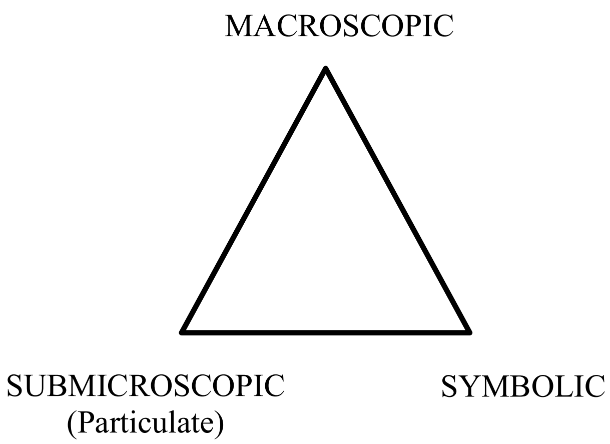


Figure 2.1. Three levels of chemistry.

Each of these representation types targets a different level of conceptual understanding. Macroscopic level representations show behavior of substances in different situations, that is also what we see with naked eyes. Whereas submicroscopic level representations give a view of the behavior of the particles and so they provide understanding of the invisible (Velazques-Marcano *et al*., 2004; Taber, 2013). In this study, a submicroscopic level iPad application was used in order to be able to see and understand the gas particles' behaviors. A macroscopic level iPad application was used instead of a hands-on experiment, in order to keep the medium of the instruction the same with the submicroscopic one. The study done by Velazques-Marcano *et al*. (2004) consisted two types of representations, namely molecular animations, which was submicroscopic level, and video demonstrations, which was macroscopic in the subject of effusion/diffusion in an undergraduate chemistry course. In that study influences of the order of these two types of representations were investigated and the researchers found that the integration of the two types of representations gave students an understanding of the process. However, the study did not suggest that there should be a preferred order in the presentation of the representations. Another research again about the order of representations on the subject of effusion/diffusion in chemistry was done by Williamson *et al*. (2012). The purpose was to investigate the submicroscopic level explanations that students give after various visualizations and to investigate any effect of order. The results showed the order in which video and animation visualizations were presented to students appeared to make a difference for their particulate level explanations of the experiment.

2.2. Technology and Its Usage in Classroom: Towards a learning society

Technology can help facilitate the classroom environment in the way that students take more responsibility of their learning. It is stated that with the use of computers in the classroom, schools would become more student-centered and that more individualized learning would take place than ever before (Muir-Herzig, 2004; Melhuish and Falloon, 2010). By saying individualized learning it is meant that; with this emerging ubiquitous technology, there could be an opportunity to design curriculum more student-centered, and thus individualized self-driven discovery, student managed learning and collaborative learning acquisition become key mechanisms (Cresente & Lee, 2011; Murphy, 2011). And if teachers develop expertise over a prolonged period of time to apply a high-level technology use, then this might lead to a change towards a student-oriented teaching practice (Ifenthaler and Schweinbenz, 2013). But the shift from teacher-centered delivery to a student-centered model potentially leads to resistance in change. To incorporate student-centered teaching seems to be challenging for educators because they may need to restructure their teaching methods and strategies. Negroponte, Resnick, and Cassell (1997; cited in Muir-Herzig, 2004) argue about technology in the classroom as:

> *"... that digital technologies can enable students to become more active and independent learners. The Internet will allow new "knowledge-building communities" in which children and adults from around the globe can collaborate and learn from each other. Computers will allow students to take charge of their own learning through direct exploration, expression, and experience. This shifts the student's role from "being taught" to "learning" and the teacher's role from "expert" to "collaborator" or "guide" (p.1).*

Moreover, about that change that is to be created via technology, a study done by Sandholtz *et al.* (1997) on the Apple Classrooms of Tomorrow (ACOT) over a 10-year period shows changes in teacher and student interactions. Teachers are observed more as being guides or mentors and less as lecturers. The cooperative and task-related interactions among the ACOT students are spontaneous and more extensive than in traditional classrooms. Student interest in computers did not decline with routine use. Teachers and students start to show mastery of technology and start to integrate several kinds of media into lessons or projects. Thus, this new technology has a potential to support students' learning processes (Wise *et al.*, 2006).

2.3. Learning Chemistry with Computers

Chemistry includes three levels of representation (Johnstone, 1993): macroscopic, submicroscopic and symbolic. The submicroscopic representation in chemistry is very important for conceptual understanding of what is happening at the macroscopic level. To provide this understanding in submicroscopic level, interactive modeling via computers has been used for scaffolding scientific understanding (Ardaç & Akaygün, 2004; Ebenezer, 2001; Barak & Dori, 2005; Barnea & Dori, 2000; Korkmaz & Harwood, 2004; Pallant & Tinker, 2004). As macroscopic level representations, hands-on laboratory experiments are essential in chemistry courses. Nersessian (1991) claims that "hands-on experience is at the heart of science learning" and Clough (2002) declares that laboratory experiences "make science come alive." On the other hand, now with the improvement of technology there are simulated labs (Ma & Nickerson, 2006), which are the imitation of the operation of a real experiment process. The entire infrastructure required for laboratories is not real, but simulated on computers. Those labs are considered necessary and also valuable. First, they are for cheaper lab experiences. Additionally, they are seen as effective as the real hands-on experiments since students become able to 'stop the world' and 'step outside' of the simulated process to review and understand it better, (Parush *et al.*, 2002; Shin *et al.*, 2002).

Besides, the use of both types of representations is also valuable in conceptual understanding of chemical concepts. The studies (Russell *et al.*, 1997; Velazquez-Marcano *et al.*, 2004; Williamson *et al.*, 2012) showed that when both macroscopic and submicroscopic level representations are used, students' conceptual understanding of the concept was improved as well. In the study done by Russell *et al.* (1997) molecular animations and video demonstrations were used, students seemed to better correlate the three levels of representations as their conceptual understanding and the ability to create dynamic mental models improve. The study of Velazquez-Marcano *et al.* (2004) was about the effect of video demonstrations and animations on students' performance of effusion/diffusion phenomena. The results showed that the integration of the two types of visualizations gave students an understanding of the process on both macroscopic and submicroscopic levels, however the study did not suggest that there should be a preferred order in the presentation of the visualizations. And the study done by Williamson *et al.* (2012) as a continuation of the study of Velazquez-Marcano *et al.*, (2004) showed that the order in which video and animation visualizations were presented to students appeared to make a difference to their particulate level explanations of the experiments done. The results of that study suggested that it was much better for students to see a video or macroscopic visualization before a particulate level visualization.

2.4. Tablet Computers in Education

Tablet PCs are first released in 2002 (Mock, 2004) and have since then gained educators' attention as a useful tool in learning and instruction. In 2010 Apple released the first iPad with many applications (apps)[1]; the apps are grouped in main categories such as newsstand, kids, games, finance, etc. One of those categories is 'education'. There, people may find applications to use in educational settings: like dictionaries, note-taking programs, mind-map apps, etc. Tablet PCs are now called post-PC devices (PPDs), which gives recognition that "this type of a device perhaps does indeed deserve its own category, possessing significant differences over and above existing desk-bound or mobile technologies such as smart phones and laptops" (Murphy, 2011, p. 19). Melhuish and Falloon (2010) indicated five capabilities offered by these devices: portability; affordable and ubiquitous access to content; situated "just-in-time" learning opportunities; connection and convergence to other devices; networks and technologies; and finally individualized and personalized experiences.

The first usage of Tablets or PPDs in education was for "Classroom Presenter" system. The system allows an instructor to lecture from a Tablet PC that communicates wirelessly with a server connected to a data projector. This allows the instructor to roam freely about the room and even into the audience, like a TV talk show host, and allows students to write comments that are visible to everyone in the class (Mock, 2004; Rogers & Cox, 2008).

Mock (2004) who used Tablet PC in his Java programming - classes at the college level, identified advantages and disadvantages of using such a system. Advantages are: the lecture can be conducted entirely by drawing in digital ink without preparing a material in advance, as is necessary with PowerPoint. Alternately, material can be prepared in advanced and annotated during lecture which means other than already written document, the instructor may put extra notes that will remain in the document; the instructor can easily redisplay previously covered material that would normally have been erased on a blackboard; convenient access to multiple pens in different colors, widths, and styles; digital ink can be saved and viewed later through a web browser. Also he gave some disadvantageous points: to project correctly, the tablet must be placed in landscape mode instead of the more comfortable portrait mode; poor display angles for some models; need for a data projector and the Tablet PC. After using the Tablet PC in the

[1] Computer software that is designed to do a particular job (http://www.macmillandictionary.com/dictionary/british/application)

classroom, Mock conducted a survey to get student ideas about Tablet PC usage, it was found that most of the students preferred the Tablet PC over traditional blackboard; they found the classroom recordings very helpful.

Students are generally motivated to follow the lectures if the lectures are done with Tablet PCs. A study done by Galligan *et al.* (2010) is supporting this information. They demonstrated in their study how a Tablet PC and associated technology could be used for teaching in university or school settings. Tablet PC provides a number of ideas how tablet PCs can be used in teaching face-to-face and online in distance. Tablet PC can create an environment that can maximize student learning opportunities, empowering both student and teacher. But again these researchers emphasize that the challenge is to create the learning materials that would engage and assist learning.

Another research about Tablet Computer usage was done by Amelito G. Enriquez (2010). In contrast to Mock's study for the purpose of instruction, Enriquez compared students' grades from homework averages, quizzes, tests and final exam averages in an Introductory Circuit Analysis course for the purpose of learning. The group studied with Tablet PC – called interactive learning network – show higher scores in quizzes, homework and exams. All differences, except homework, are statistically significant. Enriquez (2010) concluded that the studies done show that interactive learning environment resulted in improvements in student performance compared with the traditional instructor-centered environment.

Today, one of the popular tablet PC brands is the iPad. IPad serves like a small computer – tablet computer – with some additional aspects. An iPad can shoot video, take photos, play music, and perform Internet functions such as web browsing and emailing. Downloading and installing apps can enable other functions – games, reference, GPS navigation, social networking, etc. (Apple Inc, 2013). As technology becomes a part of people's lives and with the birth of digital natives (Prensky, 2001), schools are attempting to utilize technology to help provide new and innovative ways of accessing and relating to information for their students (Henderson & Yeow, 2012). Since in the classes iPads can be used alternatively for computers, music players, animations and even notebooks, many schools are trying to adapt tablet computers in their learning program. Murphy

(2011) indicates that PPDs are good candidates for the delivery of course content via multi-media and e-books. That advantage could increase the dynamic nature of course content beyond the print textbook. The ability to store a vast diversity of materials such as e-texts, PDF files, slideshows, videos, podcasts, and word processing documents on a highly portable and readable device has clear advantages to both educators and students (Economides and Nikolaou, 2008).

It is very important to carry education outside the borders of the school and iPad can be a means to achieve this. Students and teachers have a chance to use a dynamic device on field trips, at home, or wherever activities take place. Compared to the computers, which have fixed places to work or need cables to connect to Internet, the laptops are preferable. And compared to laptops or netbooks, tablet PCs do not have keyboard and track pad (Henderson & Yeow, 2012). The standard iPad weighs min 312 and max 613 grams (Apple Inc, 2014), making it a lot lighter than laptops or netbooks. IPad can be used efficiently, having just one button and no cables attached. IPad can connect to Internet in any location having wireless connectivity since it has Wi-Fi and 3G with Bluetooth.

However, the adaptation process is generally painful (Henderson & Yeow, 2012). According to Manuguerra and Petocz (2011), it is important to catch up with the world and the culture in which the students live. Schools need to know the needs of new generation of students and their new ways of learning, offering the same content in new formats. Cultural change of teachers is needed, and this is difficult when the technology level required to evolve is too high. To facilitate such change, teachers need a new generation of devices and software, easy to use and without a steep learning curve: the new class of post-PC devices such as the iPad could be just what is needed.

To give a numerical data about the total applications in iPads, the research done by Murray & Olcese (2011) could be helpful to see the whole picture. According to their research, 30000 applications are included under the heading of ‘education’. After they find a representative group of applications they differentiate them as being *tutor* type, *explore* type, *tool* type and *communication* type. After categorization, they found that most of the apps (112 out of 279) are *tutor* type, which means the technology does the teaching directly, like a lecture type lesson. Then, 79 out of 279 are *explore* type, which means the users can make decisions about the information they access and gain. And 73 out of 279 apps are *tool* type, meaning when the technology is not designed explicitly for school use but can be put to educational purposes. Lastly, 15 out of 279 apps are *communication* type, meaning students can send and receive messages and other information through networks. In addition to these four types of applications, some apps in Tablets are useful for practical reasons. For example, classroom response systems can be a part of Tablet usage. Using those systems, students' attention, attendance and interest (and even learning depending on the pedagogical approach taken) can enhance (Terrion & Aceti, 2012). Also in their study, Terrion and Aceti (2012) indicated that via clickers students are forced to give answers to the questions asked. This property provides getting answers from reluctant students as well. Clickers as a tool afford students the opportunity to voice their misunderstandings anonymously and, as a result, the professor can respond to those students without centering them out when the teacher sees incorrect responses on the screen.

Murphy (2011) states that increased screen sizes, larger storage capacity and the ability to run word-processing, spreadsheet and slideshow applications allow students the ability to generate, rather than simply consume materials on PPDs. Also with the coming of iPad 2, users are allowed to create videos (via iMovie) and music (via GarageBand); and with the usage of PDF annotators and drawing applications students can work in groups, creating and sharing of output easily and quickly between interested parties.

According to Manuguerra and Petocz (2011), iPad allows lecturers to have a very quick, efficient and sustainable workflow in their marking of student work. Students could be able to send their papers electronically, usually in pdf format, and the lecturer does not have to print them. This fits nicely in the culture that the students inhabit, where increasingly sustainability is seen as a valuable principle. The next step is simply to open the papers in one of the several apps on the iPad that allow annotating the pdf files.

There are also critical approaches to the technological push in education. According to Hemmi, Bayne and Land (2009), education has a well established history of taking in devices that are not originally intended for educational purposes, and attempting to appropriate them for educational gain. Traxler (2010) interprets this as a 'parasitic' relationship between technology and education, with Oppenheimer's (2003) assumption that *technology, which works outside of school, will work just as well in school*. However, Peluso (2012) describes a modern day classroom as one will find him/herself that the classroom is filled with a ubiquitous array of multimodal and digital resources, yet a majority of these revolutionary resources are likely not school issued, rather they were brought by the young people themselves. Also, Regelski (2006) states that, with contemporary society tasking educational curriculum and teachers to engage in the role of preparing young people for the escalating expectations and demands of the globalized workplace, it is increasingly seeming futile to exclude these technological advances that youth were already embracing to connect on a global level.

There are many studies about computer-assisted classrooms and usage of animations and simulations in chemistry, and the effectiveness of tools, such as online educational games and 3D virtual environments (Merchant *et al.*, 2012; Chee & Tan, 2012). What if those studies were now done with Tablets, would the results be the same? Also, it is worth investigating if the appropriate use of applications on tablet computers contributes to students' understanding.

There is a bunch of research done about PPD usage in education. In Australia the University of Adelaide's Science department provides iPads for their first-year science students to let them access lecture notes, documents and textbooks through tailored web-based apps (Cross, 2010). University of California Irvine Medical School deployed iPads to their medical students with preloaded coursework, podcasts, online tutorials and activities for the entire year. Also they developed a digital stethoscope application, (Murphy, 2011). Sussman (2010) noted that, Duke University staff own iPads to access 'The Duke University Blackboard' application. And in another university, Illinois Institute of Technology, the instructors at also use iPads to enhance educational resources. They released a university app for all Apple devices to access course lists, events, news and maps (Murphy, 2011). However, it shouldn't be understood like youth will automatically benefit in their learning by simply making technological devices (like iPads) available (Peluso, 2012). That should be questioned. Jenkins (2009) noted that the spectrum of technological knowledge and understanding is not equal across all students, as not all young people have equal access to become proficient in these digital and social media. While it may seem that all young people are highly capable of using iPads and digital media to learn and express themselves, it is not universal, nor something to be ignored when considering the incorporation of these technologies into the classroom.

> *"Tablets like iPad will make it second nature to not just facilitate but actually make effective pedagogical use of ubiquitous learning, that is, teaching and learning that can take place any time, in small burst, convenient to all, asynchronously or in real-time, as students and teachers alike immerse themselves in a more engaging and practical learning dialog, seamlessly forming part of the aforementioned digital continuum."*
> *(Ed Garay, cited in Kolowich, 2010)*

The present study is done in a high school that adopted the iPad in 2012. The participants of the study are 9th graders who had already used the iPad and its educational applications for an entire year. In the study, experiments were done through iPad applications both in macroscopic level and submicroscopic level representations. Students do the experiments on a simulated world on iPad.

2.5. IPads used in learning science/chemistry

Studies done by using iPads or Tablet Computers specifically in science classes are few. Generally the studies were done at the undergraduate level rather than high school level. For example, a study (Cooper *et al.*, 2009) with undergraduate chemistry students included the use of an application called *OrganicPad* allowing users to draw free-form chemical structures using an interface that closely mimicked the use of pen and paper. After one semester using this application, a survey was completed by the students (N=81). Students overwhelmingly reported their positive experiences with using *OrganicPad* to draw structures. Another study (Derting and Cox, 2008) describing the integration of a tablet PC into an introductory organic chemistry course compared the traditional regular classroom teaching with one-tablet format. In one-tablet format, all the presentations were done by using one-tablet. That gave the opportunity to annotate during presentation on the document, for teacher to roam in the classroom and save the new annotated material and share with the students. The aim of the study was to investigate the educational value and opportunities associated with the pen-based technology of a single tablet PC. Overall, it was found that there was a shift to higher standardized test scores when the one-tablet model was adopted. There was a significant difference in the mean test scores of students taught with the traditional approach compared with those with the one-tablet approach. O'Malley (2010) welcomed Tablet Computers into a physical chemistry course at the undergraduate level. Tablets were used instead of whiteboard for saving lecture notes as screencasts. In this research, students' feedback was taken; on a response rate of 70% most students expressed positive ideas and they gave positive constructive comments.

A high school usage experience in chemistry classes were reported by Lewis *et al.* (2012). Students used an app "Lewis Dots." in their chemistry classes with iPads. Specifically, students were asked to form the Lewis structures of the pre-determined molecules after learning how to use the application. Then they saved their work as images into the iPads. Those images were checked as data source. The results showed that, after the implementation 83% of students understood the concept, compared to %73 of students before the app usage. Again with iPads fifth grade students designed, developed and published their iBooks in science lessons. In this research (Encheff, 2013) students' work in the iBook compared to their previous written work revealed an improvement in expository writing in multiple ways: better organization and connection of ideas, increased use of academic vocabulary, and an increased use of clarifying details and analogies. It was reported that students also gained a deeper understanding of science concepts as reported through their comments after the project was finished. As seen from the research done with Tablet computers, different tools for note taking and annotating, screen casting, concept mapping were used to enhance learning. Other than those characteristics of the apps, researchers investigated science-related apps, like *Lewis Dots* and *OrganicPad*.

Using science applications in the lessons, researchers found out that students' feedback were positive (Derting and Cox, 2008; Cooper *et al.*, 2009; O'Malley, 2010) on the usage of tablet applications, also they reported (Lewis *et al.*, 2012; Encheff, 2013) that students' conceptual understanding got improved. In the present study, the implementations were all done on iPad. That is, students worked on GasLawsHD and iGasLaw applications on their iPads and also completed the accompanying worksheets again on their iPads. There was no control group created to investigate the effect of the iPad usage, but students' feedback were taken via journal reflections about the two applications' positive and negative aspects.

3. SIGNIFICANCE OF THE STUDY

When teaching chemistry with understanding at three levels, macroscopic, microscopic and symbolic, a variety of approaches were adapted. Conceptual change model (Krajcik, 1991), introducing laboratory activities in classroom setting (Johnstone & Letton, 1990), modeling with concrete materials (Copolo & Hounshell, 1995), and technological tools (Kozma *et al.*, 1996) are all used to promote conceptual understanding in chemistry. Among all, technology opens the door by offering dynamic and three-dimensional environment (Wu *et al.*, 2001). The multimedia tools allow students to visualize molecules, atoms both in macroscopic and submicroscopic levels at the same time.

There has been a great deal of effort in using multimedia applications in the schools for years. Starting with the computers, computer animations, simulations, web-sources and web-applications: there have been many studies about the effects of these tools on understanding and learning. Recently, the tablets have entered the classroom scene. As mentioned earlier, there were many studies (Ifenthaler and Schweinbenz, 2013; Henderson and Yeow, 2012; Peluso, 2012; Murray and Olcese, 2011; Manuguerra and Petocz, 2011; Galligan *et al.*, 2010; Melhuish and Falloon, 2010; Rogers and Cox, 2008; Yarnall *et al.*, 2006) about tablet computers; however, just a few (Silverberg, 2013; Lewis *et al.*, 2012; O'Malley, 2010; Cooper *et al.*, 2009; Derting and Cox, 2008) focuses on conceptual understanding of science topics. In the present study, students' conceptual understanding in the subject of gas laws were investigated where all the implementation process were carried out using iPads. Students worked with iPad applications on gas laws and completed worksheets about those applications again by using an application allowing annotation.

The three levels of representations, namely macroscopic, submicroscopic and symbolic level representations had already given importance in teaching chemistry. This study investigates whether or not the order of those representations has an effect on conceptual understanding of students. In the research done by Velazquez-Marcano *et al.* (2004), the importance of combining both macroscopic and submicroscopic visualizations in the subject of effusion/diffusion in chemistry was shown, however the study was not suggested any preferred order in the presentation of representations. Contrary to that study, Williamson *et al.* (2012) suggested that it was much better for students to see a macroscopic representation before a submicroscopic level one in the same subject matter. Therefore, it was valuable to research whether or not the order created a difference on students' conceptual understanding of gas laws. The results of this study would give some suggestions to chemistry teachers and instructional designers not only about the order of representations but also the usage of iPad applications.

3.1. Aim of the study

Learning chemistry requires understanding representations in three levels: macroscopic, submicroscopic and symbolic levels. In the present study, we focus on the gas laws, investigating whether or not the order of macroscopic and submicroscopic representations make a difference on students' conceptual understanding. This research emphasizes the order of submicroscopic and macroscopic level representations affecting the students' understanding of the gas laws. The subject of gas laws was selected since generally this subject was covered using ideal gas law equation quantitatively or doing macroscopic level experiments. Also, the existence of both macroscopic and submicroscopic level iPad applications was another reason for selecting this topic.

Both macroscopic and submicroscopic animations were used in this study. Each of these types targets a different level of conceptual understanding. While macroscopic level iPad animations give students a view of the observable behaviors of gases; submicroscopic iPad animations provide students with an understanding of the invisible submicroscopic world.

Although studies have shown that computer modules providing three levels of representations (macroscopic, submicroscopic and symbolic) simultaneously were effective in helping students understand the particulate models (Ardaç & Akaygün, 2004; Snir *et al.*, 2003), in the present study the GasLaws HD iPad application includes only macroscopic level, iGasLaw iPad application includes submicroscopic level representations. Thus, each application selected shows only one level of representation.

This is done on purpose since the aim of the study includes whether or not the order of the representations has an effect on understanding gas laws.

Both types of representations are used in this study to investigate the following research questions:

Research Question 1: Is there any significant difference in students' conceptual understanding of gas laws when students work macroscopic and submicroscopic level iPad applications in reverse orders?

Research Question 1a: Is there any significant difference between MaMi and MiMa groups' GCT-Posttest scores of the questions including *only macroscopic level* representations?

Research Question 1b: Is there any significant difference between MaMi and MiMa groups' GCT-Posttest scores of the questions including *only submicroscopic level* representations?

Research Question 1c: Is there any significant difference between MaMi and MiMa groups' GCT-Posttest scores of the questions including *both macroscopic and submicroscopic level* representations?

Research Question 2: Is there any significant effect of working with iPad applications including both macroscopic and submicroscopic level representations on promoting 9^{th} grade students' conceptual understanding of gas laws?

Research Question 2a: Is there a significant difference between each group's GCT-Pre and GCT-Posttest scores for questions at either level of representations (macroscopic or submicroscopic)?

Research Question 2b: Is there a significant difference between each group's GCT-Pre and GCT-Posttest scores for questions at both levels of representations?

Research Question 2c: Is there any significant difference between MaMi and MiMa students' total scores in worksheets regarding conceptual understanding of Boyle's Law and Charles' Law?

Research Question 3: What kinds of conceptual understandings held by MaMi and MiMa students about gas laws were revealed during the interviews after working with iPad applications?

Research Question 4: What factors do students perceive as the dominant features and contributors of the iPad applications used in this research?

3.2. Statement of the Research Hypotheses

In this study it is hypothesized that:

Hypothesis 1: Students working with the macroscopic level activity first, will perform significantly better in the GCT-Posttest about gas laws compared to the ones who first work with the submicroscopic level activities.

Hypothesis 2: Working with iPad applications including both macroscopic and submicroscopic level representations makes a significant effect on improving 9^{th} grade students' conceptual understanding of gas laws.

4. METHODOLOGY

This research was designed as mixed methods design where both quantitative and qualitative methods are used to collect and analyze data (Creswell, 2012). This type of design was selected because both qualitative and quantitative data would provide a better understanding of the research problems.

This study was performed using crossover research design (Quinn & Keough; 2002) in which two groups of students received the same two treatments (macroscopic and submicroscopic level activities), and the difference between the groups was the order in which they received each treatment. There were two instructional materials, namely Boyle's Law and Charles' Law, each including two treatments that are mentioned above, macroscopic and submicroscopic level.

This section gives information about the design, sampling, procedure and instruments used to collect the data - from pre- & post-tests, classwork, interviews and journal reflections.

4.1. Sample

The subjects of the study were 44 ninth grade students, average age of 15, enrolled in a private high school, located in Sarıyer, İstanbul. The students have 2 class-hours (2 times 40 minutes) of chemistry lessons per week. Most of the students have good academic record in chemistry course in the first semester of 2013-14. About 59% of the students had Grade Point Average of 70 or above; and only %11 of the students failed in the chemistry course, as given in Table 4.1. Each class was divided into two groups according to the research design; each group included similar number of female and male students as illustrated in Table 4.2.

Convenient sampling was used for the sampling procedure for the study because there were only three ninth grade classes in the school. The subject of interest in this research, Gas Laws, was a topic included in the ninth grade chemistry curriculum. Also, the researcher was the only chemistry teacher of this grade level. The assignment of the different groups in each class was done randomly.

Table 4.1. First semester chemistry grade percent of the participants.

Grade	A & A^+ (85-100)	B & B+ (70-84)	C & C+ (60-69)	D (50-59)	F (0-49)
% Students	12.96	46.30	16.67	12.96	11.1

As Table 4.2 shows, number of students in each treatment group was equal. In the first group called MaMi, the students worked on macroscopic level activity first and then continued with the submicroscopic level activity. The second group called MiMa, the students first worked on submicroscopic level activity and then continued with the macroscopic level activity. In total, all students experienced the same activities. This process was shown in Table 4.3 in detail.

Table 4.2. Demographic characteristics of the sample.

Treatment Group	**Sample Size**	**Gender**	**Frequency**	**Percent**
MaMi	22	Female	12	27.3
		Male	10	22.7
MiMa	22	Female	10	22.7
		Male	12	27.3

4.2. Research Design and Procedure

In this study, there were two different groups having different paths as shown in Table 4.3. In the research process students followed those paths. In each class of ninth graders, students were divided randomly into two groups as MaMi and MiMa. These groups followed two different paths to compare the effect of the sequence of treatments, in other words the activities including macroscopic and submicroscopic level representations. Specifically, MaMi group started the activities first working at the macroscopic level, then at the submicroscopic level; and MiMa group did the reverse; first working with submicroscopic, then doing macroscopic level activities.

Students had not learned specific gas laws (e.g. Boyle's Law, Charles' Law, etc.) or gas particles' behaviors before the study. At the beginning of the study, students took the pretest, Gas Concept Test (GCT) which had two parts: the first part included 3 open-ended questions on understanding of gas behaviors and relationship among gas properties such as pressure, volume, temperature, and amount. The second part included 13 multiple-choice questions, including submicroscopic level representations as well as macroscopic level conceptual understanding questions. Students in each class were randomly divided into two treatment groups, MaMi and MiMa. At the end of the process, students took the post-test, GCT. The design is represented briefly as in Figure 4.1.

MaMi: O1 $X_{1,2} - Y_{1,2}$ O2 MiMa: O1 $X_{2,1} - Y_{2,1}$ O2	O1: pre-test (GCT) O2: post-test (GCT) X: Boyle's Law Class Y: Charles' Law Class 1,2: first macroscopic, then submicroscopic 2,1: first submicroscopic, then macroscopic

Figure 4.1. Brief representation of the research process.

In Figure 4.1, O1 refers to GCT; $X_{1,2}$ refers to iPad activity of Boyle's Law for MaMi group (studying first macroscopic, then submicroscopic) and $X_{2,1}$ refers the reverse: iPad activity of Boyle's Law for MiMa group (studying first submicroscopic, then macroscopic). $Y_{1,2}$ refers to iPad activity of Charles' Law for MaMi group (studying first macroscopic, then submicroscopic) and $Y_{2,1}$ refers to the reverse: iPad activity of Charles' Law for MiMa group (studying first submicroscopic, then macroscopic). Lastly, O2 refers to the post-test, GCT.

Each activity had its own worksheet. Students filled out the worksheets on their iPads, in accordance with their own path. For instance, in MaMi group, while working on the macroscopic activity of Boyle's Law, students completed a different worksheet then the one they completed during the submicroscopic activity. However, those two worksheets were prepared compatible to each other for the purpose of comparing their answers. The same situation was also valid for the iPad activities of Charles' Law.

The groups first completed the activities for Boyle's Law and then they completed the ones for Charles' Law. After students completed the first activity, they sent their reports to the teacher's chemistry folder via an application called *My WebDav* on iPad. Students had been using this application from the beginning of the academic year to share all the materials in each lesson. Once they uploaded their work to the portal via My WebDav, they did not have a chance to change it. Similarly, after the second part of the treatment – Charles' Law iPad activities, students sent their worksheets again to the same portal via My WebDav application.

Two iPad applications were used for both Boyle's and Charles' Law activities. For the macroscopic level in Boyle and Charles' Law classes, GasLaws HD Lite application (https://itunes.apple.com/us/app/gas-laws-hd-lite/id397601784?mt=8) was used; and for the submicroscopic level activities, iGasLaw application (https://itunes.apple.com/kn/app/igaslaw/id583538810?mt=8) was run. Both applications were in English and for free; both were on the AppStore under the heading of Education. GasLaws HD Lite was released in 2010; iGasLaw was in 2012. The screenshot in Figure 4.2 represents the entrance pages of the applications.

Figure 4.2. The screen pages of iGasLaw and GasLaws HD applications.

GasLawsHD application was used in the macroscopic level activities. It has two parts: Boyle's Law and Charles' Law. In both parts instructions were given on how to use the application. In the GasLawsHD application's Boyle's Law part, there is a syringe containing gas at constant temperature. Its plunger can be dragged back and forth to increase or decrease the volume of the gas. The digital meter on the right upper corner of the screen gives pressure values corresponding to the volume of the syringe (Figure 4.3).

Figure 4.3. An image from the macroscopic level GasLawsHD application for Boyle's Law.

In the Charles' Law part, there is a gas sample in a closed container at constant pressure. Students by using red and blue buttons below the display could set the target temperature. Then they observe the change in the volume of the container. Thus, students could get the volume values of the container corresponding to specific temperature values (Figure 4.4).

Figure 4.4. An image from the macroscopic level GasLawsHD application for Charles' Law.

iGasLaw application was used in the submicroscopic level activities. Different than GasLawsHD, in iGasLaw application students were able to see the submicroscopic level representation of gas particles. iGasLaw application had an option to control variables: volume, temperature and pressure. In Boyle's Law activity, students were asked to control temperature, so that it would not change while students took their values for volume and pressure. In this application, students were able to change the volume, and observe the pressure value of a selected volume, as seen in Figure 4.5.

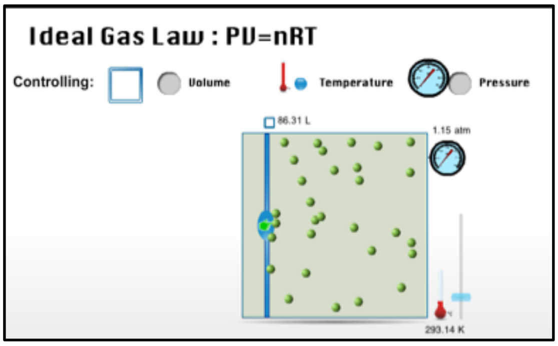


Figure 4.5. An image from the submicroscopic level iGasLaw application for Boyle's Law.

For the submicroscopic part of the Charles' Law, students first control the pressure just after opening the iGasLaw application. Then, they would be able to see the volume difference of the container and also the difference in the motion of the particles when the temperature was decreased or increased (Figure 4.6).

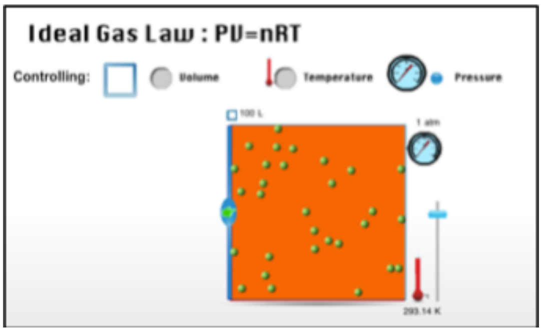


Figure 4.6. An image from the submicroscopic level iGasLaw application for Charles' Law.

GasLawsHD application provided a good macroscopic level activity since what students did include no submicroscopic level representation. Also, iGasLaw application presented the motion of the gas particles in a container in different situations. Containing only one of the macroscopic and submicroscopic level representations was the first reason of selecting these two applications. Other than that, both were for free and easy to use. Also, both could give numerical data for the variables, for example students could read the volume of the container in GasLawsHD application while changing the temperature of the system. Therefore, students could get data from the applications and understand the relationship between the variables.

Table 4.3. Design of the research.

<table>
<tr><th></th><th>MaMi (N=22)</th><th>MiMa (N=22)</th></tr>
<tr><td>Pre-test</td><td colspan="2">GCT</td></tr>
<tr><td rowspan="8">Treatment 1:
iPad Activity for
Boyle's Law
(Two class hours:
80 minutes)</td><td>MACROSCOPIC</td><td>SUBMICROSCOPIC</td></tr>
<tr><td>GasLawsHD</td><td>iGasLaw</td></tr>
<tr><td>Worksheet-1a</td><td>Worksheet-1b</td></tr>
<tr><td colspan="2">Interviews</td></tr>
<tr><td>SUBMICROSCOPIC</td><td>MACROSCOPIC</td></tr>
<tr><td>iGasLaw</td><td>GasLawsHD</td></tr>
<tr><td>Worksheet-1b</td><td>Worksheet-1a</td></tr>
<tr><td colspan="2">Interviews</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="8">Treatment 2:
iPad Activity for
Charles' Law
(Two class hours:
80 minutes)</td><td>MACROSCOPIC</td><td>SUBMICROSCOPIC</td></tr>
<tr><td>GasLawsHD</td><td>iGasLaw</td></tr>
<tr><td>Worksheet-2a</td><td>Worksheet-2b</td></tr>
<tr><td colspan="2">Interviews</td></tr>
<tr><td>SUBMICROSCOPIC</td><td>MACROSCOPIC</td></tr>
<tr><td>iGasLaw</td><td>GasLawsHD</td></tr>
<tr><td>Worksheet-2b</td><td>Worksheet-2a</td></tr>
<tr><td colspan="2">Interviews</td></tr>
<tr><td>Post-test</td><td colspan="2">GCT</td></tr>
</table>

Two independent groups, MaMi and MiMa completed the very same activities in total; however they followed different paths. Namely, crossover research design (Quinn & Keough; 2002), which is a type of experimental design in which groups receive the same treatments in different orders, was used in the study. Table 4.3 gives the detailed flow of the research design.

Procedure: All participants first involved in the treatment 1: iPad activity for Boyle's Law (Table 4.3). Students were told that they would work with an iPad application about Boyle's Law, and by doing that they learned the idea behind the law. Then, the students were divided into two groups with the criterion that, two students from the same group could not sit next to each other. First group of students were asked to download the GasLawsHD application, and the others were to download iGasLaw application before starting the activities. They first examined the usage of the application. Afterwards, each group were asked to download the corresponding worksheet from the official website of the school. Students tried to complete their worksheets by using only the iPad applications. They worked individually. They collected data by using iPad applications and answer the questions. The teacher was roaming in the classroom, observing the students. If students had problems understanding the application or a question from the worksheet, they could ask only to the teacher. The teacher guided them and directed them by posing questions to make them think about the concept that they had problems. Students were given a maximum of 25 minutes to complete the worksheets and send them to the teacher. In this process, if there would be an early finisher, teacher asked him/her to go to the interviewer's desk to explain his/her answers in the worksheet.

After 5 minutes of break time, they continued to work on the Boyle's Law again. However, the students who worked with GasLawsHD application in the first lesson, started working with iGasLaw in this second lesson, and vice versa. All the procedure was same with the first lesson. Since students got familiar with the process, they did not spend much time investigating the application and understanding the questions in the worksheet. Again interviews took place at the end of the lesson. Also, the last minutes were spent talking about the relation between the variables, namely volume and pressure. Students were asked to explain the relation; talk about what was happening when volume increases or decreases.

In treatment 2, Charles' Law iPad activities were done (Table 4.3). The implementation process was same with the Boyle's Law classes. However, here the student groups were taken to be the same. That is, a student worked first with GasLaws HD application in Boyle's Law classes, again started working with the same application in the Charles' law classes as well. This was the essence of the research process.

4.3. Instruments

The data for this investigation was collected through May – June 2014 and originated in five forms: (i) GCT, (ii) worksheets to be filled out while doing macroscopic or submicroscopic level iPad activities, (iii) GCT to conduct after all gas law activities end, (iv) one-to-one interviews that conducted with some students to clarify their statements in their worksheets, (v) and also journal reflections where students noted what they had known before and what they learned after each activity.

The items in all the instruments used in this study did not require a mathematical operation. Instead, they required conceptual understanding of gas properties and behaviors in terms of gas laws, as well as the ability to apply this knowledge in different situations. Example could be that gas particles spread all over the container homogeneously that they are in; thus when a balloon was inflated the gas particles move randomly around and fill the inside of the balloon homogeneously. Students were expected to make such inferences in the questions (see APPENDIX A).

4.3.1. Gas Concept Test (GCT)

GCT was originally developed by Azizoğlu (2004), with 40 questions, five-alternative multiple-choice items. For the present study, quantitative questions were excluded since ideal gas law equation was not in the scope of the aim of this study. Besides, some parts of the test were revised. The revisions were about redrawing some submicroscopic level representations and rewriting some sentences in order to make the situations, given in the questions clear for the students.

2) Kauçuk bir balon Haziran ayı öğle saatlerinde Hidrojen gazı ile doldurulduktan ve balonun hava kaçırmadığı kontrol edildikten sonra ağzı sıkıca bağlanarak bir odaya konur. Ancak, balon aynı gece kontrol edildiğinde sönmüş olduğu görülür. Aşağıdakilerden hangisi bu durumu en iyi açıklamaktadır?

A) Zamanla moleküllerin enerjisi tükenir ve hareketleri durur.

B) Balon deliktir.

C) Hava soğumuştur ve moleküller bir araya kümelenmiştir.

D) Moleküller çarpışa çarpışa küçülmüşlerdir.

E) Hava basıncı artmış ve balonu küçültmüştür.

Figure 4.7. A sample multiple-choice question from Gas Concept Test (GCT).

2) Sabit sıcaklıkta, V_1 boyutundaki balonu alıp bir uçağa bindiğinizi ve yaklaşık 6000 metre yükseldiğinizi düşünün, çiziminizi tekrarlayınız. Balonun yeni hacmi V_3 olsun. V_1 ve V_3 ü kıyaslayınız. (Not: yukarılara çıkıldıkça hava basıncı azalır)

Hacim	Çizim	Kıyaslama
V_3 →	Balon Balonun içi	V_1 ...... V_3 (">" ya da "<" işareti kullanarak kıyaslamanızı yapınız)

Figure 4.8. A sample open-ended question from Gas Concept Test (GCT).

Other than revisions, three open-ended questions were also added into the test. Those 3 open-ended questions were given before the multiple-choice part of the GCT. These open-ended questions were aimed to measure students' understanding on the relations among (i) pressure and volume, (ii) temperature and volume. In this part, students were asked to draw both macroscopic and submicroscopic level representations of the given situations about gases. Also, these three open-ended questions were intentionally given before multiple-choice questions. Since multiple-choice questions included submicroscopic level representations, students should not see those before they drew their own understanding of gases in the open-ended questions. Seeing the representations in the multiple-choice part of GCT may influence their own representations that they were asked to draw in the open-ended part. A question from multiple-choice part of GCT was given below as a sample in Figure 4.7 and an open-ended question example was given in Figure 4.8 GCT was given in Appendix A.

Scoring: In total GCT included 3 open-ended and 13 multiple-choice questions. Each multiple-choice question scored as correct or incorrect. A student selecting the correct alternative in multiple-choice test got 1 point, otherwise 0 point. Thus, maximum score one could get from multiple-choice part was 13.

On the other hand, open-ended questions were analyzed according to the criteria given in Table 4.4. Question 1a was asking to draw particles, and this drawing had 1 point. Question 1b was asking to draw the balloon itself and the particles in a unit volume if the balloon was inflated at constant temperature. In this question the criteria were drawing the macroscopic shape of the balloon, drawing the particles in a unit volume, drawing the particles in equal sizes with the ones in question 1a, drawing more particles compared to the ones in 1a and last making comparison about the sizes of the balloons in 1a and 1b in symbolic level. In total, the maximum score one could get from the first open-ended question was 6 points.

Question 2 was asking to draw the balloon itself and the particles in a unit volume if the balloon was put in a place with low air pressure at constant temperature. In this question the criteria were drawing the macroscopic shape of the balloon, drawing the particles in a unit volume, drawing the particles in equal sizes with the ones in question 1a, drawing same number of particles with to the ones in 1a and last making comparison about the sizes of the balloons in 1a and 2 in symbolic level. In total, the maximum score one could get from the second open-ended question was 5 points.

Question 3 was asking to draw the balloon itself and the particles in a unit volume if the balloon was put in a place having higher temperature compared to the situation 1a. In this question the criteria were drawing the macroscopic shape of the balloon, drawing the particles in a unit volume, drawing the particles in equal sizes with the ones in question 1a, drawing same number of particles with to the ones in 1a and last making comparison about the sizes of the balloons in 1a and 3 in symbolic level. In total, the maximum score one could get from the second open-ended question was 5 points.

Table 4.4. The criteria of scoring the open-ended part of GCT.

Question	**Criteria**		**Points**
1a	Drawing the particles in a unit volume of a balloon.	1	1
The balloon in 1a was inflated at constant temperature.			
1b	Drawing the macroscopic shape of the balloon.	1	5
	Drawing the particles in a unit volume.	1	
	The size of the particles was equal with the drawing in 1a.	1	
	The number of particles was correct according to the ones in 1a.	1	
	The symbolic level comparison of the sizes of the balloons in 1a and 1b.	1	
The balloon in 1a was put in a place with low air pressure at constant temperature.			
2	Drawing the macroscopic shape of the balloon.	1	5
	Drawing the particles in a unit volume.	1	
	The size of the particles was equal with the drawing in 1a.	1	
	The number of particles was correct according to the ones in 1a.	1	
	The symbolic level comparison of the sizes of the balloons in 1a and 2.	1	
The balloon in 1a was put in a place having higher temperature.			
3	Drawing the macroscopic shape of the balloon.	1	5
	Drawing the particles in a unit volume.	1	
	The size of the particles was equal with the drawing in 1a.	1	
	The number of particles was correct according to the ones in 1a.	1	
	The symbolic level comparison of the sizes of the balloons in 1a and 3.	1	

The open-ended questions included 16 items to be scored in total. Combined with the 13 questions in multiple-choice part; a student could get a maximum of 29 points from GCT.

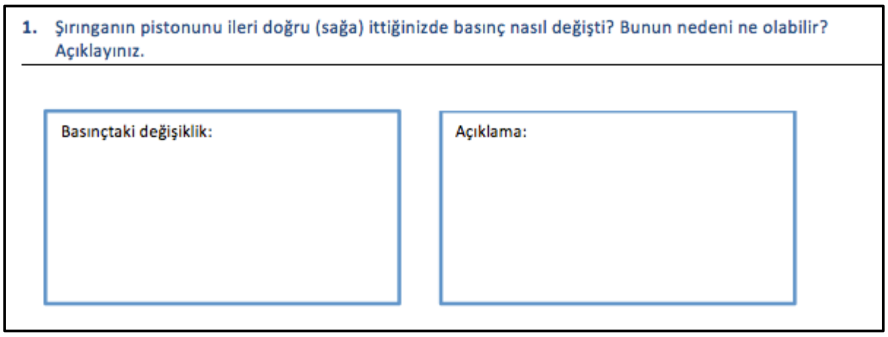
Reliability: GCT included 3 open-ended and 13 multiple-choice questions of were found to be reliable (Cronbach's Alpha=.777). The reliability of the GCT was tested in a private high school in Istanbul. This school was located in the same district with the research school and its student profile, like socio-economic status was similar with the participants of this research. 31 ninth grade students' answers were analyzed. There were 32 items in the beginning both from open-ended and multiple choice questions, with .683 Cronbach's Alpha value. Then 3 multiple-choice questions were removed from GCT to increase reliability.

Inter Rater Reliability: The consistency of the test scoring (Gay and Airasian, 1996) gave the inter-rater reliability. Because the multiple-choice section of the GCT had a single correct answer only the open-ended questions were assessed by the two scorers. 8 students' GCT open-ended questions (18% of students) were analyzed also by a PhD student, studying in the same content area. And then the researcher and PhD student met and compared the scores and reached a consensus. Since the scoring of the open-ended questions was also made together with that PhD student, a full consensus was reached in the analysis.

Validity: The validity of GCT was established qualitatively. The content validity of the questions was achieved by taking expert opinion. The experts were a university professor from the department of Science and Mathematics Education in the field of teaching Chemistry and a Chemistry teacher. They assessed the appropriateness of the questions for the instructional objectives at the 9^{th} grade. Also the test was checked with respect to its grammatical aspects and understandability, and it was used as an evidence for face validity.

4.3.2. Worksheets

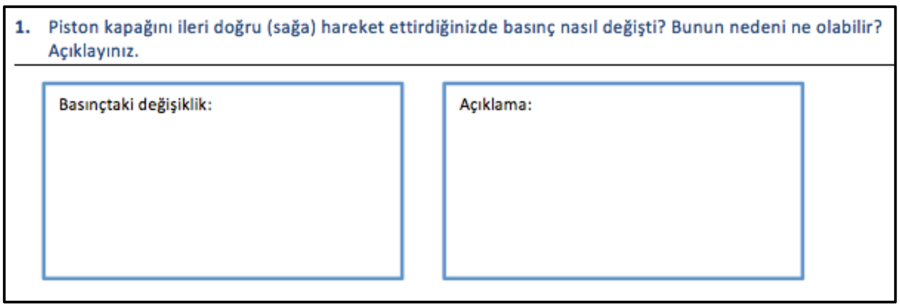
There were a total of four activities and so four worksheets throughout the study: two of them were used in Boyle's Law activities (macroscopic and submicroscopic) and two were used in Charles' Law activities (macroscopic and submicroscopic). For each activity, the participants were provided worksheets (See Appendix B, C, D and E) so that students were able to record their data, observations and explanations, drawings of phenomena at submicroscopic level, in written form for activities done in their iPads. For the two Boyle's Law activities, students were asked compatible questions, as shown in Figure 4.9 and Figure 4.10. Types of the questions were same; for example, the first questions in the two Boyle's Law worksheets asked students to explain what happened when the volume of the container was changed. The same is also valid for Charles' Law worksheets, as shown in Figure 4.11 and Figure 4.12. Each participant sent the completed worksheet just after it was finished and those sheets were used as an important data source for the research.


1. Şırınganın pistonunu ileri doğru (sağa) ittiğinizde basınç nasıl değişti? Bunun nedeni ne olabilir? Açıklayınız.

Basınçtaki değişiklik:

Açıklama:

Figure 4.9. A sample question from Boyle's Law macroscopic level worksheet answered with the GasLaws HD application on iPad.


1. Piston kapağını ileri doğru (sağa) hareket ettirdiğinizde basınç nasıl değişti? Bunun nedeni ne olabilir? Açıklayınız.

Basınçtaki değişiklik:

Açıklama:

Figure 4.10. A sample question from Boyle's Law submicroscopic level worksheet answered with the iGasLaw application on iPad.

In the first week of the implementation, two different activities of Boyle's Law were done on iPad and the students filled out related worksheets on iPad, not on paper. In the macroscopic level activity students used GasLaws HD application, in the submicroscopic level they used iGasLaw application and answered the questions on the related worksheets.

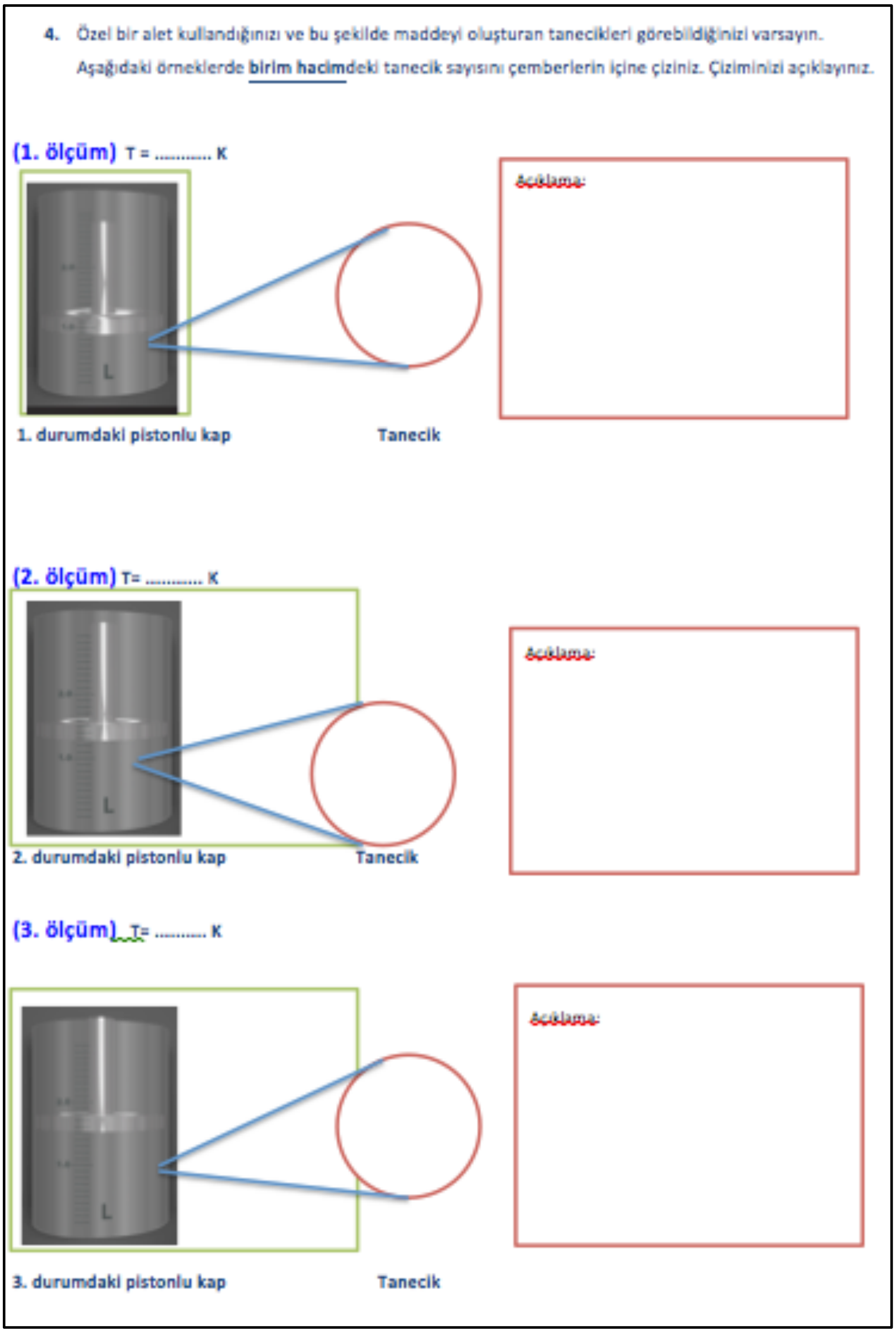


Figure 4.11. A sample question from Charles' Law macroscopic level worksheet answered with the GasLawsHD application on iPad.

In the second part of the research, Charles' Law macroscopic and submicroscopic level activities were performed. The worksheets were again prepared compatible to each other; example questions were shown in Figures 4.7a and 4.7b. For the Charles' Law, the second parts of the iPad applications (GasLawsHD and iGasLaw) were used.

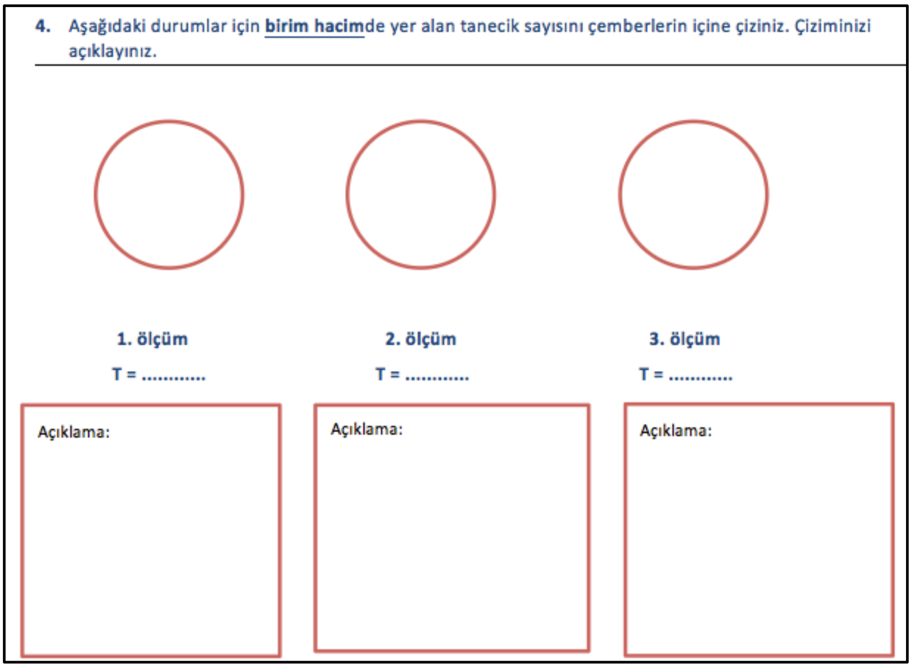


Figure 4.12. A sample question from Charles' Law submicroscopic level worksheet answered with the iGasLaw application on iPad.

The worksheets were prepared compatible to each other: even though the MaMi and MiMa groups were working with different iPad applications, they were asked the same type of questions. Figure 4.9, 4.10, 4.11 and 4.12 showed two questions for each activity. However, in the submicroscopic level iPad activities, in which students saw the particular level representation of gas particles' behavior, in addition to the questions based on the application, a macroscopic question including also drawing submicroscopic level representation was added to check whether or not students could go beyond what they saw (Figure 4.13 and 4.14). This strategy was used to see whether or not students could see the whole picture in that specific activity. Johnstone, (1991) stated that one reason why students find chemistry difficult was that students make observations at the macroscopic level in the laboratory, but instructors expect them to interpret their findings at the microscopic level. In the present study, students were asked four questions based on the application, including explanations about the relations among variables, graphing this relation and drawing the gas particles in submicroscopic level. By asking an extra macroscopic level question, students were tested whether or not they would cope with the difficulty of transforming their observations in submicroscopic level into macroscopic world.

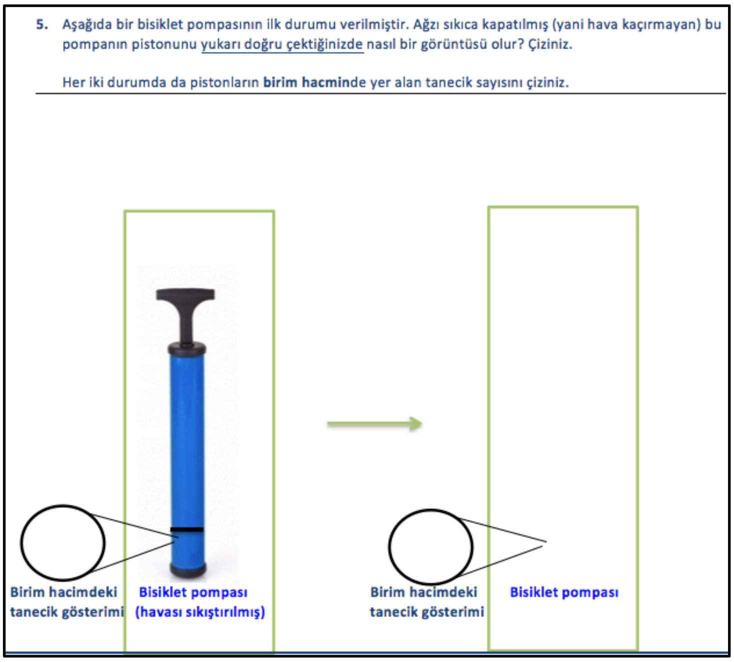


Figure 4.13. The extra question asking to draw both the new form of the pomp and the particles from Boyle's Law submicroscopic level worksheet answered with the iGasLaw application on iPad.

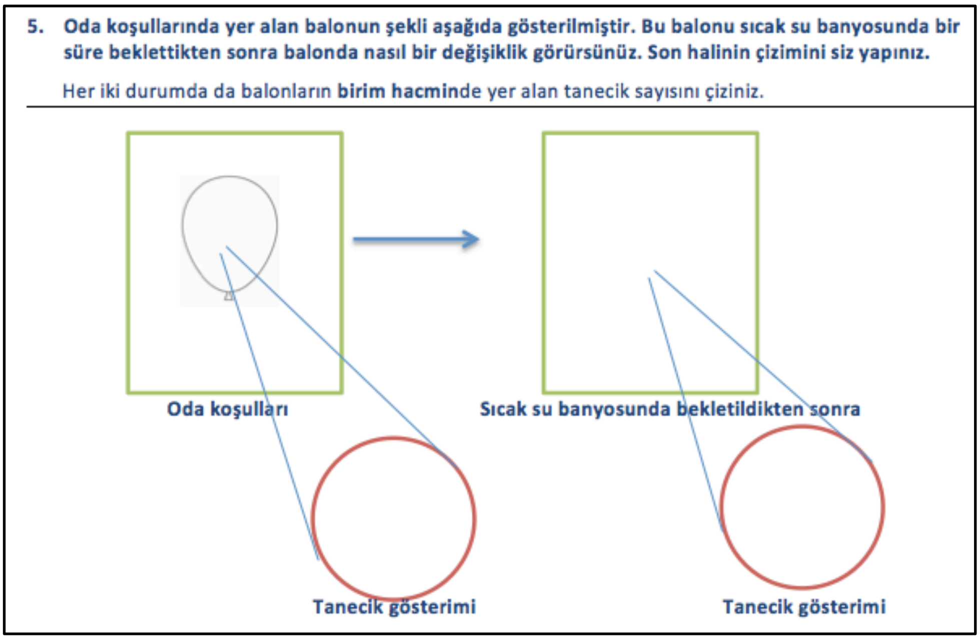


Figure 4.14. The extra question asking to draw both the new form of the balloon and the particles from Charles' Law submicroscopic level worksheet answered with the iGasLaw application on iPad.

Inter Rater Reliability: The data of student worksheets was also scored by a PhD student, studying in the same subject area. The researcher and PhD student met and compared the scores. Then they tried to come to agreement. 12 student worksheets were analyzed: 6 for Boyle's Law and 6 for Charles' Law. For the Boyle's Law worksheets the agreement was at 80.95% and for the Charles', it was 86.9%. When the different scores were evaluated and consensus was reached the agreement increased to 96.43% for Boyle's Law and 95.23% for Charles' Law worksheets. The Spearman rho coefficients between the two scorers; in other words inter-rater reliability was found to be .899.

4.3.3. Interviews and Journal Reflections

Interviews: Interviews were audio-visual sources in this study. Semi-structured interviews were conducted with some students in each classroom in order to collect more insightful and extensive data about participants' way of thinking (Patton, 2002). Selection of the interviewee had no special criteria (a student who finished his/her worksheet earlier, were asked to go to the interviewer's desk to answer some extra questions). In total 34 interviews were conducted; 22 of those were with MaMi group and 12 with MiMa. The difference between the numbers of interviews had no special reason; the only criterion to conduct an interview with a student was that s/he had finished the worksheet. The interviews were done at the end of each activity session (Table 4.3). The content and the focus of interview questions were given in Table 4.5. There were two interviewers; they were master students from the Department of Science and Mathematics Education with a degree in Teaching Chemistry. The interviews were conducted individually and took approximately 5-6 minutes. The interviews were video-recorded.

All the interviews were video-recorded and transcribed entirely. The researcher did all the transcription; read the transcripts, watched and listened to the interview records individually. The transcripts were analyzed in accordance with the questions in Table 4.5.

The interview protocol is summarized in Table 4.5, presenting the description of the context of the questions in the worksheets and the corresponding interview questions.

Table 4.5. The content and the focus of the interview questions.

Questions	Description of the Context of the Question	Interview Question
1 & 2	Conceptual question about the relation between volume & pressure (Boyle's Law), or between temperature & volume (Charles' Law) both in macroscopic and submicroscopic level worksheets.	• Could you explain the relation between volume and pressure / temperature and volume? (Both for macroscopic and submicroscopic level activities)
3	Graphical representations of the two variables (volume vs pressure / temperature vs volume).	• Why did you draw the graph like this?
4	Drawing the gas particles in a unit volume for three different situations according to the corresponding law.	• What does unit volume mean? • If the particles were drawn homogeneous/heterogeneous: Why did you draw the particles homogeneously/heterogeneously? • About the number of particles in each unit volume for three different situations: Why did the number of particles increase/decrease/equal in each situation? • Were those particles moving? If yes: Do you think you could show their motion? How?
5 (only in submicroscopic level worksheets)	Transformation type of question: since in the app, only submicroscopic level was given. This question asked to draw the situation in macroscopic level. Also, the particles in unit volume again.	About macroscopic level drawing: • Why did you make the object smaller/bigger? About the submicroscopic level particle drawing: • If the particles were drawn homogeneous/heterogeneous: Why did you draw the particles homogeneously/heterogeneously? • About the number of particles in each unit volume for three different situations: Why did the number of particles increase/decrease/equal in each situation? • Were those particles moving? If yes: Do you think you could show their motion? How?
Extra questions	About using the iPad application.	• Were you able to answer those questions if you did not work with that app? • Were there any difficulties while using the app? • Was the app helpful while answering the questions? • Have you ever seen such models or representations of gas molecules before?

At the end of each activity, students were assigned to write journals about the activities they had performed. The purpose was to identify the issues that they did not understand or they were confused about or they learned.

Journals: Students were asked to write which iPad application was more helpful while answering the worksheets. Writing these journals were not compulsory; only some bonus points were given to the ones who wrote. That was why the rate of completion of those journals was pretty low, 25 out of 44 students (56.8%) sent their reflections to the researcher.

4.4. Data Analysis

In this section, the analysis of GCT, worksheets, student interviews and journal reflections are discussed.

4.4.1. Quantitative Analysis

In response to the research questions, a number of analyses were performed using the quantitative information from GCT and worksheets.

In the analyses, both parametric and non-parametric statistics were used where appropriate. Independent samples t-test and Mann-Whitney U were used to compare the groups MaMi and MiMa. Related samples t-test and Wilcoxon-signed ranks test were used to compare the groups MaMi and MiMa in themselves.

There are some assumptions to use parametric tests. First, the dependent variable should be measured on a continuous scale (interval or ratio); second, the independent variable should consist of two categorical, independent groups; and third, the dependent variable should be approximately normally distributed for each group of independent variable. In order to check the normality, Shapiro-Wilk Test was used since it is more appropriate to use this test other than Kolmogorov-Smirnov for small sample sizes and Shapiro-Wilk test was found to be the most powerful normality test (Razali and Wah, 2011). In the present study, when the normality was not obtained, non-parametric tests were used to analyze the data.

4.4.2. Qualitative Analysis

The interviews were video-recorded, instead of audio recorded. This was done to record both the students' drawings on the worksheets and their related oral explanations. All the interview recordings were transcribed. The transcripts were read, watched and listened before starting the qualitative data analysis. While listening the interviews and reading the transcripts several times, some tentative labels were created. Then themes were identified and all transcripts were analyzed again to sort student responses (Taylor-Powell & Renner, 2003).

Abraham, Grzybowski, Renner and Marek (1992) used six categories to evaluate students' understanding in an open-ended question: Sound understanding, partial understanding, partial understanding with specific misconception, specific misconception, no understanding and no response. The responses of the students on the worksheets were categorized through similar five categories:

- Good Understanding (GU); a response that indicated a correct understanding in the worksheet as a whole.
- Partial Understanding (PU); an insufficient response of the phenomenon.
- Partial Understanding with Specific Misconception (PUSM); a response, which included both some misconception and partial understanding.
- No Understanding (NU); an answer that indicated no information about the phenomenon.
- No Explanation (NE) category was used when the student gave no information about the phenomenon.

4.5. Threats to internal validity

Threats to validity were described as the uncontrolled extraneous variables that affect the performance on the dependent variable (Gay *et al.*, 2006). History was one of these threats. Creswell (2012) described history as events that occur between the pretest and posttest that influence the outcome. In this study, there were three 9^{th} grade classes involved in the two-week implementation process. The time between the two weeks were not equal for all classes. That situation might have affected the outcomes.

Maturation, as a threat to validity, might be another concern that is related to participants' development or change that might affect the scores between pre-and post-test (Creswell, 2012). However, all the research process took two weeks; therefore, maturation was not an issue at this level.

Testing, a potential threat to internal validity, referred to that the participants might become familiar with the outcome measures and remember responses for later testing (Creswell, 2012). In order to minimize the testing effect, GCT-pretest was administered one-week before the implementation began; and GCT-posttest was given one-week after. Also, a similar form of GCT was administered to participants as the post-test. Minor changes were made, such as changing the order of the questions.

When participants drop out during the experiment for any reason, which is called mortality, drawing conclusions from scores can be difficult (Creswell, 2012). In this study, two students were absent during some parts of the implementation. Thus, the scores of these students were omitted from the analyses.

5. RESULTS

5.1. Analysis of Gas Concept Test (GCT)

5.1.1. Comparison of the GCT-Posttest scores of the MaMi and MiMa groups

To determine the effect of independent variable (the order of the instruction) on the dependent variable (conceptual understanding of the gas particles' behavior), the data were gathered from 44 students, which were conveniently selected from three classes of the same school.

To test this research question, Gas Concept Test (GCT) was used in pre- and post-tests. In the pretest, the mean scores of the participants of MaMi was found to be M=13.6 (SD=4.1); and the scores of MiMa group was found to be M=14.2 (SD=3.3) as given in Table 5.2.

Table 5.1. Test of normality for GCT-Pretest scores.

	Group	Shapiro-Wilk		
		Statistic	df	Sig.
GCT-Pretest	MaMi	.914	22	.056
	MiMa	.947	22	.279

In order to decide to use whether a parametric or a non-parametric test, first normality of the distribution of the GCT-Pretest scores was checked. As given in Table 5.1, Shapiro-Wilk Test was used to check the normality of the distribution of the GCT-Pretest scores. Both MaMi and MiMa scores were found to be normally distributed ($p>.05$).

Since the scores were found to be normally distributed, in order to check whether or not MaMi and MiMa groups were initially similar, a parametric test, namely independent samples t-test was used to compare the mean GCT-Pretest scores of the groups. The results of the test analysis showed that the groups were not significantly different from each other (p=.60>.05) as shown in Table 5.2.

Table 5.2. Descriptive statistics and Independent Samples t-test results for comparing GCT-Pretest scores of MaMi and MiMa.

				t-test for Equality of Means		
Group	Mean	Std. Dev.		t	df	Sig. (2-tailed)
MaMi (N=22)	13.59	4.08	Equal variances assumed	-.529	42	.600
MiMa (N=22)	14.18	3.29	Equal variances not assumed	-.529	40.199	.600

Furthermore, students' GCT-Pre and GCT-Posttest scores were analyzed by differentiating the open-ended and multiple-choice questions in the GCT. In the GCT-Pretest open-ended questions (where the maximum score was 16) the mean scores of the group MaMi was M=9.50 (SD=2.94), and the scores of MiMa was found to be M=10.09 (SD=2.89) as given in Table 5.3. In the GCT-Pretest multiple-choice type of questions (where the maximum score was 13) the mean scores of the MaMi and MiMa was same, M=4.09; but standard deviations was SD=1.72 and SD=1.82, respectively. That is, in the both open-ended and multiple-choice type of questions in the GCT-Pretest there is no significant difference between the groups MaMi and MiMa (Table 5.3 and Table 5.4).

Table 5.3. Independent Samples t-test results for comparing GCT-Pretest open-ended questions' scores of MaMi and MiMa.

				t-test for Equality of Means		
Group	Mean	Std. Dev.		t	df	Sig. (2-tailed)
MaMi (N=22)	9.50	2.94	Equal variances assumed	-.672	42	.505
MiMa (N=22)	10.09	2.89	Equal variances not assumed	-.672	41.989	.505

Table 5.4. Independent Samples t-test results for comparing GCT-Pretest multiple-choice questions' scores of MaMi and MiMa.

				t-test for Equality of Means		
Group	Mean	Std. Dev.		t	df	Sig. (2-tailed)
MaMi (N=22)	4.09	1.72	Equal variances assumed	.000	42	1.000
MiMa (N=22)	4.09	1.82	Equal variances not assumed	.000	41.845	1.000

After ensuring that the groups were initially similar to each other, their GCT-Posttest scores were compared. As seen from Table 5.5, normality distribution was also confirmed (p>.05) for the GCT-Posttest scores for both groups, therefore, again a parametric test, independent samples t-test was used.

Table 5.5. Test of normality for GCT-Posttest scores.

	Group	Shapiro-Wilk		
		Statistic	df	Sig.
GCT-Posttest	MaMi	.952	22	.353
	MiMa	.942	22	.217

Table 5.6. Independent Samples t-test results for comparing GCT-Posttest scores of MaMi and MiMa.

				t-test for Equality of Means		
Group	Mean	Std. Dev.		t	df	Sig. (2-tailed)
MaMi (N=22)	19.86	3.33	Equal variances assumed	1.226	42	.227
MiMa (N=22)	18.54	3.79	Equal variances not assumed	1.226	41.313	.227

As shown in Table 5.6, the results of analysis showed that, MaMi and MiMa groups were not found to be significantly different (p=.227>.05) in the GCT-Posttest. Therefore, the first hypothesis saying that, MaMi students would perform better in the GCT-Posttest compared to MiMa students was rejected.

Table 5.7. Independent Samples t-test results for comparing GCT-Posttest open-ended questions' scores of MaMi and MiMa.

				t-test for Equality of Means		
Group	Mean	Std. Dev.		t	df	Sig. (2-tailed)
MaMi (N=22)	11.86	1.81	Equal variances assumed	1.435	42	.159
MiMa (N=22)	10.91	2.54	Equal variances not assumed	1.435	37.900	.159

MaMi and MiMa students' posttest scores were also analyzed according to both open-ended questions and multiple-choice ones. The mean scores of the group MaMi was found to be M= 11.86 (SD=1.81) and MiMa was found to be M=10.91 (SD=2.54) in the GCT-Posttest open-ended questions. No significant difference was found between the groups according to t-test (Table 5.7). Besides, in the GCT-Posttest multiple-choice type of questions, mean scores of MaMi and MiMa was found to be M=8.00 (SD=2.37) and M=7.64 (SD=2.50), respectively. Again in the independent samples t-test there was no significant difference found between the groups (Table 5.8).

Table 5.8. Independent Samples t-test results for comparing GCT-Posttest multiple-choice questions' scores of MaMi and MiMa.

				t-test for Equality of Means		
Group	Mean	Std. Dev.		t	df	Sig. (2-tailed)
MaMi (N=22)	8.00	2.37	Equal variances assumed	.495	42	.623
MiMa (N=22)	7.64	2.50	Equal variances not assumed	.495	41.884	.623

5.1.2. Comparison of GCT-Pre and GCT-Posttest scores of MaMi and MiMa

As indicated above (see Table 5.4), there was no significant difference between MaMi and MiMa groups in the post-test. In this section, each group's GCT-Pre and GCT-Posttests were individually compared to check whether or not there was an improvement in groups' understandings of the gas concept.

Table 5.9. GCT-Pre and GCT-Posttest results of MaMi and MiMa.

	Pretest		**Posttest**	
Group	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
MaMi (N=22)	13.59	4.08	19.86	3.33
MiMa (N=22)	14.18	3.29	18.54	3.79

Table 5.9 presents the mean scores of participants on the GCT-Pre and GCT-Posttests. The mean of the MaMi participants' scores on the pre-test was M=13.59 (SD=4.08). The mean of the post-test scores was M=19.86 (SD=3.33). The MaMi participants achieved higher scores in the GCT-Posttest compared to the pre-test. Also Table 5.10 shows that MaMi group's GCT-Pre and GCT-Posttest results were significantly ($p<.05$) different from each other. Further, Cohen's effect size value ($d=1.68>.8$) suggested a large significance.

Table 5.10. Paired samples t-test results of GCT-Pre and GCT-Posttest scores for group MaMi.

Compared tests	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Std. Error Mean
GCT-Pre and GCT-Posttest	-6.499	21	.000	-6.27273	4.52698	.96515

In addition, MaMi students' scores in the GCT-Pre and GCT-Posttest open-ended and multiple-choice questions were also analyzed individually. In the open-ended questions, MaMi students' GCT-Pre and GCT-Posttest scores were significantly ($p<.05$) differ from each other with a large effect size ($d=.97>.8$). Also, in the multiple-choice questions MaMi students achieved higher scores in the post-test compared to pre-test. Table 5.11 showed that there was a significant difference in the scores of GCT-Pre and GCT-Posttest multiple-choice questions for the group MaMi. Cohen's effect size value ($d=1.88>.8$) suggested a large significance.

Table 5.11. Paired samples t-test results of GCT-Pre and GCT-Posttest open-ended & multiple-choice questions' scores of MaMi.

Compared tests	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Std. Error Mean
GCT-Pre and GCT-Posttest Open-ended Questions	-3.328	21	.003	-2.36364	3.33160	.71030
GCT-Pre and GCT-Posttest Multiple-choice Questions	-8.092	21	.000	-3.90909	2.26588	.48309

Table 5.12. Paired samples t-test results of GCT-Pre and GCT-Posttest scores for group MiMa.

Compared tests	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Std. Error Mean
GCT-Pre and GCT-Posttest	-5.186	21	.000	-4.36364	3.94661	.84142

MiMa group's GCT-Pre and GCT-Posttest results were also given in Table 5.10. Mean score of GCT-Pretest was 14.18 (SD=3.29), and GCT-Posttest 18.54 (SD=3.79).

As MaMi participants, MiMa group also achieved higher scores in the post-test. Table 5.12 supported this increase; MiMa group's GCT-Pre and GCT-Posttest results significantly ($p<.05$) differed. Further, Cohen's effect size value ($d=1.23>.8$) suggested a large significance. Therefore, the second hypothesis indicating that, working with iPad applications including both macroscopic and submicroscopic level representations would make a significant effect on improving 9th grade students' conceptual understanding of gas laws was supported.

MiMa students' scores in the GCT-Pre and GCT-Posttest open-ended and multiple-choice questions were also analyzed individually. In the open-ended questions, students' GCT-Pre and GCT-Posttest scores were not significantly ($p>.05$) different from each other. Cohen's d value was also found to be .3, which indicated a small effect size. However, in the multiple-choice questions MiMa students achieved higher scores in the post-test compared to pre-test. Table 5.13 showed that there was a significant difference ($p<.05$) in the scores of GCT-Pre and GCT-Posttest multiple-choice questions for the group MiMa. Cohen's effect size value ($d=1.62>.8$) suggested a large significance as well.

Table 5.13. Paired samples t-test results of GCT-Pre and GCT-Posttest open-ended & multiple-choice questions' scores of MiMa.

Compared tests	t	df	Sig. (2-tailed)	Mean	Std. Deviation	Std. Error Mean
GCT-Pre and GCT-Posttest Open-ended Questions	-1.306	21	.206	-.81818	2.93803	.62639
GCT-Pre and GCT-Posttest Multiple-choice Questions	-6.152	21	.000	-3.54545	2.70321	.57633

5.1.3. Comparison of the MaMi and MiMa GCT-Posttests in terms of the questions including only macroscopic level, only submicroscopic level, both macroscopic and submicroscopic level representations

In the GCT, there were three different types of questions: questions including only macroscopic level, questions including only submicroscopic level, questions including both macroscopic and submicroscopic level representations. In this sub-section, the results of the analysis regarding whether or not MaMi and MiMa groups performed significantly different from each other in terms of these three types of questions was discussed.

Table 5.14. Normality scores for GCT-Pretest question types.

Question Types	**Group**	**Shapiro-Wilk**		
		Statistic	**df**	**Sig.**
Macroscopic	MaMi	.907	22	.041
	MiMa	.846	22	.003
Submicroscopic	MaMi	.773	22	.000
	MiMa	.877	22	.011
Macroscopic and submicroscopic	MaMi	.921	22	.081
	MiMa	.883	22	.014

Before analyzing the post-test questions, first it was investigated whether or not MaMi and MiMa were similar in terms of their answers in the different types of GCT-Pretest questions. Non-parametric tests were used since the scores, for all three types of questions, in the GCT-Pretest were not normally distributed ($p<.05$) according to Shapiro-Wilk test as Table 5.14 indicated.

Since the two groups, MaMi and MiMa, were independent from each other, Mann-Whitney U test was used to analyze the GCT-Pretest scores in different types of questions. Results of Mann-Whitney U test were given in Table 5.15. Results showed that no significant difference between MaMi and MiMa in three different types of questions in the GCT-Pretest was found, (GCT-Pre-macro: U= 216, $p > 0.05$; GCT-Pre-submicro: U= 217.5, $p > 0.05$; GCT-Pre-both: U= 213.5, $p > 0.05$).

Table 5.15. Mann-Whitney U Test results for three types of GCT-Pretest questions.

Question Types	**Groups**	**N**	**Mean Rank**	**Sum of Ranks**	**U**	**Z**	**p**
Macroscopic	MaMi	22	21.32	469.00	216.000	-.632	.527
	MiMa	22	23.68	521.00			
Submicroscopic	MaMi	22	21.39	470.50	217.500	-.586	.558
	MiMa	22	23.61	519.50			
Macroscopic and submicroscopic	MaMi	22	23.80	523.50	213.500	-.693	.488
	MiMa	22	21.20	466.50			

Before testing the GCT-Posttest scores of MaMi and MiMa for three different types of questions, normality analysis was done by using Shapiro-Wilk test. Normality test results were given in Table 5.16. Since not all the values indicate normality, non-parametric statistics, namely, Mann-Whitney U test was chosen for the group comparison of scores in different type of questions.

Table 5.16. Normality scores for GCT-Posttest question types.

Question Types	**Group**	**Shapiro-Wilk**		
		Statistic	**df**	**Sig.**
Macroscopic	MaMi	.835	22	.002
	MiMa	.897	22	.026
Submicroscopic	MaMi	.909	22	.045
	MiMa	.967	22	.642
Macroscopic and submicroscopic	MaMi	.923	22	.086
	MiMa	.888	22	.017

.

Results of Mann-Whitney U test (Table 5.17) showed no significant difference between MaMi and MiMa in any types of post-test questions, (GCT-Post-macro: U= 190.5, $p > 0.05$; GCT-Post-submicro: U= 219.5, $p > 0.05$; GCT-Post-both: U= 200.5, $p > 0.05$).

Table 5.17. Mann-Whitney U Test results for three types of GCT-Posttest questions.

Question Types	Groups	N	Mean Rank	Sum of Ranks	U	Z	p
Macroscopic	MaMi	22	24.84	546.50	190.500	-1.259	.208
	MiMa	22	20.16	443.50			
Submicroscopic	MaMi	22	23.52	517.50	219.500	-.534	.594
	MiMa	22	21.48	472.50			
Macroscopic and submicroscopic	MaMi	22	24.39	536.50	200.500	-1.005	.315
	MiMa	22	20.61	453.50			

5.1.4. Comparison of the progress of MaMi and MiMa in terms of GCT-Pre and GCT-Posttest questions including only macroscopic level representations

In this sub-section, the progress of MaMi and MiMa in itself was compared according to GCT-Pre and GCT-Posttest macroscopic level questions. Wilcoxon signed rank test was applied since the scores of those groups were not normally distributed.

Table 5.18. Results of the Wilcoxon signed rank test for GCT-Pre and GCT-Posttest macroscopic level questions.

			N	Mean Rank	Sum of Ranks	Z	Asymp. Sig. (2-tailed)
MaMi	Postmacro - Premacro	Negative Ranks	2[a]	9.75	19.50	-2.958	**.003**
		Positive Ranks	16[b]	9.47	151.50		
		Ties	4[c]				
		Total	22				
MiMa	Postmacro - Premacro	Negative Ranks	4[a]	6.25	25.00	-1.153	**.249**
		Positive Ranks	8[b]	6.63	53.00		
		Ties	10[c]				
		Total	22				

a. Postmacro < Premacro b. Postmacro > Premacro c. Postmacro = Premacro

Results of Wilcoxon signed rank test (Table 5.18) indicated that there was a statistically significant difference between GCT-Pre and GCT-Posttest macroscopic level questions for the group MaMi (p=.003<.05). However, for the group MiMa there was no significant difference between GCT-Pre and GCT-Posttest macroscopic level questions (p=.249>.05).

5.1.5. Comparison of the progress of MaMi and MiMa in terms of GCT-Pre and GCT-Posttest questions including only submicroscopic level representations

In this sub-section, the progress of MaMi and MiMa in itself was compared according to GCT-Pre and GCT-Posttest submicroscopic level questions. Wilcoxon signed rank test was applied since the scores of those groups were not normally distributed.

Table 5.19. Results of the Wilcoxon signed rank test for GCT-Pre and GCT-Posttest submicroscopic level questions.

			N	Mean Rank	Sum of Ranks	Z	Asymp. Sig. (2-tailed)
MaMi	Postmicro - Premicro	Negative Ranks	4[a]	4.63	18.50	-3.385	**.001**
		Positive Ranks	17[b]	12.50	212.50		
		Ties	1[c]				
		Total	22				
MiMa	Postmicro - Premicro	Negative Ranks	5[a]	5.70	28.50	-2.684	**.007**
		Positive Ranks	14[b]	11.54	161.50		
		Ties	3[c]				
		Total	22				

a. Postmicro < Premicro b. Postmicro > Premicro c. Postmicro = Premicro

The Wilcoxon Signed Rank Test results (Table 5.19) showed that there was a statistically significant difference between the scores of GCT-Pretest and GCT-Posttest submicroscopic level questions for the group MaMi (p=.001<.05) and for the group MiMa (p=.007<.05). The analysis showed that the order of level of representations given in the instruction had no significant effect in differentiating the groups in understanding the submicroscopic level gas concept questions because both groups achieved significantly higher in the submicroscopic level questions given in the GCT-Posttest regardless of the level of representation they had worked on.

5.1.6. Comparison of the progress of MaMi and MiMa in terms of GCT-Pre and GCT-Posttest questions including both macroscopic and submicroscopic level representations

In this sub-section the questions, which include both macroscopic and submicroscopic levels were analyzed. Again MaMi and MaMi were evaluated within themselves; whether or not, there was a significant difference between GCT-Pre and GCT-Posttests.

The Wilcoxon Signed Rank Test results (Table 5.20) showed that there was a statistically significant difference between GCT-Pre and GCT-Posttest macroscopic & submicroscopic level questions' scores for both the group MaMi ($p=.000<.05$) and for the group MiMa ($p=.000<.05$). The analysis showed that the order of presenting the levels of representations had no significant effect in understanding gas concepts given in the macroscopic & submicroscopic level of questions.

Table 5.20. Results of the Wilcoxon signed rank test test for GCT-Pre and GCT-Posttest macroscopic & submicroscopic level questions.

			N	**Mean Rank**	**Sum of Ranks**	**Z**	**Asymp. Sig. (2-tailed)**
MaMi	Postboth - Preboth	Negative Ranks	1[a]	11.00	11.00	-3.546	**.000**
		Positive Ranks	19[b]	10.47	199.00		
		Ties	2[c]				
		Total	22				
MiMa	Postboth - Preboth	Negative Ranks	2[a]	4.50	9.00	-3.505	**.000**
		Positive Ranks	17[b]	10.65	181.00		
		Ties	3[c]				
		Total	22				

Preboth: Questions including both macroscopic and submicroscopic level representations in the GCT-Pretest.

Postboth: Questions including both macroscopic and submicroscopic level representations in the GCT-Posttest.

5.2. Analysis of Worksheets

5.2.1. MaMi and MiMa comparison according to the answers given to the clarification questions in the worksheets

The participants filled out specific worksheets (see Appendix B, C, D, E) for each activity based on the application they used. Each group (MaMi - MiMa) filled out a total of four worksheets, two about Boyle's Law, and two about Charles' Law.

In this sub-section, the analysis of the answers given in the first two questions of those worksheets was discussed. These two questions were clarification type of questions. The two sample questions are from Boyle's Law macroscopic level worksheet and Charles' Law submicroscopic level worksheet first questions, respectively.

Example Question-1: What happened to the pressure value when the piston of the syringe was pushed to decrease the volume? What could be the reason for this? Explain.

Example Question-2: What happened to the volume of the container when the temperature was increased? Explain the reasons.

Table 5.21. Analysis criteria for the explanations for the first two questions in the worksheets.

Points	Coding
0	Wrong answer / No answer
1	Partial understanding with misconception
2	Partial understanding without misconception
3	Total understanding

Students' answers for the first two clarification questions were analyzed. The analyses were done according to three criteria: whether or not the answer included the correct change (for example Question-1 given above, the answer was an increase in pressure); the correctness of the explanation given; and the level of the explanation: macroscopic or submicroscopic level.

First criterion was analyzed in terms accuracy: as being correct or incorrect. For the second one, a scale was used as given in Table 5.21. Students' answers were scored according to the coding; also, the answers were checked whether or not they included any misconceptions about gas concept. The third criterion was analyzed by studying the words that students used to explain the situation. If the answer included any submicroscopic level explanation, this answer was coded as submicroscopic level; if not, the answer was coded as macroscopic level.

An example student answer was given in Figure 5.1. In this example, the student gave the correct answer according to the first criterion; also the explanation was correct – total understanding; and the level of explanation was submicroscopic, since the student explained the increase in volume by telling about the movement of the particles.

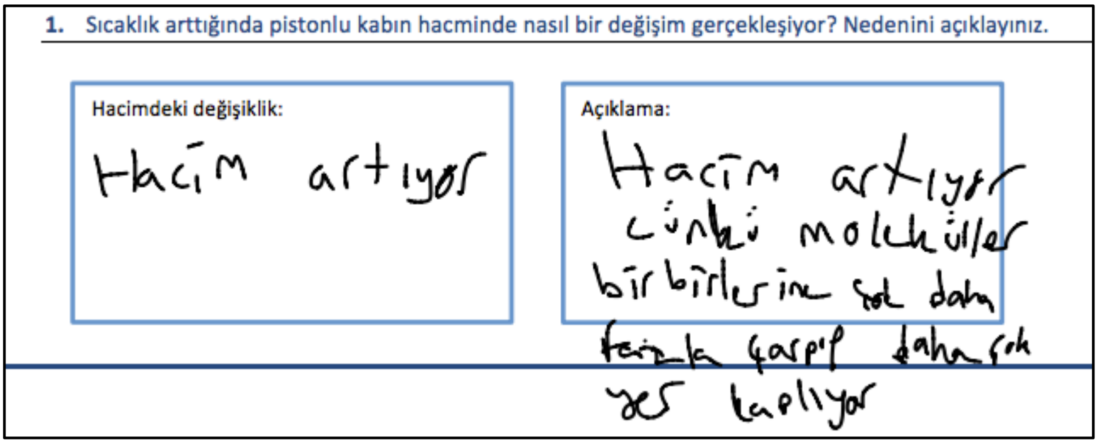


Figure 5.1. An example student answer given to the first question in iGasLaw application worksheet for Charles' Law (Student #10).

The results of the analysis showed that %50 of the students in the MaMi group explained the situation using submicroscopic level words; and the other half answered at the macroscopic level. On the other hand, for the MiMa, %59 of the students explained the situation using submicroscopic level words. The main difference between these two groups was that, the iPad application MiMa used was at submicroscopic level, in other words, the application showed them the gas particles. That might have been why MiMa students' explanations were dominantly in submicroscopic level, (see Table 5.22).

Table 5.22. Students' explanations' level for the first questions in Boyle's Law worksheets for MaMi and MiMa.

	1st ACTIVITY: BOYLE'S LAW Macroscopic level iPad application		**2nd ACTIVITY BOYLE'S LAW Submicroscopic level iPad application**	
	Answer in macroscopic level	Answer in submicroscopic level	Answer in macroscopic level	Answer in submicroscopic level
MaMi (N=22)	11	11	9	13
	%50.0	%50.0	%40.91	%59.09
	1st ACTIVITY: BOYLE'S LAW Submicroscopic level iPad application		**2nd ACTIVITY BOYLE'S LAW Macroscopic level iPad application**	
	Answer in macroscopic level	Answer in submicroscopic level	Answer in macroscopic level	Answer in submicroscopic level
MiMa (N=22)	9	13	11	11
	%40.91	%59.09	%50.0	%50.0

In the second worksheet, MiMa group worked with macroscopic level iPad application. Maybe that might be the reason why, in the second worksheet MiMa students gave their answers %50 in submicroscopic and %50 macroscopic level, (see Table 5.22). On the other hand, MaMi group, worked on a submicroscopic level application in their second activity accompanied with a worksheet. It was observed that their answers' level to the first question had changed and included submicroscopic level (%59) when compared with the first worksheet, which was macroscopic, and %50 of students gave submicroscopic level explanation.

After the students finished the two activities of Boyle's Law in the first week of implementation, they started to work on the two activities of Charles' Law. Similarly, MaMi group first worked with a macroscopic level iPad application of Charles' Law, then with the one at submicroscopic level. MiMa, worked in reverse order, in other words, they first worked with submicroscopic level iPad application, then a macroscopic level application. When the answers given in worksheets by the students in MaMi and MiMa groups were compared, it was observed that the number of students giving submicroscopic level explanations in their first worksheet in Charles' Law were higher than the number of students giving submicroscopic level explanations in their first and second worksheets in Boyle's Law (Table 5.22 and 5.23). The students' perceptions seem to have changed toward thinking about submicroscopic level explanations for the given situations. Besides, as seen in Table 5.23, in the first worksheet 64% of MaMi and MiMa students gave submicroscopic level explanations; and then in the second worksheet 72.7% of MaMi and 68.2% of MiMa students made explanations including submicroscopic level words.

Table 5.23. Students' explanations' level for the first questions in Charles' Law worksheets for MaMi and MiMa.

	1st ACTIVITY: CHARLES' LAW Macroscopic level iPad application		**2nd ACTIVITY: CHARLES' LAW Submicroscopic level iPad application**	
	Answer in macroscopic level	Answer in submicroscopic level	Answer in macroscopic level	Answer in submicroscopic level
MaMi (N=22)	8	14	6	16
	%36.36	%63.64	%27.27	%72.73
	1st ACTIVITY: CHARLES' LAW Submicroscopic level iPad application		**2nd ACTIVITY: CHARLES' LAW Macroscopic level iPad application**	
	Answer in macroscopic level	Answer in submicroscopic level	Answer in macroscopic level	Answer in submicroscopic level
MiMa (N=22)	8	14	7	15
	%36.36	%63.64	%31.82	%68.18

Up to now, only the first clarification question was analyzed. However, the results for the second question were same with the first one. Since the first two questions were opposite to each other, but asking about the same concept, students gave the reverse answer to the second question, after answering the first one. Two sample questions were given to exemplify the opposition of the first two questions in the all worksheets. These sample questions were from Boyle's Law submicroscopic level worksheet (see Appendix C).

Question 1: What happened to the pressure value when the piston of the syringe was pushed towards right side? What could be the reason for this? Explain.

Question 2: What happened to the pressure value when the piston of the syringe was pushed towards left side? What could be the reason for this? Explain.

5.2.2. Comparison of MaMi and MiMa according to the total scores of Boyle's law worksheets

All students first worked with Boyle's Law activities on iPad and filled out two worksheets, one about macroscopic level iPad application, and the other about submicroscopic level. In this sub-section, students' total scores in Boyle activities were analyzed. The analyses for the first two questions were given before. The other questions' types and evaluation parts were given in Table 5.26.

Table 5.26 gave a general look to the question types in Boyle and Charles' worksheets and the maximum points that one could get. In the first two questions, if the student gave the correct answer for the change in pressure in Boyle's worksheets and for the change in volume in Charles' worksheets, s/he could get 1 point. And for the explanation parts of the first two questions, the grading would be according to Table 5.21. In the third question, students were expected to place their volume-pressure or temperature-volume values to a graph. If one wrote down the units of the variables to the axes of the graph correctly, s/he got one point for each axes. Also, if the scaling of the values were correct, one point was given. And for the correctness of the graphs, the maximum point was 4 for a totally correct graph (see Table 5.24).

Table 5.24. Analysis criteria for the explanations for the third question in the worksheets.

Points	Coding
0	No answer
1	Data was plotted incorrectly; thus incorrect graph
2	Correct drawing according to the data; however the data was wrong
3	Correct plotting, but no graph was drawn
4	Totally correct

In the 4th questions, students were asked to draw the particles per unit volume for three different situations. This situation was three different volumes for the Boyle's Law worksheets; and three different temperature values for Charles' Law worksheets. Each drawing was scored in accordance with the Table 5.19.

Table 5.25. Analysis criteria for the explanations for the forth question in the worksheets.

Points	Coding
0	No answer
1	No understanding
2	Partial Understanding with Specific Misconception (PUSM)
3	Partial Understanding (PU)
4	Good Understanding (GU)

Also, in the forth question, students were asked to explain each of their drawings. If the drawings and the corresponding explanations were correct, student got 2 points; if either explanations or the drawings were correct, student got 1 point; and if both the drawings and the explanations were wrong, student got 0 point from this question (Table 5.26).

Table 5.26. Question types and their evaluations in the worksheets.

Question number	Question type	Evaluation parts	Max point
1	Clarification question	Change	1
		Explanation	3
2	Clarification question	Change	1
		Explanation	3
3	Graphing ability	Correctness	4
		Scaling	1
		Writing units	2
4	Submicroscopic level drawings	First measurement	4
		Second measurement	4
		Third measurement	4
		Overall explanations	2
5*	Extension question	Macroscopic level drawing	1
		Submicroscopic level drawing	2
			Total: 32 points

* Included only in submicroscopic level worksheets.

The extension question was only included in the submicroscopic level worksheets of Boyle's and Charles' Law. In this question, students were asked to draw a macroscopic and two submicroscopic drawings. Here, if the macroscopic one was correct, student got 1 point. And if both the submicroscopic level drawings were correct, s/he got 2 points; if only one of the submicroscopic was correct, s/he got 1 point; and if no correct submicroscopic drawing existed, no points were given (Table 5.26).

Since students first completed the activities of Boyle's Law, first the total scores of these worksheets were evaluated. The total scores were calculated by adding the total points of macroscopic and submicroscopic level questions. The maximum point that they can get in macroscopic level worksheets' total point was 29, and that of submicroscopic ones were 32. Thus, the sum of the maximum points was 61. As Table 5.27 indicated, the mean score of MaMi was found to be 47.4 (SD=7.69) and MiMa was 51.5 (SD=6.23).

Table 5.27. Descriptive statistics for MaMi and MiMa for Boyle's Law worksheets.

	Group	N	Mean	Std. Deviation	Std. Error Mean
Total Scores on Boyle's Law worksheets	MaMi	22	47.4545	7.68875	1.63925
	MiMa	22	51.5455	6.23147	1.32855

Table 5.28. Mann-Whitney U test results for comparing MaMi and MiMa in terms of total scores of Boyle's Law worksheets.

Question Types	Groups	N	Mean Rank	Sum of Ranks	U	Z	p
Total Scores on Boyle's Law worksheets	MaMi	22	19.16	421.50	168.500	-1.728	.084
	MiMa	22	25.84	568.50			

According to Mann-Whitney U test (Table 5.28), results showed no significant difference between MaMi and MiMa at the end of Boyle's Law worksheets, ($U = 168.5$, $p > 0.05$).

5.2.3. Comparison of MaMi and MiMa according to the total scores of Charles' Law worksheets

After students finished working on Boyle's Law activities accompanied with worksheets, they continued with Charles Law activities. In this sub-section, the analysis of students' total scores in Charles' Law worksheet was reported. Evaluation of the total scores of Charles' Law worksheets was same with the Boyle's (see Table 5.26).

Table 5.29. Descriptive statistics for MaMi and MiMa for Charles' Law worksheets.

	Group	N	Mean	Std. Deviation	Std. Error Mean
Total Scores on Charles' Law worksheets	MaMi	22	44.9091	10.00909	2.13394
	MiMa	22	45.1818	9.46993	2.01900

As Table 5.29 indicated, the mean score of MaMi was found to be 44.9 (SD=10.01) and MiMa was 45.2 (SD=9.47). And also according to Mann-Whitney U test (Table 5.30), results showed no significant difference between MaMi and MiMa at the end of Charles' Law worksheets, ($U = 241.0$, $p > 0.05$).

Table 5.30. Mann-Whitney U test results for comparing MaMi and MiMa in terms of total scores of Charles' Law worksheets.

Question Types	Groups	N	Mean Rank	Sum of Ranks	U	Z	p
Total Scores on Charles' Law worksheets	MaMi	22	22.45	494.00	241.000	-.023	.981
	MiMa	22	22.55	496.00			

5.2.4. Comparison of MaMi and MiMa according to the overall scores of both Boyle's and Charles' Law worksheets

In this sub-section, students' total scores (the sum of the total scores of Boyle's and Charles' Law worksheets) in the worksheets were compared. Since the maximum score one student could get from either Boyle's Law or Charles' Law worksheet was 61, the maximum overall score then could be 122.

Table 5.31. Descriptive statistics for MaMi and MiMa according to the overall scores of both Boyle's and Charles' Law worksheets.

	Group	N	Mean	Std. Deviation	Std. Error Mean
Total Scores on Boyle's and Charles' Law worksheets	MaMi	22	92.3636	15.19883	3.24040
	MiMa	22	96.7273	12.26758	2.61546

Table 5.32. Mann-Whitney U test results for comparing MaMi and MiMa groups with respect to the total scores in the worksheets.

	Groups	N	Mean Rank	Sum of Ranks	U	Z	p
Total Scores on Boyle's Law worksheets	MaMi	22	20.80	457.50	204.500	-.881	.378
	MiMa	22	24.20	532.50			

As Table 5.31 indicated, the mean score of MaMi was found to be 92.4 (SD=15.20) and MiMa was 96.7 (SD=12.28). And also according to Mann-Whitney U test (Table 5.32), results showed no significant difference between MaMi and MiMa at the end of Charles' Law worksheets, ($U = 204.500$, $p > 0.05$).

5.2.5. Comparison of MaMi and MiMa according to the extension question given only in submicroscopic level Boyle's and Charles' Law worksheets

In this sub-section, students' answers to the distinguishing question, which includes both macroscopic level and submicroscopic level drawings was analyzed. This question was added as an extra to only submicroscopic level worksheets of both Boyle's and Charles' Law activities.

First in the Boyle's Law activity, students were given a picture showing a bicycle pump with no air in it (Figure 5.2); and they were asked to draw the last picture if it is filled with air. The analysis of this question was done in two parts: first, macroscopic drawing was evaluated as correct or wrong; second, submicroscopic level drawings were evaluated as correct (2 pts), partially correct (1pts) or wrong (0 pts) (Table 5.33).

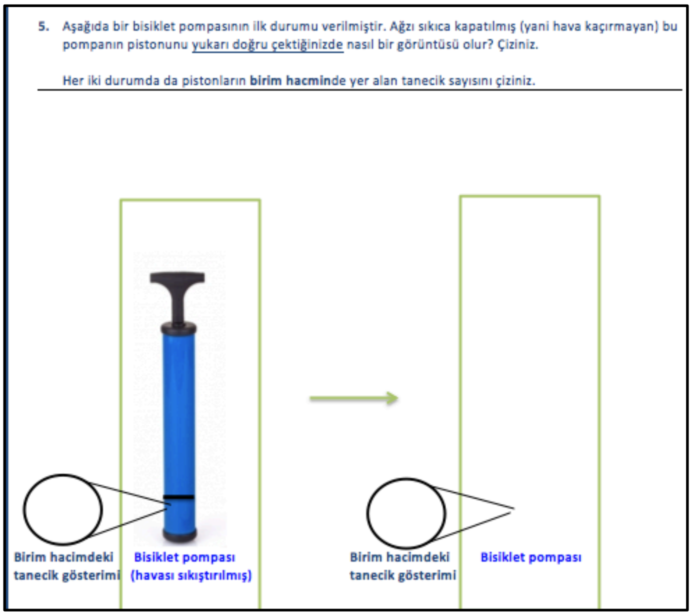


Figure 5.2. The extension question in Boyle's Law submicroscopic level worksheet.

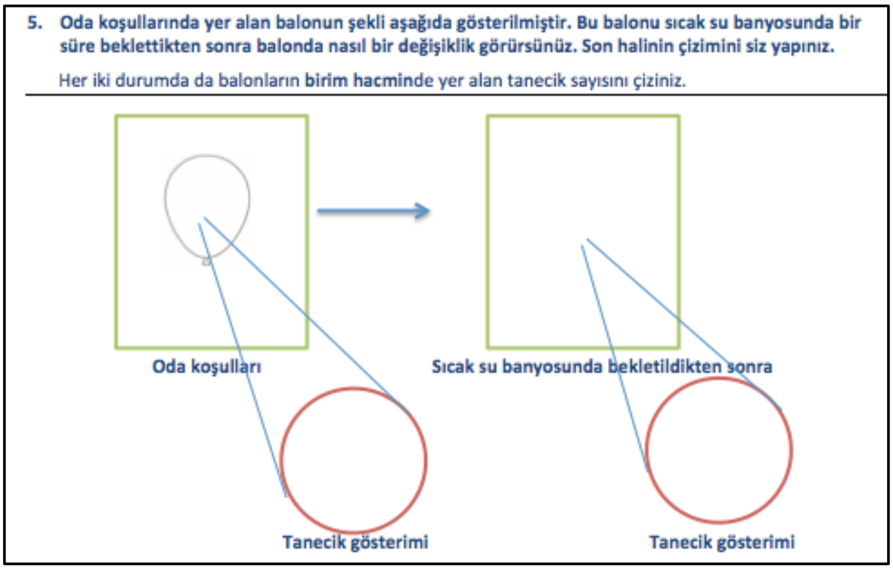


Figure 5.3. The extension question in Charles' Law submicroscopic level worksheet.

Then in Charles' Law, students were asked to draw a balloon when it was put into a hot water bath (Figure 5.3). Also, they were expected to draw for each representation the particles in unit volume. The analysis of this question was same with the one in Boyle's Law. Table 5.33 and 5.35 gave the number of students for each drawing in Boyle's and Charles' Law worksheets, respectively.

Table 5.33. Number of students who used macroscopic and submicroscopic level drawings in the extension question in Boyle's Law worksheet.

	Macroscopic level drawing		Submicroscopic level drawing		
	Correct	Incorrect	Correct	Partial	Incorrect or no answer
MaMi (N=22)	20 students	2 students	16 students	6 students	0
	%91	%9	%73	%27	
MiMa (N=22)	15 students	7 students	15 students	7 students	0
	%68	%32	%68	%32	

As seen in Table 5.33, the MaMi group performed better in macroscopic level drawing compared to the MiMa. Also drawings considering particles, again MaMi group performed better. Mann-Whitney U test was used to analyze whether or not this difference was significant or not. As Table 5.34 showed, the difference between groups was not significant (p>0.05).

Table 5.34. Mann-Whitney U test results for MaMi and MiMa for the extension question in Boyle's Law worksheet.

	Group	**N**	**Mean Rank**	**Sum of Ranks**	**U**	**Z**	**p**
Macroscopic level extension question	MaMi	22	25.00	550.00	187.000	-1.847	.065
	MiMa	22	20.00	440.00			
Submicroscopic level extension question	MaMi	22	23.00	506.00	231.000	-.327	.744
	MiMa	22	22.00	484.00			

Table 5.35. Number of students who used macroscopic and submicroscopic level drawings in the extension question in Charles' Law worksheet.

	Macroscopic level drawing		Submicroscopic level drawing		
	Correct	Incorrect	Correct	Partial	Incorrect or no answer
MaMi (N=22)	10 students	12 students	12 students	8 students	2
	%45	%55	%54	%36	%9
MiMa (N=22)	15 students	7 students	13 students	6 students	3
	%68	%32	%59	%27	%14

Different than Boyle's Law, in Charles Law MiMa group perform better in macroscopic level drawing (balloon). However, this time MaMi group made better particle level representations than MiMa. Table 5.36 showed that these differences also not significant.

Table 5.36. Mann-Whitney U test results for MaMi and MiMa for the extension question in Charles' Law worksheet.

	Group	N	Mean Rank	Sum of Ranks	U	Z	p
Macroscopic level extension question	MaMi	22	20.00	440.00	187.000	-1.504	.132
	MiMa	22	25.00	550.00			
Submicroscopic level extension question	MaMi	22	22.27	490.00	237.000	-.133	.895
	MiMa	22	22.73	500.00			

5.3. Findings Related to the Interviews

Interviews were done during the same class-hours, after finishing the activities accompanied with worksheets. When a student came to the end of his/her study and sent it to the teacher, he/she was asked to go back side of the classroom (to the lab section) in order to have an interview about the study.

There were 34 interviews in total (Table 5.37). The interviews were done with 28 students; 15 of them belonged to MaMi and 13 belonged to MiMa. In some cases, some students were interviewed more than once at different parts of the study. Interviews were made with 26 students. In order to ensure that there is no significant difference between the students that were involved in the interviews and the ones that were not a part of the interviews, Mann Whitney U test was applied. When these students' GCT-Posttest scores were analyzed, no significant difference was found ($p=.486>.05$).

Table 5.37. Number of interviews done in Boyle's and Charles' Law activities.

Boyle's Law		**Charles' Law**	
Number of interview done regarding the macroscopic level worksheet	Number of interview done regarding the submicroscopic level worksheet	Number of interview done regarding the macroscopic level worksheet	Number of interview done regarding the submicroscopic level worksheet
7	7	10	10

The interviews were analyzed in five themes. These themes were set after listening the recordings and reading the transcripts several times (Creswell, 2012).

- Understanding of the concept and transforming it to a graphic
- Concept of unit volume
- The number of particles in unit volume
- Homogeneity of particles in unit volume
- The motion of the particles in unit volume

Table 5.38 gave a total picture for the interview analysis. The results of the analysis of these themes were discussed in the subheadings.

Abraham, Grzybowksi, Renner and Marek (1992) used six categories to evaluate open-ended questions: Sound understanding, partial understanding, partial understanding with specific misconception, specific misconceptions, no understanding and no response. Similar five categories used in this study were as follows:

- Good Understanding (GU); a response that indicated a correct understanding in the worksheet as a whole.
- Partial Understanding (PU); an insufficient response of the phenomenon.
- Partial Understanding with Specific Misconception (PUSM); a response, which included both some misconception and partial understanding.
- No Understanding (NU); an answer that indicated no information about the phenomenon, namely wrong answer.
- No Explanation (NE) category was used when the student gave no information about the phenomenon.

Table 5.38. Interview analysis.

5 themes:	Categories				
	GU	PU	PUSM	NU	NE
1) Understanding the whole concept	28	3	3	-	-
	%82.35	%8.82	%8.82		
2) Unit volume	13	18	-	-	3
	%38.24	%52.94			%8.82
3) Number of particles	22	5	-	7	-
	%64.70	%14.70		%20.59	
4) Homogeneity	19	6	2	6	1
	%55.88	%17.65	%5.88	%17.65	%2.94
5) Motion of particles	12	10	-	1	11
	%35.29	%29.41		%2.94	%32.35

5.3.1. Understanding of the concept and transforming it to a graphic

In this subsection, students' understanding about the concepts and the transformation of this understanding into a graphic were analyzed. When 34 interviews were analyzed, %82 of them indicated that students understood the concept and drew the relation in a correct way into a graphic (see Table 5.38). These were coded as Good Understanding (GU).

In Boyle's Law worksheets, they were expected to draw the correct relation between Volume and Pressure both in their explanations and in their graphics. Student #2's answer evaluated as Good Understanding (GU) about Boyle's Law GasLawsHD worksheet was as follows:

"[Soru] Şunu söylüyordu: şırınganın pistonunu ileri itince basınç nasıl değişti? Basıncın arttığını gördük ve bunun sebebi de bunu ileri ittiğinde daha fazla kuvvet uygulamamız ve o gazın hacmini küçültüp gaz taneciklerinin sıkışmasına sebep olmamızdı. Daha çok sıkışınca da daha fazla basınç olmasına sebep oldu." (The question asked: how did the pressure change when the piston was pushed forward) We saw that

pressure increased and the reason behind that was we applied force to the piston and we caused squeezing the gas particles. The more they were squeezed, the more pressure was applied) (Student #2).

The graphic accompanied to this explanation of Student #2 was given in Figure 5.4. This drawing was also counted as totally correct.

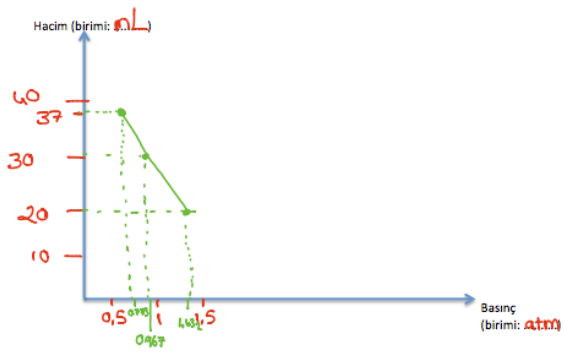


Figure 5.4. Student #2's graph for Boyle's Law.

Another student's answer about Charles' Law, again coded as GU, was as follows:

"Sıcaklık artınca pistonlu kabın hacmi de daha fazla artıyor çünkü moleküller daha hızlı hareket ettikleri için daha fazla alana gereksinim duyuyorlar ve büyüyor hacim." (When temperature increases the volume of the container increases, because molecules move faster and need more space and so volume increases) (Student #8)

An example to GU type of graph for Charles' Law was like: (Student #9)

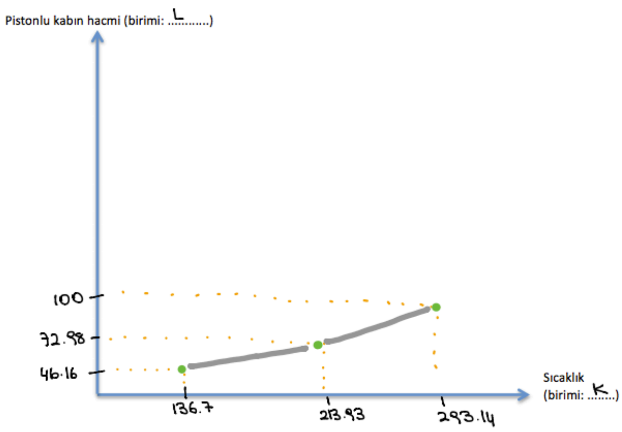


Figure 5.5. Student #9's graph for Charles' Law.

As seen from Table 5.38, three interviews (~%9) were counted as Partial Understanding (PU) type. Two of those interviews included correct explanations, but wrong graphs (see Figure 5.6). During the interview the student (Student #1) understood his mistake and corrected it.

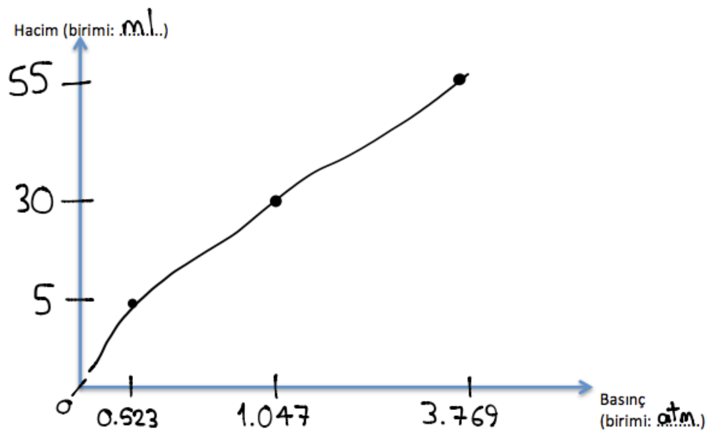


Figure 5.6. Student #1's graph for Boyle's Law.

Last category found from the interviews about understanding the concept and transforming it to a graph was Partial Understanding with Scientific Misconception (PUSM) type. Three students (~%9) gave answers including misconceptions, coded as PUSM. They mentioned about the expansion of the molecules when the temperature increases. Student #11 gave the following answer in Charles' Law:

"Sıcaklık ile hacim doğru orantılı. Sıcaklık arttığında taneciklerin hacmi genişliyor, dolayısıyla hacim de büyür yazdım." (Temperature and volume are directly proportional. When temperature increases, the volume of the particles expands. So, the volume increases) (Student #11).

5.3.2. Concept of unit volume

In this subsection, students' understanding about the concept of unit volume was analyzed based on the interviews conducted. In each worksheet, students were asked questions about motion, homogeneity and number of particles in a unit volume.

Understanding the macroscopic behaviors of gases, number of particles in unit volume and motion of them should be interpreted. In this criterion, both students' explanations about unit volume and their drawings were taken into account. During the interviews, students were asked to explain the concept of unit volume. If the student's explanation was correct and his/her drawings in the worksheets complemented the explanation, it was counted as Good Understanding (GU). When 34 interviews were analyzed, only %38 of them included correct explanation and drawings. %53 partially understood the concept and %9 had no explanation, (see Table 5.38).

A student answer when asked to explain unit volume in Charles' Law worksheet is given below. Since when temperature increases, volume of the container increases as well, the student (Student #19) explained unit volume in this context. Both the explanation and the drawing were coded as GU since the student got the idea of unit volume and reflected this in her drawing.

"Ben insanlar olarak düşünüyorum aslında bunu her zaman. Alan arttıkça kilometrekareye düşen insan sayısı da azalacağı için ben tanecik sayılarının azalacağını düşündüm." (I always take this as people actually. When the area increases, the number of people per square kilometer decreases. That is why; I think the number of particles decrease) (Student #19).

Student #19 drew her own unit volumes while answering the question. This drawing was coded as GU:

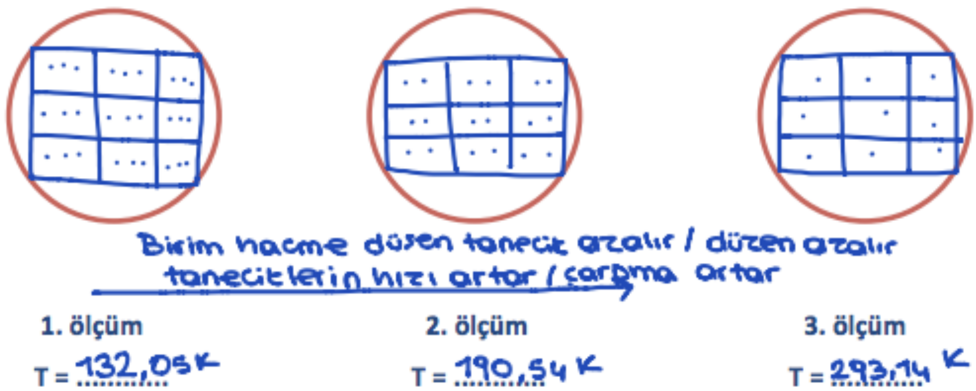


Figure 5.7. Student drawing for Charles' Law, coded as GU for the unit volume concept (Student #19).

53% of the given answers were coded as PU (partially understood). This was used if the explanation given was not enough. Also when the explanation was correct but the drawing was wrong or vice versa. An example, which included a correct drawing but insufficient explanation of Student #1 was as follows (see Figure 5.8):

"Yani bir birimdeki hacim miktarı" (Unit volume is the amount of volume in one unit) (Student #1).

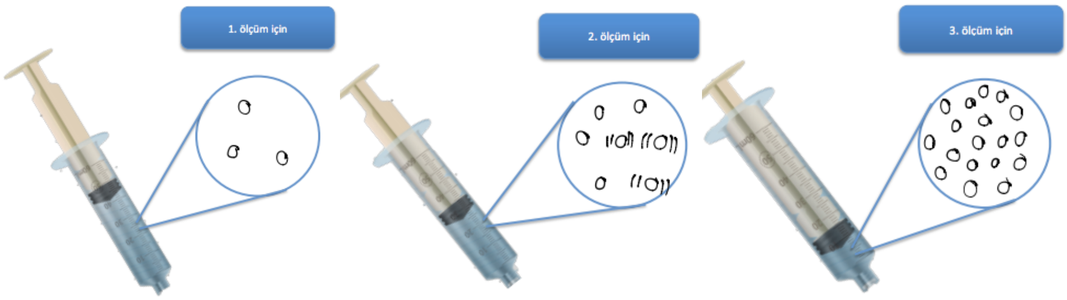


Figure 5.8. Student drawing for Boyle's Law, coded as PU for the unit volume concept (Student #1).

Three students (~%9) gave no explanation about the concept of unit volume during the interview (see Table 5.38).

5.3.3. The number of particles per unit volume

Each worksheet included one question asking the number of particles in unit volume for different situations. For Boyle's Law, this situation was the volume, whereas in Charles' Law it was the temperature. In the Boyle's Law activity, students were asked to decrease the volume of the container and so draw the number of particles in unit volume of the container. So they were expected to draw more particles in unit volumes when the container was getting smaller and smaller.

In Charles' Law, on the other hand, students were asked to increase the temperature of the container and so draw the number of particles in each volume. So they were expected to draw less particles in unit volumes when the container was getting bigger and bigger due to the increase in temperature.

A majority of the students (~%65) drew the number of particles correctly. A correct student drawing, coded as GU from Boyle's Law worksheet was given in Figure 5.9, (Student #22).

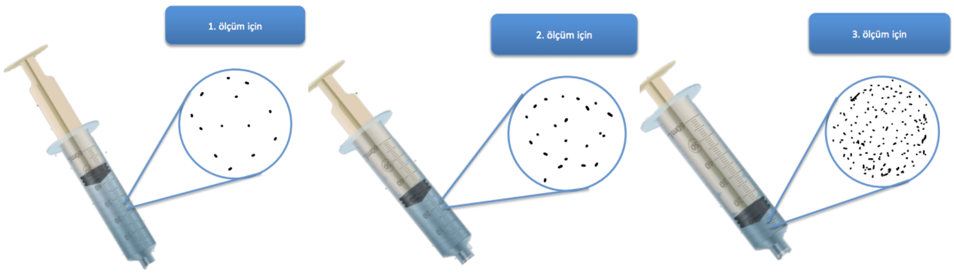


Figure 5.9. Student drawing for Boyle's Law, coded as GU for the number of particles in unit volume (Student #22).

The student paid attention not only the number of particles but also the homogeneity in his drawings.

At about %15 of the students' answers were counted as partial understanding (PU). One example drawing for that was as follows: (Student #11)

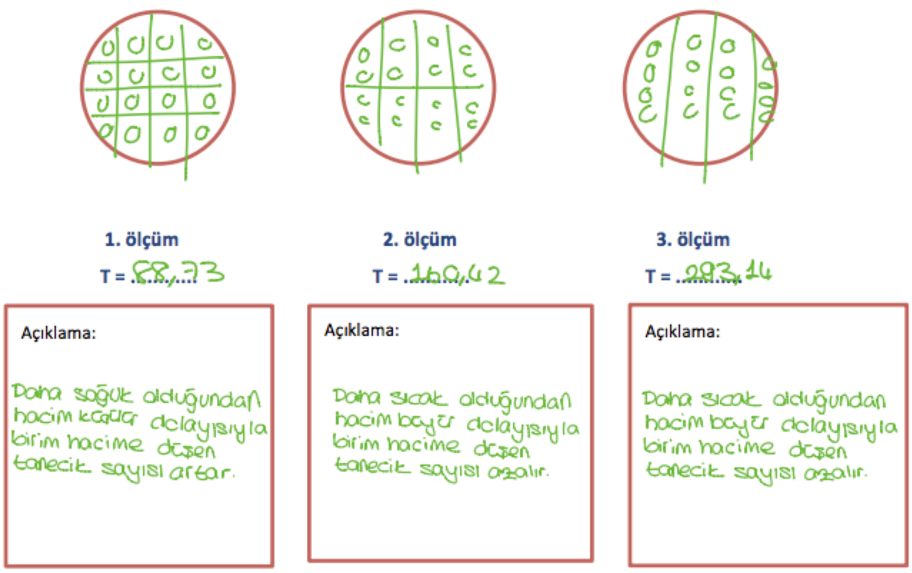


Figure 5.10. Student drawing for Charles' Law, coded as PU for the number of particles in unit volume (Student #11).

Although in her explanation she mentioned, “when temperature increases, the number of particles in unit volume decreases”, she exactly drew the same number of particles in each unit volume. Also she tried to draw her own unit volumes, but she misunderstood the concept of unit volume, since she drew each unit volume in different sizes. This example was counted as PU – partial understanding, since she explained the situation correctly, but could not draw it.

Last, almost %21 of the answers was taken as NU, wrong answer. One example from the Charles’ Law worksheet was as follows:

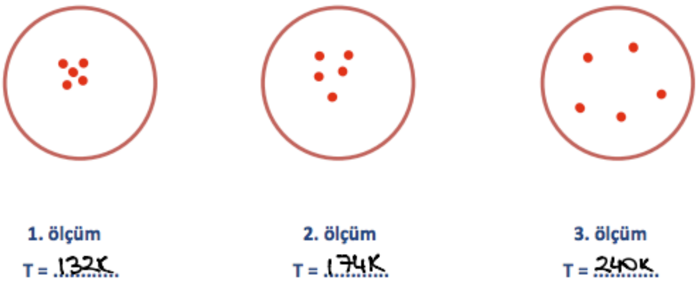


Figure 5.11. Student drawing for Charles’ Law, coded as NU for the number of particles in unit volume (Student #15).

Here in this drawing, the student did not change the number of particles in unit volume when the temperature increases. Her explanation for this was:

“Tanecik sayısını sabit tuttum. Mesela burada 5 tane varken, burada da 5. Daha rahat açıklayabilmesi için. Tanecik sayısı artar gibi bir izlenim olmasın diye.” (I kept the number of particles constant in order to explain easily. In order not to give an impression like: an increase in the number of particles) (Student #15).

In this example, the student did not understand that the red circles were indicating the unit volumes. She thought that the number of particles in the container didn’t change, so that’s why she might have drawn the same number of particles in each circle. This inference could be made since first she drew the particles near to each other, and then drew them far apart.

5.3.4. The homogeneity of particles in unit volume

In this subsection, students' drawings in unit volumes were coded and analyzed whether or not the particles they drew were homogeneous or not. Here, at about %56 of the interviews, good understanding examples were seen (see Table 5.38). In this part, good understanding requires correct explanations and also correct drawings. The drawings of Student #22 could be taken as GU – good understanding because student drew the particles homogeneously and also he explained the drawings in the correct way (Figure 5.12).

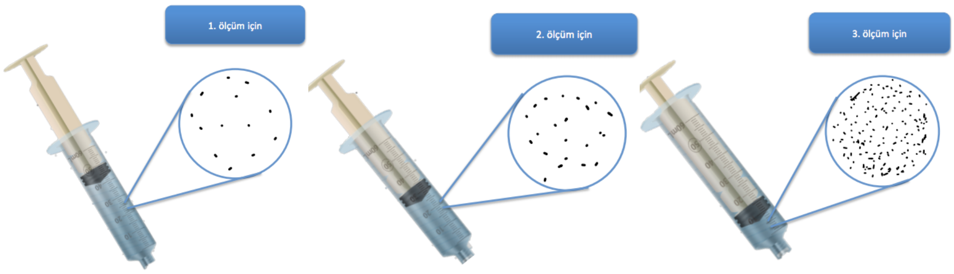


Figure 5.12. A student drawing from Boyle's Law worksheet, showing the number of particles in unit volume-coded as GU for Homogeneity (Student #22).

"Hacim gitgide azaldığından, birim hacimdeki tanecik sayısı ve basınç artar." (Since the volume is decreasing gradually, the number of the particles in unit volume and so the pressure increase.) (Student #22).

There were interviews (%18) as examples for PU – partial understanding. Those were the ones including homogeneous drawings but when asked, students couldn't explain why they drew like this or they just didn't know the meaning of homogeneous (Figure 5.13).

"Öğretmen: Peki, homojen olarak mı yerleşiyor tanecikler?
Öğrenci: Hayır.
Öğretmen: Birim hacimlere?
Öğrenci: Bilmiyorum."
(Interviewer: Ok, do the particles locate homojeneously?
Student: No.

Interviewer: Into the unit volumes?

Student: I don't know.) (Student #9)

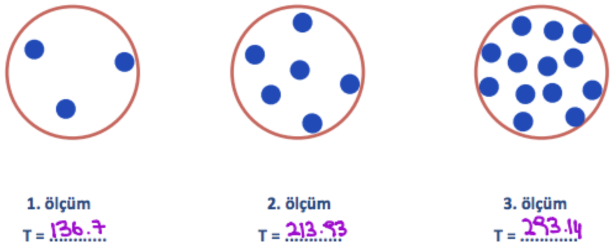


Figure 5.13. Student drawing for Charles' Law, coded as PU for Homogeneity of the particles (Student #9).

In almost %6 of the interviews there were answers including misconceptions (PUSM) to the question of homogeneity. The two drawings below showed them. In Figure 5.14, the student drew particles close to each other when the temperature was low. While temperature was increasing gradually, he started to draw the particles near the walls of the container. The Student #28 explains as, *"Sıcaklık artınca tanecikler hareketlendi, çepere yaklaştı." (When the temperature increased, the particles started to move and moved towards the wall of the container.)*

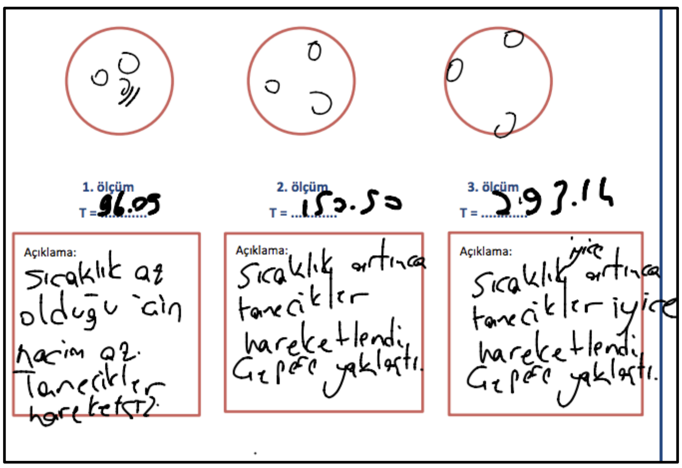


Figure 5.14. Student drawing for Charles' Law, coded as PUSM for Homogeneity of the particles (Student #28).

Student #27 in Figure 5.15 wrote down that *"Sıcaklık az olduğundan tanecikler hızlı hareket edemez ve kabın etrafına dağılır; sıcaklık arttığında kabın kenarlarına bağlı* *kalmazlar.” (When the temperature is low, the particles cannot move fast and spread to the walls of the container; when temperature increases, they will not bound to the walls of the container.)*

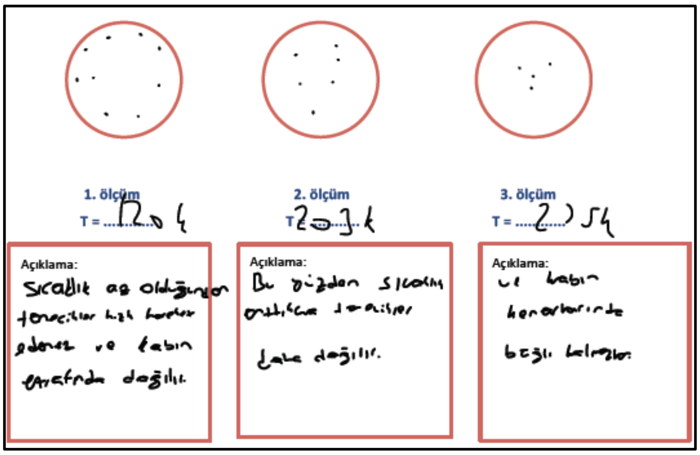


Figure 5.15. Student drawing for Charles’ Law, coded as PUSM for Homogeneity of the particles (Student #27).

These two students thought that when temperature changes, the place of the particles would change as well. Student #27 wrote down as: “when the temperature increased, the particles would not bind to the walls of the container.” And so he drew the particles (Figure 5.15, the right one) in the middle. The other student (#28) thought the reverse: “when the temperature increases, particles move more and they get close to the walls of the container.” These two ideas were not correct; gas particles always spread homogeneously into the container they were located.

Also almost %18 of the answers was categorized as NU – no understanding or wrong understanding. In this one, students both couldn’t explain the homogeneity and couldn’t draw particles homogeneously (Figure 5.16). One example was as follows:

“Öğretmen: Burada çizimini yaparken taneciklerin birim hacim içerisine, kabın içerisine homojen olarak dağılmasına dikkat ettin mi?
Öğrenci: Homojen olarak dağılması gerekiyor mu?
Öğretmen: Öyle mi dağıttın yani?
Öğrenci: Yok.”

(Interviewer: Here in this drawing, did you draw particles homogeneously in the unit volumes?
Student: Did they need to disperse homogeneously?
Interviewer: Did you draw like that?
Student: No. (Student #26)

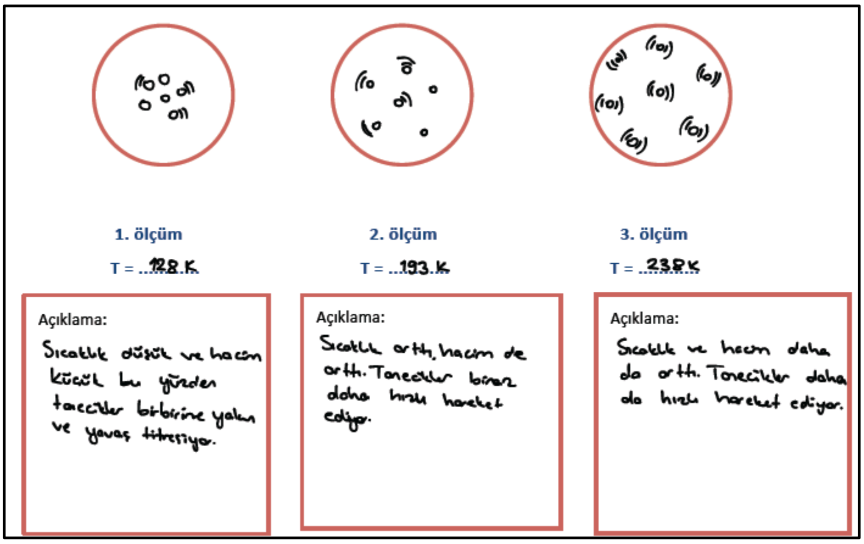


Figure 5.16. Student drawing for Charles' Law, coded as NU for Homogeneity of the particles (Student #26).

Student #26 did not draw the particles homogeneously in unit volumes. Also she was even not aware of the situation. So the drawings were wrong, this example was categorized as NU, wrong understanding.

5.3.5. The motion of particles in unit volume

In this subsection, students' understanding of the motion of the particles revealed in the interviews is reported. Here, if the student showed the motion in his/her drawing and also explained it correctly, it was counted as GU – good understanding. Student #6 drew the particles showing that they had motion. So this was taken as GU. However, when the number of particles was counted, it could be seen that she did not pay attention to decrease the number of particles per unit volume (Figure 5. 17).

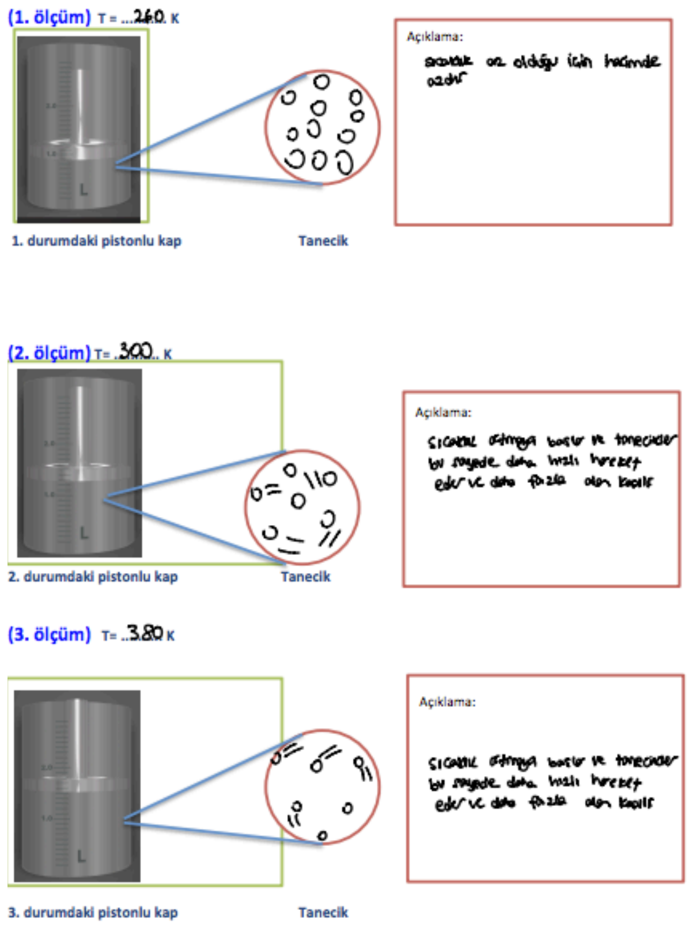


Figure 5.17. Student drawing for Charles' Law, coded as GU for the motion of the particles (Student #6).

PU – partial understanding coding was used for the answers that were generally included correct explanations but no motion signs were included in the drawings.

There is just one NU interview, in which student also couldn't explain the motion in the correct way:

"Sıcaklık arttığında mesela moleküller daha rahat yayılıyor ve daha iyi yayılabiliyorlar. Daha iyi hareket ediyorlar rahat bir şekilde." (For example, when the temperature increases, the molecules spread out easily more freely. They move better in a free way.) (Student #15)

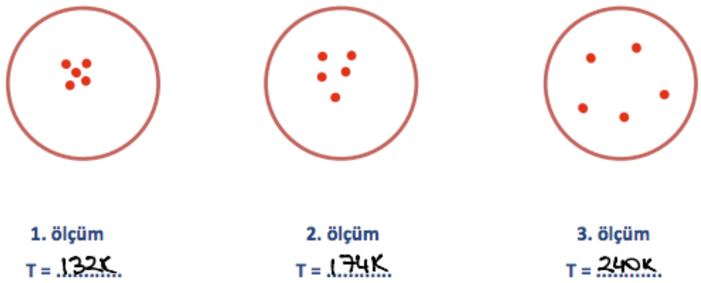


Figure 5.18. Student drawing for Charles' Law, coded as NU for the motion of the particles (Student #15).

In the interviews sometimes the interviewer did not ask questions about motion, and so there was no explanation given by the students. Those ones were categorized as NE and at almost %32 of the interviews there was no talk about motion (see Table 5.38).

Journal Reflections: Students were sent a form to fill out after the activities finished. In total, 26 out of 44 students sent their reflections. 14 of those students were from the group MaMi and 12 of them were from MiMa.

Students were asked to prefer one of the applications from GasLaws HD and iGas Law and wrote down the reasons of their selection. From 14 MaMi students, 9 of them (64%) selected GasLawsHD application. Their reason for that was the simple use of the application. Other 4 students preferred iGasLaw since that application was the detailed one and it showed the motion of the particles. Just one student from MaMi stated that both applications were useful for understanding the topic. From the 12 MiMa students, only 2 students selected the GasLaws HD application. Students said that GasLaws HD was practical and simple. Other 10 students (83%) selected iGasLaw; again saying that it was designed in a detailed way and gas particles' motion and collision could be seen. In total, 11 students (42%) selected GasLaws HD and 15 students (58%) preferred iGasLaw.

6. DISCUSSION AND CONCLUSION

This study investigated the effect of conducting macroscopic and submicroscopic level iPad activities by switching the order of treatments on 9th grade students' conceptual understanding of gas laws. For this aim, two instructional sequences were prepared: while one group first received the macroscopic level representations on an iPad application and then worked with the submicroscopic level iPad application, the second group followed the reverse order. So that, the effects of these instructional sequences on promoting conceptual understanding of gas laws were compared.

The results were analyzed both quantitatively and qualitatively. The conceptual understanding of the gas laws was measured by the total scores gained in the Gas Concept Test (GCT) and the classroom worksheets both in Boyle's and Charles' Laws. GCT was conducted as pre-test at the beginning of the study, before the implementation; and was conducted as post-test at the end of the study. On the other hand, the classroom worksheets were completed during each implementation. There were four different iPad activities and four worksheets for each activity: Boyle's Law macroscopic, Boyle's Law submicroscopic, Charles' Law macroscopic and Charles' Law submicroscopic level worksheets. In addition, semi-structured interviews were conducted after each implementation. These interviews were transcribed and common patterns about the gas particles' behaviors were analyzed qualitatively. And at the end of the research process, students were asked to write reflections about the benefits of the iPad applications on their understanding of the gas laws.

The participants of the study were 44 ninth grade students, who were conveniently selected from a private high school in İstanbul. There were three 9th grades in the school. Although the students in each class were randomly assigned into two treatment groups, the results of the study cannot be generalized to the whole population. As it was mentioned before, there were two treatment groups in this study: MaMi received first macroscopic level iPad representations, then worked on sub-microscopic level representations; and the second group, MiMa, followed the reverse order both in Boyle's and Charles' Law activities.

The analysis data collected in the study mainly consisted of three main sections: The analysis of GCT, the analysis of worksheets and the findings related to the interviews and journal reflections were given. In order to analyze the data gained through the study, four different inferential statistical methods were carried out. First, the effects of each treatment on each dependent variable, namely conceptual understanding of gas laws were examined using paired samples t-test when the data were normally distributed and Wilcoxon signed ranks test was used when the data were not normally distributed. Second, as both groups were exposed to two different treatments in reverse order, both groups were compared with each other with respect to the changes in conceptual understanding using independent samples t-test if the data were normally distributed, or using Mann Whitney U Test if the data were not normally distributed. Finally, student interviews were analyzed qualitatively.

The analysis of the research question 2 revealed that regardless of order, conducting macroscopic and submicroscopic level activities by using iPad applications was effective to improve conceptual understanding of gas laws. More specifically, the results showed that there was a statistically significant improvement in both MaMi and MiMa participants' scores from GCT-Pre- to GCT-Posttest, regardless of the treatment order. The reason behind this finding would be that students in both treatment groups, iPad applications helped them understand the gas concept. In this study, students spent four class-hours working about macroscopic and submicroscopic level iPad applications in Boyle's and Charles' Law activities. On the other hand, when MaMi and MiMa were compared according to their scores in GCT-Posttest, namely research question 1, it was found that there was not any significant difference between MaMi and MiMa participants' conceptual understanding of gas laws on GCT-Posttest scores. It can be concluded that reversing the order of the implementation did not lead to statistically significant differences between MaMi and MiMa students' conceptual understanding on gas laws. The reason behind the absence of the significant differences between the treatment groups at the end of the study with respect to conceptual understanding of gas laws might be because of the short time interval (2-week-implementation) of conducting the study because of the time constrains of school curriculum. Besides, the power of the instructional design of this present study may lie behind the improvement of the groups, MaMi and MiMa. That is, working both macroscopic and submicroscopic level sides of the gas laws subject for two weeks interactively via iPad applications might be the reason of enhanced student understanding in the GCT-Posttest. Another reason behind this finding might be the major effect of the submicroscopic level representation. When students were exposed to work with the invisible view of the macroscopic world, they might start thinking dominantly within the submicroscopic level regarding the behaviors of gas particles. The findings support the results of other studies (Velazques-Marcano *et al.*, 2004; Taber, 2013). However, Williamson *et al.* (2012), who investigated the order of representation, found a significant difference in favor of the group first worked on macroscopic, then submicroscopic levels.

In research questions 1a, 1b and 1c, GCT-Posttest scores were analyzed in terms of different question types; namely, macroscopic, submicroscopic, both macroscopic and submicroscopic level. In the analyses for those types of questions, no significant differences were found between the groups MaMi and MiMa. No significant difference was found between the conceptual understanding of the two groups after the research process, might indicate that students learn roughly the same from both methods and that the order of the representation at least does no harm to students' conceptual understanding.

The results of analyses with regard to research questions 2a and 2b were discussed in order to investigate MaMi and MiMa groups' progress from GCT-Pre to GCT-Posttest in terms of three types of questions; namely macroscopic, submicroscopic, and both. In research questions 2a, it was found that the group MaMi performed significantly better compared to the group MiMa in terms of macroscopic level questions. The research from Williamson *et al.* (2012) mentioned above, had a similar result, that is, a significant difference in favor of the group who first worked on macroscopic level. This result might have occurred due to the familiarity: as students become familiar with a phenomenon at the macroscopic level, they could have then progressed to more abstract submicroscopic representations. When the submicroscopic type of questions was analyzed, it was found that there was a statistically significant difference for both MaMi and MiMa students from GCT-Pre to GCT-Posttest scores. When the questions including both macroscopic and submicroscopic level representations were analyzed in research question 2b, again it was found that there was a statistically significant difference for both MaMi and MiMa students from GCT-Pre to GCT-Posttest scores. Whether students started working with macroscopic or submicroscopic level representations did not limit their improvement in conceptual understanding of gas laws when the questions included only submicroscopic representations or include both submicroscopic and macroscopic level representations.

Research question 2c required analyses of worksheets according to the total scores in Boyle's Law activity, total scores in Charles' Law activity and total scores in both activities. No significant difference was found between the groups MaMi and MiMa in terms of the total scores they got from the worksheets. Since students completed two worksheets in Boyle's Law activity, they observed both macroscopic level and submicroscopic level representations in two class hours. And then they did the same in Charles' Law activity as well. Also, in the worksheets students were asked to explain their observations and drawings. By asking them to explain concepts, students were able to digest, connect, and combine the understood and newly developed concepts they learned (Abdullah and Shariff, 2008).

Finally, the interviews were analyzed with respect to the pre-determined themes for revealing students' conceptual understandings as research question 3 states. When students' answers to the interview questions were analyzed, it was seen that most of the students explained the concepts asked in the worksheets: volume-pressure relation for Boyle's Law and temperature-volume relation for Charles' Law. However, it was observed that in half of the interviews, students couldn't explain the concept of unit volume. Some students confused the concept of unit volume and the volume of the container. The other interview themes were the number of particles in unit volumes, homogeneity of the particles and the motion of the particles. Mostly the interviewees gave sufficient explanations for the number of particles per unit volume in different situations (different volumes for Boyle's Law and different temperature values for Charles' Law). Again more than the half of the interviews, students explained homogeneity of the particles correctly. The other students had incorrect drawings about the uniformity of gas particles (Cho *et al.*, 2000). However, the motion of the particles theme was the one that most students did not pay attention to. That is to say, some students in the interviews indicated that the particles were moving, however, there were no signals about that movement in the worksheet drawings. This might be due to the wording of the question. The question asked the students to draw the number of particles in each unit volume. Although this criterion was not included in the worksheets, the students were expected to put signals on their drawings or just write in the explanation boxes about the motion of the particles. The drawings might have reflected the motion of the particles, had the question asked to draw the particles in each volume by paying attention to all of the details.

In two of the themes, scientific misconceptions were noticed. The first misconception was that particles get bigger when temperature increases, and get smaller when temperature decreases (Nakhleh, 1992; Sanger *et al.*, 2000; Lin and Cheng, 2000). The other one was about the homogeneity of the particles–one student thought that particles stick together in the middle of the container when temperature was low; and another student thought that the particles would bind to the walls of the container when the temperature was low and would not do so while temperature increases (Novick and Nusbaum, 1978, 1981; Niaz, 2000).

There were two interviewers in the study, and none of them were familiar with the students. Students did not know that the interviewers were also chemistry teachers. Thus, students explain their answers to each question individually and explicitly, which was a positive aspect from the interviews.

In the analysis of research question 4, students' journal reflections were evaluated. It was found out that students generally preferred iGasLaw application since its design was more detailed than GasLawsHD application. Students indicated that iGasLaw application showed the motion of the particles and collisions. Less than a half of the interviewees selected GasLawsHD. Their reason was that GasLawsHD was practical and simple. Therefore, it can be concluded that students were exposed to both a simple designed application and a more detailed one in the concept of Gas Laws. And regardless of the order of the use of these applications, students' conceptual understanding got improved in the research process.

Finally, the crossover research design was used in this study where both groups took the same treatments in reverse order. The results of the research indicated that regardless of the order of treatment, the conceptual understanding of gas laws of both groups improved significantly. This suggested that using macroscopic and submicroscopic level representations together in the same setting created an enriched learning environment, which enhanced the understanding of the gas laws.

6.1. Limitations

This study was run in a high school, thus the research was implemented following the time schedule of the school. Each class had two lesson hours (40 minutes each) of chemistry consecutively. When students finished with the first part; for example the macroscopic level Boyle’s Law activity, after 5 minutes of break time they continued with the other part, i.e. submicroscopic level. Here the limitation is that, the questions of the two worksheets of Boyle’s Law were compatible to each other. Thus, students might have remembered what kind of a graphic he/she just drew in the previous lesson; and so this might have affected their answers in the second worksheet. This situation was observed also in the Charles’ Law activity.

Students completed first Boyle’s Law activities in two class hours (in one week); then they moved on to the Charles Law activity in the second week. Boyle’s Law and Charles’ Law activities were planned to perform in consequent weeks; however due to school holidays, the time in between Boyle and Charles’ activities were not equal in each classroom.

Using iPads created a limitation itself: such a technological device provided the users the opportunity to copy a text and paste it to somewhere else. Since the worksheets were compatible with each other, some students, copied their explanations of the first question in the first worksheet, and just pasted that to the second worksheet. This might have resulted that some students answered some questions without thinking the reasons behind the concept. This observation was confirmed with the interviews. That is, some students realized their mistake during interviews, and corrected them by improving their answers.

Last, the short time interval before the post-testing and having two different interviewers could have made a difference in the research results. Therefore, in order to compare the effects of treatments on both groups properly, it would be suggested to expand the time interval between the treatments and the administrations of the posttests and just having one interviewer.

6.2. Suggestions

In this study, the concept of unit volume was very important since the students were continuously asked to draw particles in unit volume. However, not all of them understood this notion. That is why, before starting the research students should have been shown what a unit volume represents. Also, some interviews showed that students realize their mistakes after thinking aloud. Thus, this study may include a part in which students will tell all the parts recorded in a video. These two suggestions could be taken into account for the instructional designs of further studies.

The findings in the present study are non-generalizable and applicable to other situations. In order for results to be generalized, a larger study with a varied sample selected both from private and state schools using random sampling method is needed. In addition to that, long term effects of using both macroscopic and submicroscopic level representations in different orders on students understanding could be measured as well in further studies.

This study showed the importance of the two levels of representations, macroscopic and submicroscopic in teaching gas laws. Students' conceptual understanding improved only with working with iPad applications including two-level representations regardless of order. In the process, not only working with iPad applications, but also writing their own explanations and drawing their own representations help students understand the subject conceptually. Also, interviewing about the subject, that is thinking aloud, also helped students to realize their own mistakes. And as the focus of the teacher questions about the subject shapes students' responses and the thinking process. For example, asking questions about motion of the gas particles made students think how to show the motion in their answers; and some tried to add some signs into their worksheets indicating the motion.

Last, educational application designers should take macroscopic and submicroscopic level representations into account while working on chemistry applications, especially gas laws. Gas laws applications might give their focus first to the unit volume issue, to ensure that the users were able to differentiate unit volume from the volume of the container. The usage of the applications should be practical, simple and might include parts that students think aloud where the application could perceive key words and so give feedback to students. More importantly, the applications should focus on the student misconceptions special to the subject. They should have extra parts focusing on the misused or misunderstood concepts.

APPENDIX A: GAS CONCEPT TEST (GCT)

GAZ KAVRAMLARI TESTİ

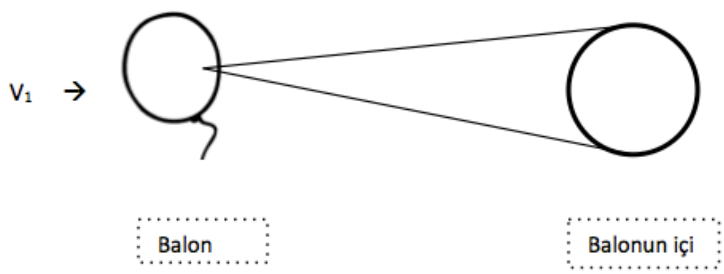
Bu test sizin Gazlar konusundaki kavramları ne derece bildiğinizi değerlendirmek için hazırlanmıştır. Testte toplam 3 tane açık uçlu ve 18 tane çoktan seçmeli soru vardır. Önce açık uçlu sorular cevaplanacak olup, açık uçlu soruların bulunduğu testi öğretmeninize teslim ettikten sonra çoktan seçmeli soruların bulunduğu kısma geçebilirsiniz.

Çoktan seçmeli sorularda her bir soru için beş cevap seçeneği sunulmuştur, ancak bunlardan sadece bir tanesi doğrudur. Soruları cevaplarken dikkatli olmanız ve tüm testi 40 dakikada tamamlamaya gayret etmeniz gerekmektedir.

Soruları cevaplarken boş bırakmayınız, en iyi tahminlerinizi yazınız ya da işaretleyiniz.

Açık Uçlu Sorular

1) a) Bir balonu şişirip ağzını sıkıca bağladığınızı düşünün (balonun hacmi V_1 olsun). Bu balonun içinde ne vardır? Çizerek açıklayınız. (Çiziminizi yaparken, balonun içinde yer alan parçacıkları görebildiğinizi düşünün)



b) Aynı balonu sabit sıcaklıkta biraz daha şişirdiğinizde çiziminizde nasıl bir değişiklik olur? Balonun bu aşamadaki hacmi V_2 olsun. V_1 ve V_2 yi kıyaslayınız.

Hacim	Çizim (Hem balonu hem de balonun içini çiziniz)	Kıyaslama
V_2 →	Balon Balonun içi	V_1 ...... V_2 (“>” ya da “<” işareti kullanarak kıyaslamanızı yapınız)

2) Sabit sıcaklıkta, V_1 boyutundaki balonu alıp bir uçağa bindiğinizi ve yaklaşık 6000 metre yükseldiğinizi düşünün, çiziminizi tekrarlayınız. Balonun yeni hacmi V_3 olsun. V_1 ve V_3 ü kıyaslayınız. (Not: yukarılara çıkıldıkça hava basıncı azalır)

Hacim	Çizim	Kıyaslama
V_3 →	Balon Balonun içi	V_1 ...... V_3 (“>” ya da “<” işareti kullanarak kıyaslamanızı yapınız)

3) V_1 boyutundaki balonun sıcaklığı T olsun. Balonun sıcaklığını 3T'ye çıkardığınızı düşünün, çiziminizi bu durum için de tekrarlayınız. Balonun yeni hacmi V_4 olsun. V_1 ve V_4 ü kıyaslayınız.

Hacim	Çizim	Kıyaslama
V_4 →	Balon Balonun içi	V_1 ...... V_4 (“>” ya da “<” işareti kullanarak kıyaslamanızı yapınız)

İsim: ....

Sınıf: 9/....

Çoktan Seçmeli Sorular

1) Bir maddenin katı halden sıvı hale ve sıvı halden gaz hale geçtikçe moleküllerinin aşağıda verilen özelliklerinden hangisi ya da hangileri değişir?

I. Kinetik enerjileri

II. Büyüklüğü

III. Moleküller arasındaki mesafe

A) Yalnız I B) Yalnız II C) Yalnız III D) I ve III E) I, II ve III

2) Gazlarla ilgili verilen ifadelerden hangisi <u>yanlıştır</u>?

A) Aynı sıcaklıkta bütün gazların ortalama kinetik enerjileri ve yayılma hızları aynıdır.

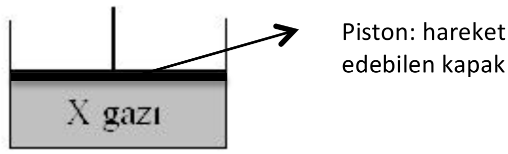
B) Gaz basıncı, gazın moleküllerinin içerdiği atom sayısına ve cinsine bağlıdır.

C) Tanecikli yapıya sahiptir.

D) Gaz basıncı, birim hacimdeki tanecik sayısına bağlıdır.

E) Gazlar, bulundukları kabın her tarafına yayılırlar.

3) Şekilde verilen sistemin pistonu aşağıya doğru itilirse X gazının niceliklerinden hangisi değişir? (P: basınç**, V:** hacim**)**



A) Sıcaklığı

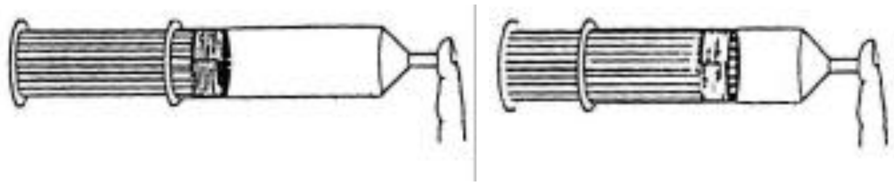
B) (PxV) değeri

C) Ortalama molekül hızı

D) Birim zamanda birim yüzeye çarpan molekül sayısı

E) Moleküllerin ortalama kinetik enerjisi

4) Hava ile dolu bir şırınganın ucu kapatılmakta ve şırınganın pistonu havayı sıkıştıracak şekilde itilmektedir. Bu sıkıştırma sonucunda havayı oluşturan moleküllere ne olur?



A) Moleküllerin hepsi şırınganın ucuna toplanır.

B) Moleküller birbirine yapışır.

C) Moleküller küçülürler.

D) Sıkıştırılan moleküllerin hareketi durur.

E) Moleküller arasındaki mesafe azalır.

5) Kauçuk bir balon Haziran ayı öğle saatlerinde Hidrojen gazı ile doldurulduktan ve balonun hava kaçırmadığı kontrol edildikten sonra ağzı sıkıca bağlanarak bir odaya konur. Ancak, balon aynı gece kontrol edildiğinde sönmüş olduğu görülür. Aşağıdakilerden hangisi bu durumu en iyi açıklamaktadır?

A) Zamanla moleküllerin enerjisi tükenir ve hareketleri durur.

B) Balon deliktir.

C) Hava soğumuştur ve moleküller bir araya kümelenmiştir.

D) Moleküller çarpışa çarpışa küçülmüşlerdir.

E) Hava basıncı artmış ve balonu küçültmüştür.

6) Bir gaz örneğinin hacmini sabit tutarak sıcaklığını düşürmek gazı oluşturan atomların/moleküllerin üzerinde nasıl bir etki oluşturur?

A) Atomların/moleküllerin enerjisi ve hızı azalır.

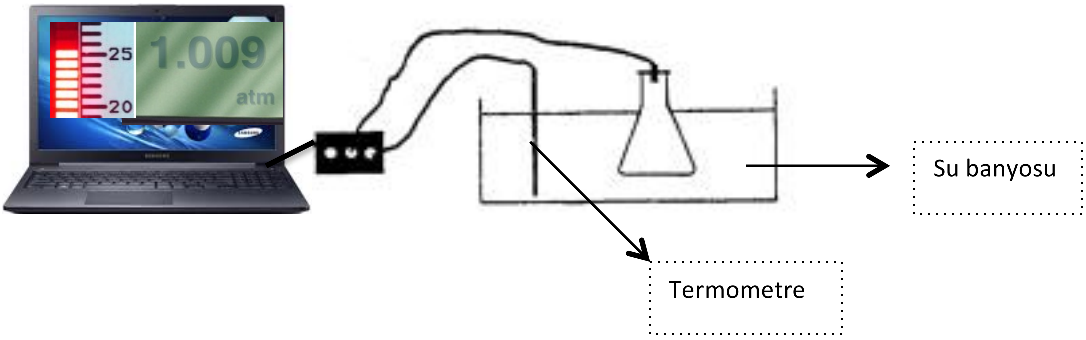
B) Atomlar/moleküller yoğunlaşır.

C) Atomlar/moleküller çökelirler.

D) Atomlar/moleküller büzülür ve küçülürler.

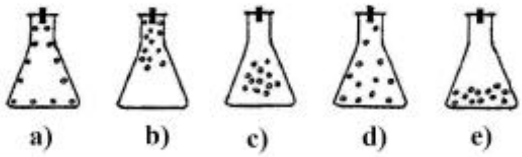
E) Atomlar/moleküller arasındaki çekim kuvveti artar.

Takip eden 7, 8, ve 9. soruları aşağıda verilen açıklamaya göre cevaplandırınız.

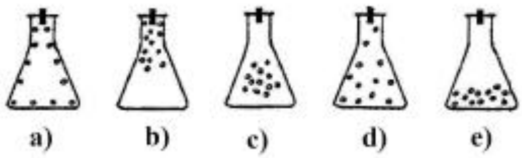


Hava içeren kapalı bir kap şekilde gösterildiği gibi su banyosunun içine yerleştirilmiştir ve bilgisayara bağlanmıştır. Sıcaklık değişimleri kaba yerleştirilen termometre ile takip edilmektedir. Ayrıca kap, basıncı ölçen bir alete de bağlanmıştır ve basınç bilgisayarda okunabilmektedir. 1 atm basınca sahip ortamdaki su banyosunun sıcaklığı ise 25^{o}C'dir.

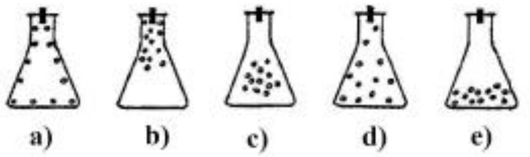
7) 25 ^{o}C'de havayı oluşturan parçacıkların kap içindeki dağılımını en iyi gösteren şekil hangisidir?



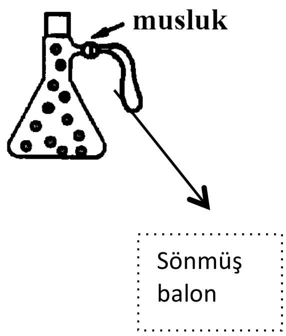
8) Su banyosuna buz ilave edilerek kaptaki sıcaklık 0^{o}C'ye kadar düşürülmektedir. Sıcaklık değişiminin havayı oluşturan parçacıkları etkileyecek kadar bekledikten sonra parçacıkların kap içindeki dağılımını en iyi gösteren şekil hangisidir?

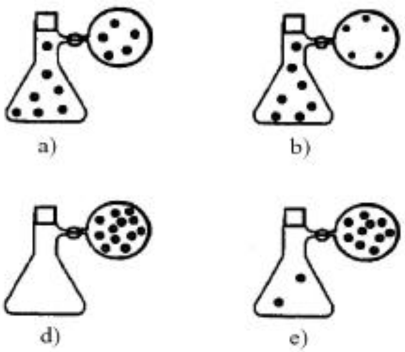


9) Isıtıcı yardımıyla su banyosundaki su ısıtılarak gazı içeren kabın sıcaklığı 60°C'ye yükseltilmektedir. Bu durumda parçacıkların kap içindeki dağılımını en iyi gösteren şekil hangisidir?



10) Hava ile dolu bir kaba şekilde gösterildiği gibi bir balon bağlanmaktadır. Daha sonra aradaki musluk açılarak kap ısıtılmakta ve balon şişmektedir. Balon şiştikten sonra kaptaki ve balondaki havanın dağılımını en iyi açıklayan şekil hangisidir?





11) Havada asılı duran bir cisme atmosfer basıncının etki edip etmediğini görebilseydiniz basıncın yönü hakkında ne derdiniz?

a) Aşağı doğru

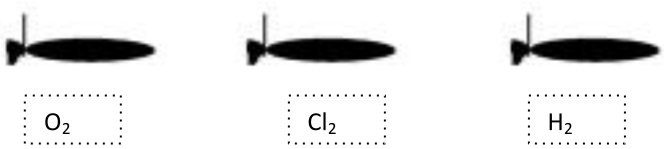
b) Yukarı doğru

c) Her yönden: aşağı yukarı, sağ ve sol

d) İki yönde: aşağı ve yukarı

e) Etkisi yoktur

12) Üç balon üç farklı gazla doldurulmaktadır. Oda şartlarındaki bu üç gazdan eşit sayıda tanecik içerecek şekilde kullanılmaktadır. Gazlarla şişirilen balonların son hacimlerini kıyaslayınız. (O:16, Cl: 35.5, H:1)



a) En büyük klor gazı içerenin olur, kütlesi daha büyük.

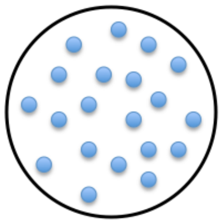
b) En büyük hidrojen gazı içerenin olur, çünkü en hafif gaz.

c) Hacmi hesaplamak için sıcaklık ve basıncı bilmek gerekir.

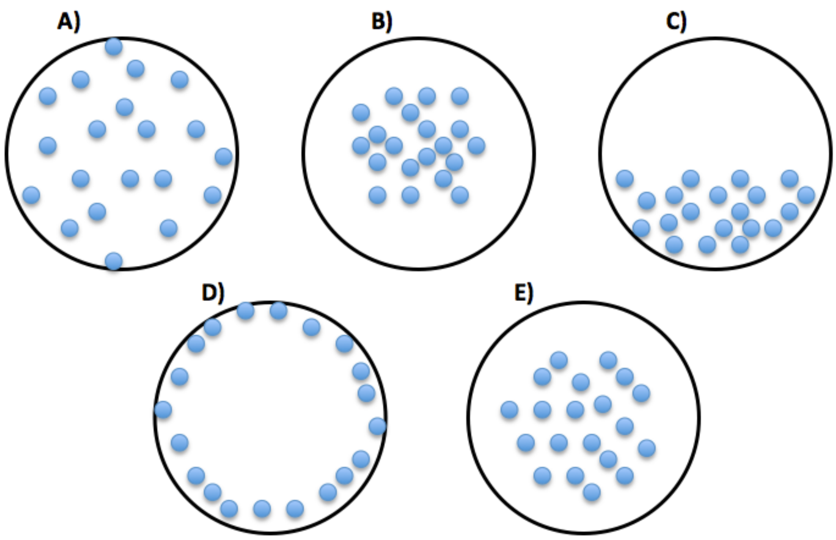
d) Üç balon da aynı büyüklükte olur.

e) Oda şartlarındaki basıncı bilmek gerekir.

13) Aşağıdaki şekil 20^{o}C ve 3 atm basınçta hidrojen gazı ile dolu silindir şeklindeki çelik bir tankın enine kesitidir. Noktalar, tanktaki bütün hidrojen moleküllerinin dağılımını temsil etmektedirler.



Sıcaklık –5^{o}C'ye düşürüldüğünde aşağıdaki şekillerden hangisi kapalı çelik tanktaki hidrojen moleküllerinin muhtemel dağılımını göstermektedir?



APPENDIX B: MACROSCOPIC LEVEL BOYLE'S LAW WORKSHEET

açı	Gaz Yasaları – çalışma kağıdı – 1a	Chem091

Amaç (Aim): Sabit sıcaklıkta belli bir miktar gazın hacmi ve basıncı arasındaki ilişkiyi saptamak.

Malzemeler *(Materials)*:

Adı(Name)	Adet/Miktar(Number/Unit)
iPad App name: Gas Laws HD Lite	

Deney Aşamaları *(Procedure)*:

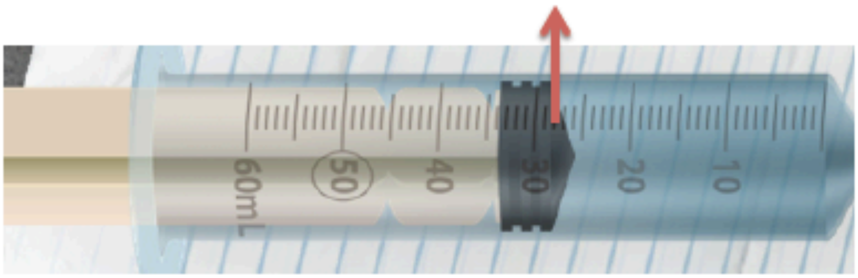
1. "Instructions" a tıklayarak app'i nasıl kullanacağınızı okuyunuz.
2. Şırınganın hacmine karşılık gelen basınç değerini not ediniz.
3. Aynı işlemi üç tane basınç ve hacim değeri elde edinceye kadar yapınız.
4. Değerlerinizi aşağıdaki tabloya not ediniz.

***Sıcaklık:** Bu deney sırasında ortamın sıcaklığı değişmemektedir.*

***Basınç:** Ölçüm cihazı üzerinden "MODE" tuşuna tıklayarak basınç değerini "atm" olarak seçiniz.*

***Hacim:** Şırınganın üzerinde okuduğunuz mL değeridir. Örneğin aşağıdaki şırınga için;*

Hacim 28 mL'dir.



Ölçümler *(Measurements)*:

	Hacim (mL)	Basınç (atm)
1. ölçüm (hacim değeri 35mL'den fazla olmalı)		
2. ölçüm (hacim değeri 25-35 mL arasında olmalı)		
3. ölçüm (hacim değeri 25 mL'den az olmalı)		

Değerlendirme *(Evaluation)*: *(Soruları cevaplandırırken sıcaklığın değişmediğini dikkate alınız)*

1. Şırınganın pistonunu ileri doğru (sağa) ittiğinizde basınç nasıl değişti? Bunun nedeni ne olabilir? Açıklayınız.

Basınçtaki değişiklik:	Açıklama:

2. Şırınganın pistonunu geri doğru (sola) ittiğinizde basınç nasıl değişti? Bunun nedeni ne olabilir? Açıklayınız.

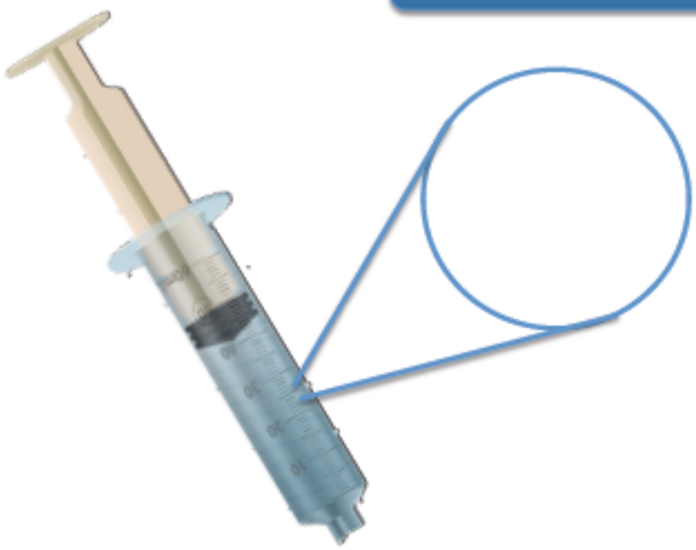
Basınçtaki değişiklik:	Açıklama:

3. İlk iki soruda verdiğiniz cevapları (hacim – basınç ilişkisini) aşağıdaki grafik üzerinde gösteriniz.

4. Özel bir alet kullandığınızı ve bu şekilde maddeyi oluşturan tanecikleri görebildiğinizi varsayın.

Aşağıdaki örneklerde **birim hacim**deki tanecik sayısını çemberlerin içine çiziniz. Çiziminizi açıklayınız.

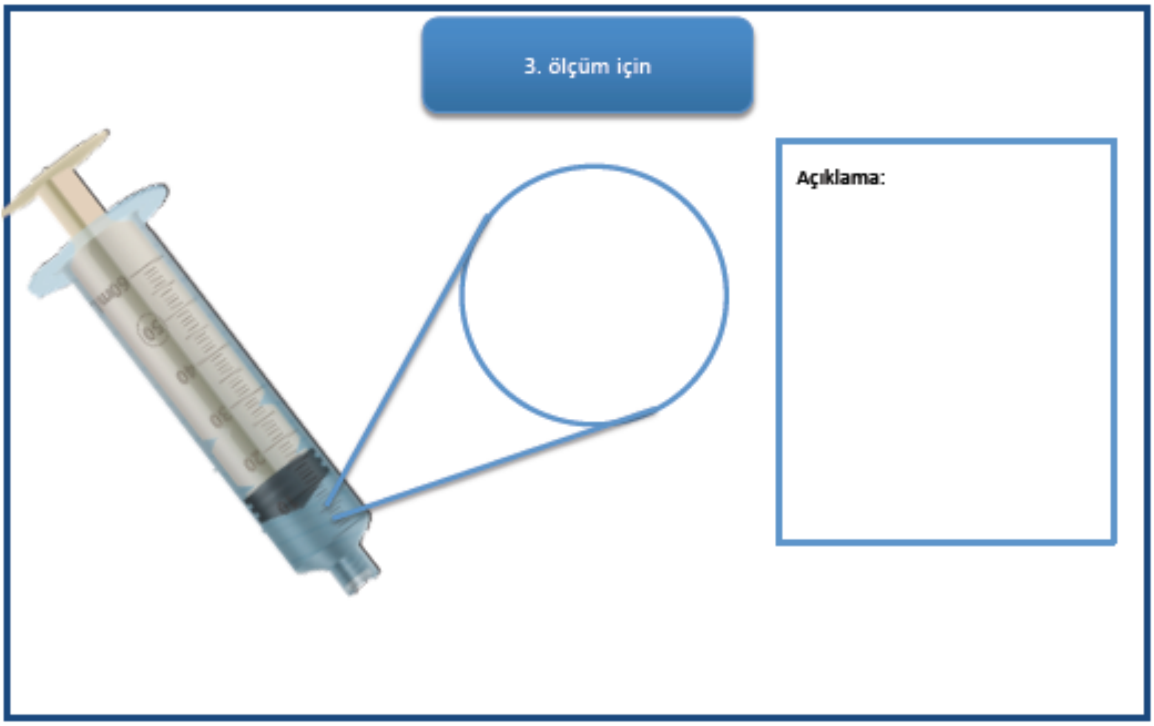
1. ölçüm için



Açıklama:

2. ölçüm için

Açıklama:


3. ölçüm için
Açıklama:

APPENDIX C: SUBMICROSCOPIC LEVEL BOYLE'S LAW WORKSHEET

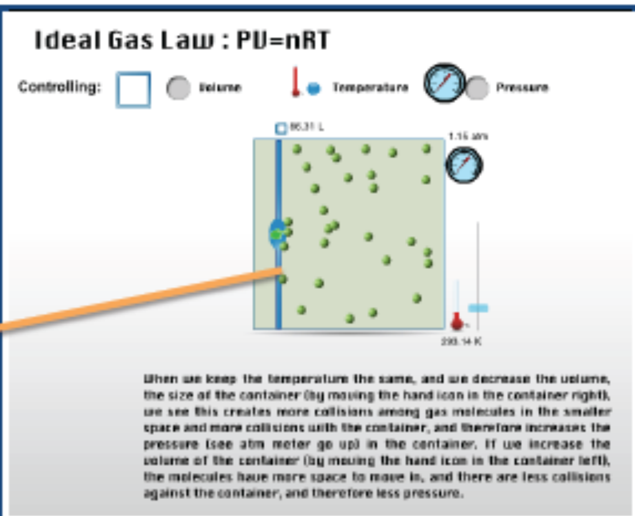
açı	Gaz Yasaları – çalışma kağıdı – 1b	Chem091

Amaç (Aim): Sabit sıcaklıkta belli bir miktar gazın hacmi ve basıncı arasındaki ilişkiyi saptamak.

Malzemeler *(Materials)*:

Adı(Name)	Adet/Miktar(Number/Unit)
iPad App name: iGasLaw	

Piston kapağı



Deney Aşamaları *(Procedure)*:

1. Sıcaklık değerini sabit olarak alınız (yukarıda verilen görselde de görebileceğiniz gibi "Temperature" üzerine tıklayarak sıcaklığı sabit tutunuz).
2. Piston kapağının yerini değiştirerek, 3 farklı durum için hacim ve basınç değerlerini not ediniz.
3. Değerlerinizi aşağıdaki tabloya not ediniz.

Hacim: Pistonlu kabın üzerinde okuduğunuz L değeridir. Örneğin aşağıdaki kap için

Basınç değerini pistonlu kabın sağ üst köşesinde bulunan ve birimi "atm" olarak verilen yerden okuyunuz.

Ölçümler *(Measurements)*:

	Hacim (L)	Basınç (atm)
1. ölçüm (hacim değeri 70L'den fazla olmalı)		
2. ölçüm (hacim değeri 40-70 L arasında olmalı)		
3. ölçüm (hacim değeri 40 L'den az olmalı)		

Değerlendirme *(Evaluation)*: *(Soruları cevaplandırırken sıcaklığın değişmediğini dikkate alınız)*

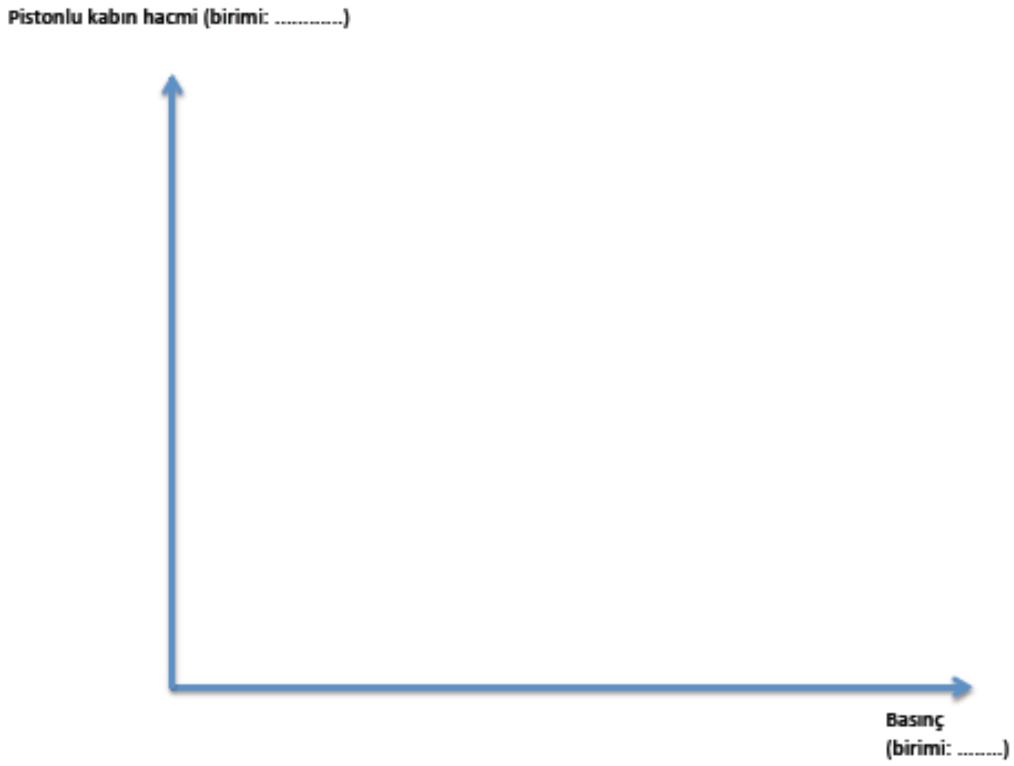
1. Piston kapağını ileri doğru (sağa) hareket ettirdiğinizde basınç nasıl değişti? Bunun nedeni ne olabilir? Açıklayınız.

Basınçtaki değişiklik:	Açıklama:

2. Piston kapağını geri doğru (sola) hareket ettirdiğinizde basınç nasıl değişti? Bunun nedeni ne olabilir? Açıklayınız.

Basınçtaki değişiklik:	Açıklama:

3. Almış olduğunuz ölçümlerden yararlanarak ilk iki soruda verdiğiniz cevapları aşağıdaki grafik üzerinde gösteriniz.

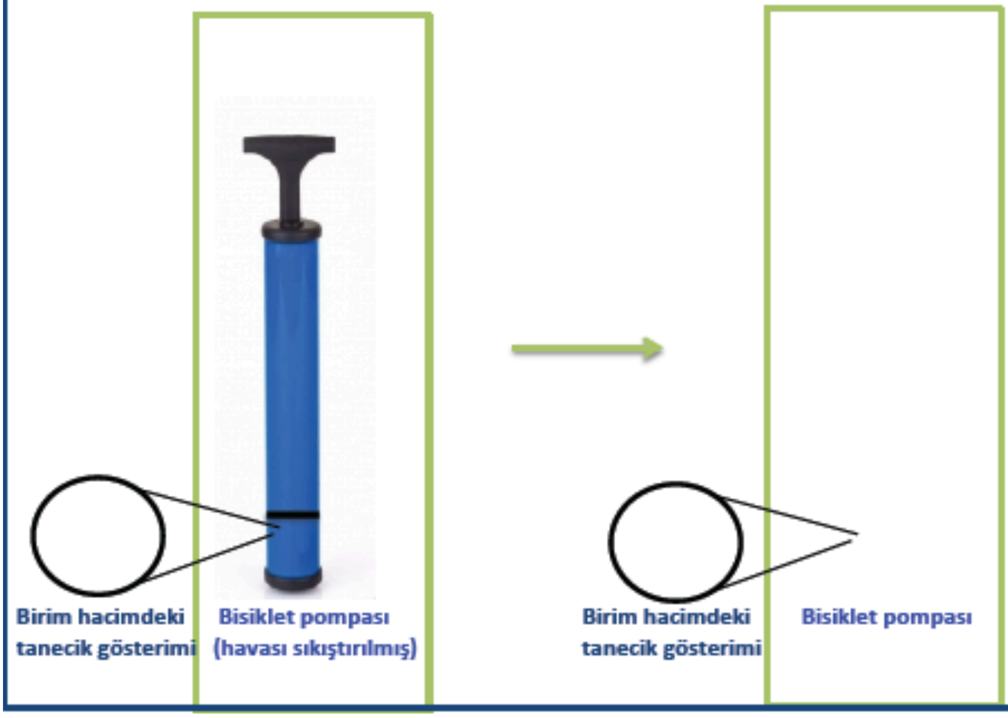


4. Aşağıdaki durumlar için **birim hacim**de yer alan tanecik sayısını çemberlerin içine çiziniz. Çiziminizi açıklayınız.

1. ölçüm	2. ölçüm	3. ölçüm
Açıklama:	Açıklama:	Açıklama:

5. Aşağıda bir bisiklet pompasının ilk durumu verilmiştir. Ağzı sıkıca kapatılmış (yani hava kaçırmayan) bu pompanın pistonunu <u>yukarı doğru çektiğinizde</u> nasıl bir görüntüsü olur? Çiziniz.

Her iki durumda da pistonların **birim hacminde** yer alan tanecik sayısını çiziniz.



APPENDIX D: MACROSCOPIC LEVEL CHARLES' LAW WORKSHEET

	Gaz Yasaları – çalışma kağıdı – 2a	Chem091

Amaç (Aim): Sabit basınçta belli bir miktar gazın sıcaklığı ile hacmi arasındaki ilişkiyi saptamak.

Malzemeler *(Materials)*:

Adı(Name)	Adet/Miktar(Number/Unit)
iPad App name: Gas Laws HD Lite	

Deney Aşamaları *(Procedure)*:

1. Uygulamada sıcaklık birimi olarak K kullanılacaktır.
2. Kırmızı/mavi ok işaretlerine tıklayarak sıcaklığı değiştiriniz, belirlediğiniz sıcaklık değerine karşılık gelen hacim değerini pistonlu silindir üzerinden okuyunuz.
3. Aynı işlemi üç tane basınç ve hacim değeri elde edinceye kadar yapınız.
4. Değerlerinizi aşağıdaki tabloya not ediniz.

Deneyin yapıldığı ortamda basınç değişmemektedir.

Ölçümler *(Measurements)*:

	Sıcaklık (K)	Hacim (L)
1. durum (sıcaklık değeri 273 K'den düşük olmalı)		
2. durum (sıcaklık değeri 273-373 K arasında olmalı)		
3. durum (sıcaklık değeri 373 K'den yüksek olmalı)		

Değerlendirme *(Evaluation)*:

1. Sıcaklık arttığında pistonlu kabın hacminde nasıl bir değişim gerçekleşiyor? Nedenini açıklayınız.

Hacimdeki değişiklik:	Açıklama:

2. Sıcaklık azaldığında pistonlu kabın hacminde nasıl bir değişim gerçekleşiyor? Nedenini açıklayınız.

Hacimdeki değişiklik:	Açıklama:

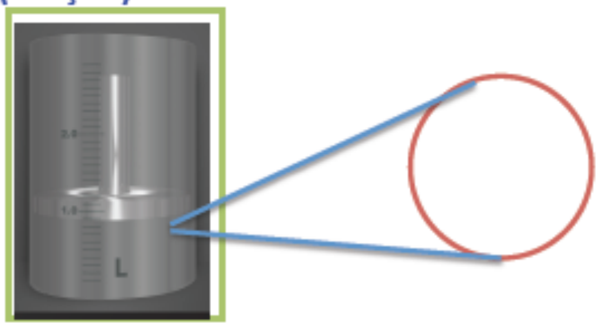
3. Almış olduğunuz ölçümlerden yararlanarak ilk iki soruda verdiğiniz cevapları aşağıdaki grafik üzerinde gösteriniz.

Kabın hacmi (birimi: ....)

Sıcaklık
(birimi: ....)

4. Özel bir alet kullandığınızı ve bu şekilde maddeyi oluşturan tanecikleri görebildiğinizi varsayın. Aşağıdaki örneklerde **birim hacim**deki tanecik sayısını çemberlerin içine çiziniz. Çiziminizi açıklayınız.

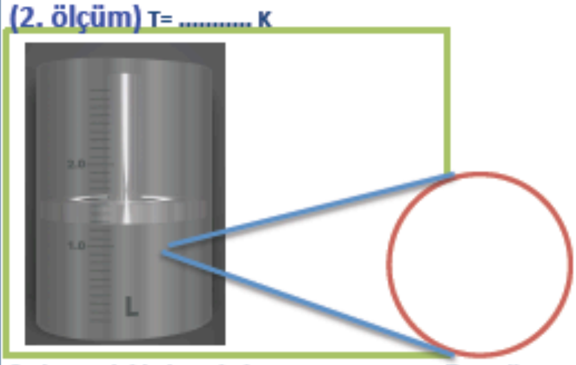
(1. ölçüm) T = ... K



1. durumdaki pistonlu kap — Tanecik

Açıklama:

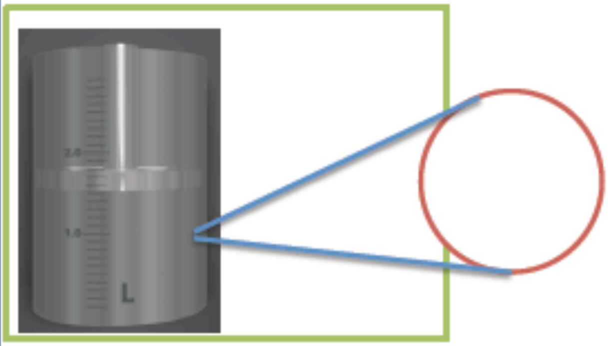
(2. ölçüm) T= .... K



2. durumdaki pistonlu kap — Tanecik

Açıklama:

(3. ölçüm) T= .... K



3. durumdaki pistonlu kap — Tanecik

Açıklama:

APPENDIX E: SUBMICROSCOPIC LEVEL CHARLES' LAW WORKSHEET

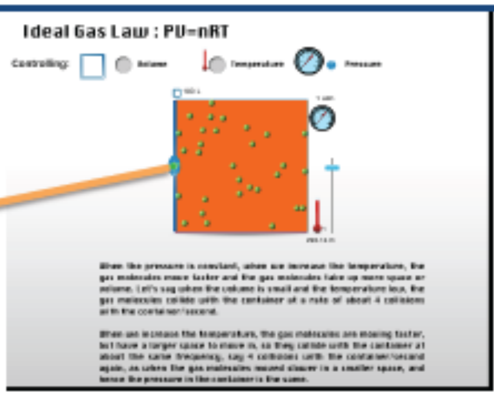
	Gaz Yasaları – çalışma kağıdı – 2b	**Chem091**

Amaç (Aim): Sabit basınçta belli bir miktar gazın sıcaklığı ile hacmi arasındaki ilişkiyi saptamak.

Malzemeler *(Materials)*:

Adı(Name)	Adet/Miktar(Number/Unit)
iPad App name: iGasLaw	

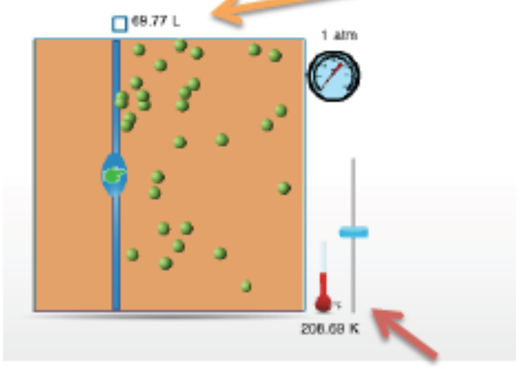
Piston kapağı



Deney Aşamaları *(Procedure)*:

1. Basınç değerini sabit olarak alınız (yukarıda verilen görselde de görebileceğiniz gibi "Pressure" üzerine tıklayarak basıncı sabit tutunuz).
2. Sıcaklık değerini değiştirerek, bu değişikliklerin kabın hacmi üzerinde yarattığı değişikliği gözlemleyiniz.
3. Her sıcaklık değeri için, buna karşılık gelen hacim değerini not ediniz.
4. Aynı işlemi üç tane sıcaklık ve hacim değeri elde edinceye kadar yapınız.
5. Değerlerinizi aşağıdaki tabloya not ediniz.

Hacim: Pistonlu kabın üzerinde okuduğunuz L değeridir. Örneğin aşağıdaki kap için



Sıcaklık değerini pistonlu kabın sağ alt köşesinde bulunan ve birimi "Kelvin" olarak verilen yerden okuyunuz.

Ölçümler *(Measurements)*:

	Sıcaklık (K)	Hacim (L)
1. ölçüm (sıcaklık değeri 150 K'den düşük olmalı)		
2. ölçüm (sıcaklık değeri 150-220 K arasında olmalı)		
3. ölçüm (sıcaklık değeri 220 K'den yüksek olmalı)		

Değerlendirme *(Evaluation)*:

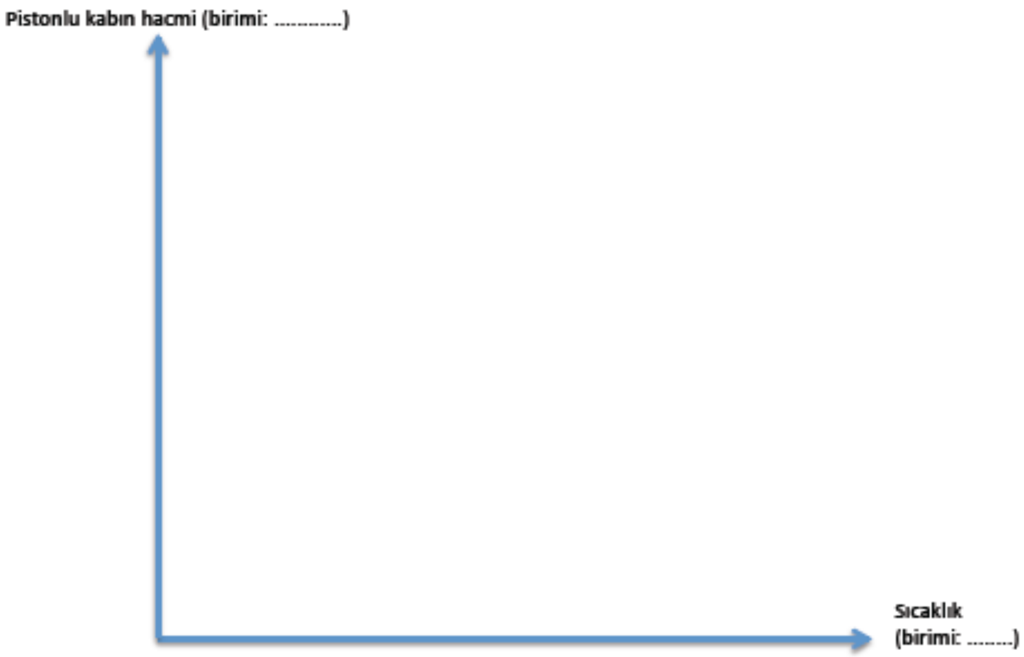
1. **Sıcaklık arttığında pistonlu kabın hacminde nasıl bir değişim gerçekleşiyor? Nedenini açıklayınız.**

Hacimdeki değişiklik:	Açıklama:

2. **Sıcaklık azaldığında pistonlu kabın hacminde nasıl bir değişim gerçekleşiyor? Nedenini açıklayınız.**

Hacimdeki değişiklik:	Açıklama:

3. Almış olduğunuz ölçümlerden yararlanarak ilk iki soruda verdiğiniz cevapları aşağıdaki grafik üzerinde gösteriniz.



4. Aşağıdaki durumlar için **birim hacim**de yer alan tanecik sayısını çemberlerin içine çiziniz. Çiziminizi açıklayınız.

1. ölçüm

T = ...

2. ölçüm

T = ...

3. ölçüm

T = ...

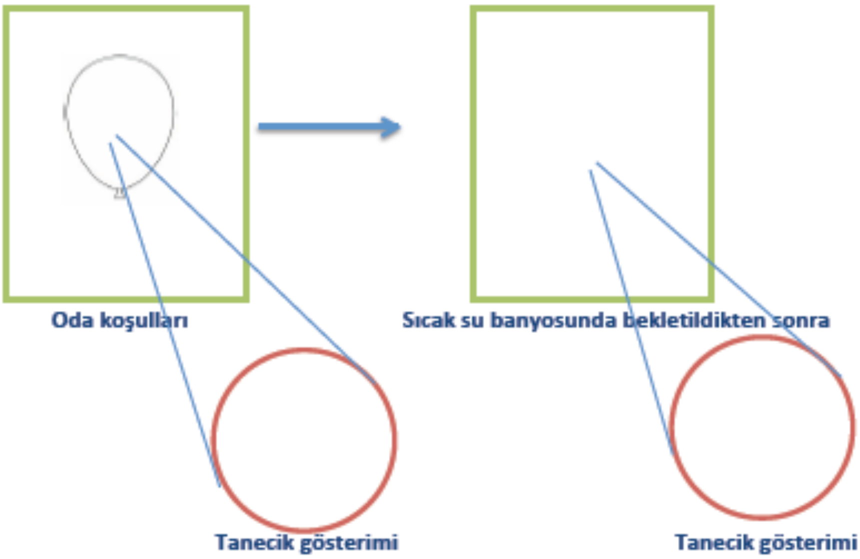
Açıklama:

Açıklama:

Açıklama:

5. Oda koşullarında yer alan balonun şekli aşağıda gösterilmiştir. Bu balonu sıcak su banyosunda bir süre beklettikten sonra balonda nasıl bir değişiklik görürsünüz. Son halinin çizimini siz yapınız.

Her iki durumda da balonların **birim hacminde** yer alan tanecik sayısını çiziniz.



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