AN EXAMPLE ACTIVITY TO SUPPORT DATA LITERACY IN CHEMISTRY EDUCATION: WHAT DOES BOYLE'S DATA SAY?[1]

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ABSTRACT

This study aims to draw attention to data literacy, which is considered an important skill of the 21st century, and to provide an example activity that would incorporate it into chemistry education. The activity was designed using real data of Robert Boyle's experiment. The activity aims to examine Boyle's data in such a way to support data literacy and understand Boyle's law. The activity was carried out with sixteen 11th grade students at an Anatolian High School connected to the Ministry of National Education in a city located in the middle of Türkiye during the 2021-2022 academic year. The students voluntarily took part in the study, which was designed according to the qualitative research method. Data was collected through a written opinion form. The results indicate that the students think that the activity used in this study is effective both in helping them understand the topic and also in supporting data literacy.
Keywords: Boyle's law, chemistry education, data literacy.

KİMYA ÖĞRETİMİNDE VERİ OKURYAZARLIĞINI DESTEKLEMEYE YÖNELİK BİR ETKİNLİK ÖRNEĞİ: BOYLE'UN VERİLERİ NE SÖYLÜYOR?

ÖZ

Bu çalışmanın amacı, 21. yüzyıl becerileri arasında sayılan veri okuryazarlığına dikkat çekmek ve kimya öğretimi sırasında veri okuryazarlığının geliştirilmesini destekleyecek bir etkinlik önermektir. Etkinlik, Robert Boyle'un deneysel verileri yani gerçek veriler kullanılarak tasarlanmıştır. Etkinlikle, Boyle'un verilerinin veri okuryazarlığının geliştirilmesini destekleyecek şekilde incelenmesi ve Boyle yasasının anlaşılması amaçlanmıştır. Etkinliğin uygulama süreci 2021-2022 eğitim öğretim yılında Türkiye'nin orta bölgesinde yer alan bir ildeki Millî Eğitim Bakanlığına bağlı Anadolu Lisesi statüsündeki bir devlet okulunda öğrenim gören 16 onbirinci sınıf öğrencisiyle birlikte yürütülmüştür. Öğrenciler çalışmaya gönüllü olarak katılmışlardır. Araştırma nitel araştırma yöntemine göre tasarlanmış ve veriler yazılı görüş formu aracılığıyla toplanmıştır. Araştırmanın sonuçları; öğrencilerin çalışmada kullanılan etkinliğin hem konuyu anlamada hem de veri okuryazarlığını desteklemede etkili olduğunu düşündüklerine işaret etmektedir.
Anahtar kelimeler: Boyle yasası, kimya öğretimi, veri okuryazarlığı.

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INTRODUCTION

In the last half-century, technology has developed rapidly and the number, variety, and complexity of the data that individuals encounter have increased considerably. Not only do we encounter data in fields such as economics and statistics, but it has now made its way into virtually every aspect of life. These improvements and changes require individuals to become data-literate (Temel Aslan, 2022, p. 5). Data literacy can be defined as the ability to identify, understand, collect, and organize data, as well as to work with, manage, evaluate, and use it, and to be able to do it all with a critical approach (Bhargava & D'Ignazio, 2015; Ridsdale et al., 2015, p. 8) because critical thinking is a foundational skill of data literacy (Ridsdale et al., 2015, p. 4). Data literacy includes the effective understanding and use of data in deciding and convincing others in their decisions (Mandinach & Gummer, 2013; Turan, 2021, pp. 7-8). Additionally, using, analyzing, and evaluating data, and making inferences based on it for revealing problems and creating solutions are among the data literacy skills as well (Vahey et al., 2006).

Data literacy is accepted as one of the 21st-century skills for individuals. Furthermore, this skill is seemed to be one of the major requirements in today's competitive work environment (Valencia, 2021). Therefore, work and incentives for improving data literacy within the formal education framework have recently begun to increase (Wolff et al., 2019). However, it is hard to say that the efforts to improve data literacy are sufficiently reflected in in-class activities (Gibson & Mourad, 2018; Nam & Pardo, 2011). This study is designed to fill the stated gap in the context of chemistry education and so its aim is to teach the chemistry concept of Boyle's law in a way to support data literacy.

Boyle's law is one of the chemistry topics taught while addressing simple gas laws (Petrucci et al., 2012, pp. 198-199). The activity designed under the scope of this study is based on the studies carried out by Boyle himself and the actual data he obtained from his work. This is the most essential aspect of the activity. It enables the students to work with real data. In the literature, it is recommended to use real-world data in teaching data literacy (Data Nuggets Project, 2022; Vahey et al., 2012). The history of science is also included in the activity to help students understand how the real data was obtained. In this regard, the activity includes the history of science in terms of examining how Boyle, who explained the relationship between gas volume and pressure, reached his conclusions. It also takes a look at the studies that came before him. The literature frequently emphasizes the importance of including the history of science in the education process. It is indicated that this contributes to students' understanding of the nature of science, developing positive attitudes towards science and supporting scientific literacy (Laçin Şimşek, 2009; Lederman et al., 2013; Matthews, 1989, 1994; Turgut, 2007). It is also stated that the history of science activities can make students realize that science is something they can do and understand themselves (Appelget et al., 2002). The history of science is used in the activity design for its explained potential benefits. In this context, it is believed that providing the data alongside the history of science can motivate the students to have a positive attitude towards learning the subject.

Another aspect of the activity is that the data creates an opportunity for students to examine the data in a way to support data literacy. It is very important to recognize data while dealing with the data and to know how to question data. Besides, when dealing with data, it is very important to be aware of the inference area when making data-based claims (Hunter-Thomson, 2020), and to rearrange the data in an understandable way if necessary. Otherwise, while the probability of wandering aimlessly among the data increases, the possibility of finding benefits from data decreases (Dykes, 2022). The activity also shows us how to benefit correctly from a data set when we encounter one and how to interact with data in order to benefit from this data set in the right direction and reach useful inferences.

ACTIVITY IMPLEMENTATION

The aim was to provide an activity to be used while addressing Boyle's law under the achievement of "Explains Gas Laws" among other achievements listed in the unit called "Gases" included in the 11th-grade chemistry curriculum. The activity was designed to support the development of students' data literacy skills by examining Boyle's data and understanding Boyle's law. Following the approval of certain permits in terms of the application of the activity (ethical committee, MEB [Ministry of National Education] permit, and voluntary participation form), the activity was carried out by the researcher with sixteen 11th-grade students at an Anatolian High School connected to the Ministry of National Education in a city located in the middle of Türkiye during the 2021-2022 academic year. The activity was implemented in the computer laboratory and lasted for three class hours.

Tools-Materials

The following tools and materials were used in the application of the activity:

- The activity paper titled "What Does Boyle's Data Say?" was prepared by the researcher
- Stationery materials (pencil, eraser)
- Computer (EXCEL should be installed)
- Smartboard (projector can be used as well)

First Phase: Introduction

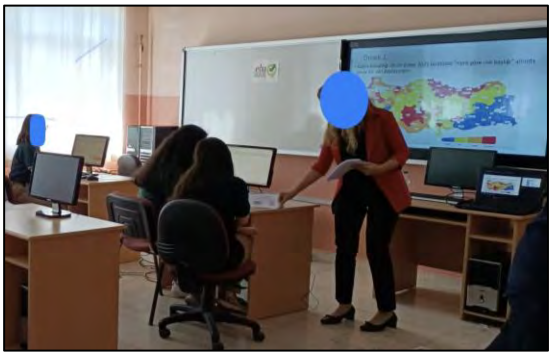
In the first phase of the activity, it was explained that Boyle's law would be examined by incorporating real data from Boyle's experiments. Explaining that data is an important component of science, it was expressed that obtaining data, working with it, and understanding it is a critical ground applied in reaching beneficial inferences and creating rational, reasonable, and acceptable arguments (Marr, 2020; pp. 59-84; Şirin, 2019; Turan, 2021, pp. 1-15). It was also emphasized that people encounter data everywhere. Expressing that we, especially during the Covid-19 pandemic lived in close contact with data, other examples of data that concerned society as a whole (Covid-19, population, PISA, data from the use of information technologies) including data presented by TÜİK (Turkish Statistical Institute), which was displayed on smart boards to prompt discussion with students. In addition, a focus was put on the role that data plays in the production of scientific knowledge. It was then concluded that in today's world where the importance of data highly increased, individuals should have data literacy skills.

Data literacy is a skill that concerns all disciplines. Because of this, activities are needed to increase data literacy in chemistry classes, and the activity to be applied should serve this purpose. Therefore, firstly we drew attention to the place data takes up in our lives, the importance of data literacy, and the data types. Using the question-and-answer method with students, it was explained that data literacy can be improved in the chemistry class that the "What Does Boyle's Data Say?" activity of Boyle's law can be used in this regard and that the aim is to both understand the topic and also help increasing the data literacy. For example, the colored map of Türkiye in Photograph 1 shared by the Ministry of Health during the Covid-19 pandemic is displayed on the screen. The dialogue while displaying this picture are given below:

Teacher: Are you familiar with the map displayed on the screen?
Students [All together]: (Laughing) Yes, we always see this map.
Teacher: What does the map show?
Student 1: The provincial risk map.
Teacher: What is it used for?
Student 2: It helps us get information.
Student 3: It informs us about the number of Covid-19 cases in the province where we are living. It tells us if the number has increased or decreased.
Teacher: Then what do we use this for?
Student 4: If the province we are living in is shown in red, that means we are at high risk. In that case, we take more precautions.

After briefly examining the population data, use of information technologies data, 2003-2009 PISA average sciences grades comparison (the review process can differ according to the class environment, interest and understanding of the students):

Teacher: Do you think the data we are examining is necessary?
Students [All together]: It is.
Teacher: Why?
Student 5: We can make decisions according to this data.
Teacher: What kinds of decisions?
Student 5: For example, population data. It is necessary to use population data to make plans for the country.
Student 6: PISA data can be reviewed to make decisions regarding education or to see how the success rate has changed. Changes can be made accordingly.



Photograph 1. An Image from the First Phase

Second Phase: A Journey to the History of Science

In the second phase of the activity, the first part of the "What Does Boyle's Data Say?" paper was distributed among the students. This section, which is the introductory part of the activity, includes a narrative of the history of science that expresses what had been done until Boyle conducted his experiments about air (Appendix 1). The students were asked to read the text on the papers. Then the studies carried out before Boyle were examined with students using the video (Bar-Yosef, t.y.; Wasserradwander, 2011) and pictures (see Appendix 1) that visually describe what was being communicated by the text. A part of the dialogue from this phase is as follows:

> Teacher: Now we are setting out on a journey to the history of science. This journey will give us important information about the studies conducted on gases. Do you remember Torricelli?
> Student [Together]: Yes.
> Teacher: Can you share what you remember, please?
> Student 1: He discovered atmospheric pressure.
> Student 2: 76 cm-Hg
> Student 3: But it is at sea level.
> Student 4: He flipped a tube filled with mercury into a cup filled with mercury as far as I remember.
> Teacher: Well. Now let's take a closer look at the studies Torricelli carried out, shall we? Later on, maybe you will see a very interesting experiment by a scientist you have never heard of before. Are you ready?
> Students [Together]: (Laughing) Yes.
> Teacher: Well, read the text I gave you by yourselves.

After reading the text, a couple of students were asked to summarize the studies written in the text conducted by Torricelli and Guericke on air. Then they watched the related videos (Photograph 2). Guericke's experiment fascinated the students. The experiment was performed by using the role-playing method and discussions were made about it:

> Teacher: As you saw, the horses had great difficulty. Why could the Magdeburg hemispheres be pulled apart with great difficulty?
> Student 1: The hemispheres were empty. That is the vacuum. That's why.
> Student 2: It is due to atmospheric pressure. There is air pressure. As my friend said, the hemispheres are empty as well.
> Student 3: Can I show it on the board? (The student made the drawing given in Figure 1)

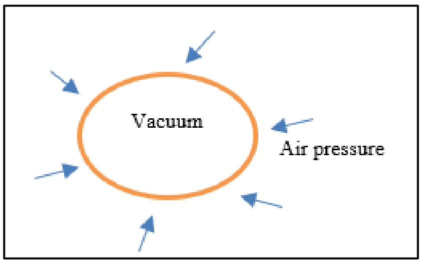
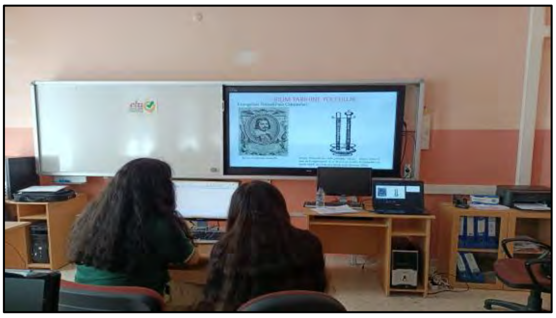


Figure 1. A Student's Drawing

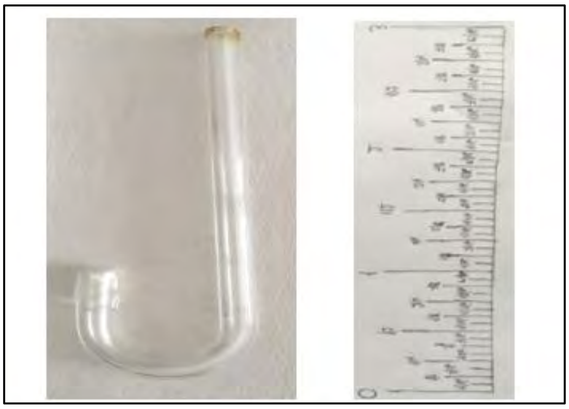
> Teacher: Good. Well, what is the result of Guericke's experiment? What was the result he reached?
> Students [A couple of students together]: He showed the existence of atmospheric pressure.



Photograph 2. An Image from the Second Phase

Third Phase: Boyle's Experiments

In the third phase of the activity, the history of science narrative, which includes Boyle's experiments on air, was distributed to the students (Appendix 2). The students were asked to read the text. Then Boyle's experiments were examined with students using the video (ChemEd X, t.y., the section until the graph) and pictures (see Appendix 2) that describe what is being communicated by the text. Here some examples were given on the J pipe used by Boyle (provided from the laboratory) and his design of length measurement (division in inches).



Photograph 3. Materials Representing the J Pipe Used By Boyle and the Paper Divided in Inches He Prepared for Length Measurement

A couple of students were asked to summarize the studies conducted by Boyle in their own words after reading the text. The materials in photograph 3 were used as well. The review of Boyle's experiment was as follows:

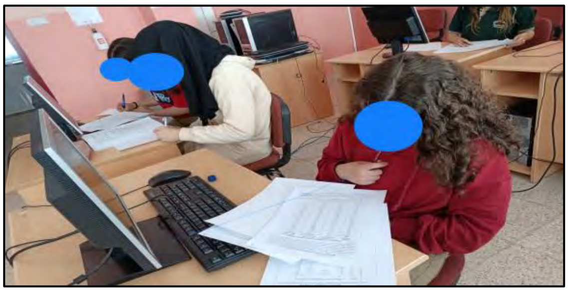
Teacher: What do you have to say about Boyle's experiment? Is there anything in his experiment that draws your attention?
Student 1: Actually, it looks easy.
Student 2: It is a well-designed experiment.
Student 3: I found it interesting that he thought of volume by relating it to length.
Teacher: How? Can you elaborate on that?
Student 3: He made a connection with the volume of the air in the short end of the pipe, that is, the closed end with the length by considering the volume of the place where it is located.
Teacher: Where is it located?
Student 3: There was a cylindrical pipe, there.
Teacher: Yes, good. Did you understand what your friend said?
Students [A couple of students]: Yes.
Student 4: I couldn't quite get it.
Teacher: Can you show on the board how you made that connection to make everything clearer for your friends?
Student 3: Of course. (Writes on the board) $V= \Pi.r^2.h$ this is the volume of the cylinder. Π is already constant, r does not change because it uses the same pipe, and h changes. V α h are proportional. I liked his logic.

Fourth Phase: Boyle's Data

In the fourth phase of the activity, the paper containing the original data of the experiment Boyle and his team carried out with a J tube was distributed among the students and shown on the smart board (Appendix 3). The students were asked whether they understood the real data Boyle and his team gathered or not. All students said that they did not understand. The students said that they did not understand the numbers and the unit used in the data. It is possible to say that the table is not comprehensible because the information on the original data is in English, and the data is given in inches. Since the inch is not a commonly used length of measurement in Türkiye, the students were not familiar with it. The table that included Boyle's data was rearranged by the researcher so that the students could better understand. To this end, the titles in the table were translated into Turkish and the data written in inches were converted into centimeters (cm). The table was recreated with the title "The Rearranged Version of Boyle's Experimental Data" (The table was prearranged by the researcher. If there would be no problem in terms of class time, Boyle's data could be rearranged with the students in the classroom as well. It should be noted that 1 inch = 2.54 cm. Web-based converters can also be used for inch-cm conversion). The paper with the table (Appendix 4) was distributed among the students and displayed on the smart board. The students were asked to examine the table (Photograph 4). They were then asked what they understood from it, and the meaning of every column in the table was examined. After understanding what the data in the table meant, the next stage was applied. A part of the dialogue from this phase is as follows:

Teacher: You have the original data Boyle gathered from his experiment. Can you share your thoughts after analyzing it?
Student 1: There is something I did not quite understand.
Students [Together]: Me too (laughing).

Teacher: Why do you think you did not understand the data?
Student 2: The numbers are different. I mean, they are interesting.
Student 3: They are different, I couldn't make any sense out of it.
Student 4: What is this unit of measurement? Is that why this is different?
Teacher: You made a really good point, well done. Yes, the unit of measure is inches with which we are not quite familiar and hardly use in our country.



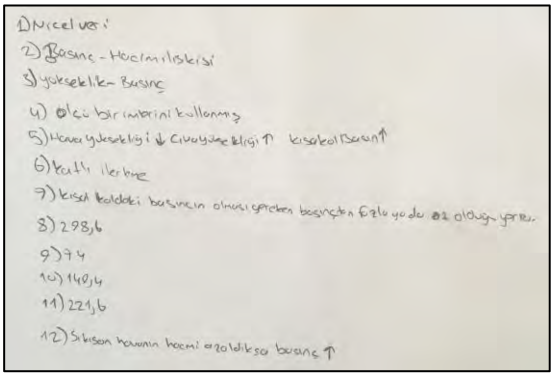
Photograph 4. An Image from the Analysis of Boyle's Data

After students analyzed the rearranged version of Boyle's data:

Teacher: What does the data in the first column of the table represent?
Student 5: The height of the air.
Teacher: The height of the air, but where?
Student 6: At the short leg of the tube.
Teacher: Can you show it with the figure on board?
By drawing a J tube, the student showed the height of the trapped air in the short leg of the tube.
Teacher: Well, what does the data in the second column represent?
Student 7: The mercury height that compresses air. The one that compresses the air in the short leg, that is, the closed end of the tube.
Teacher: How does the mercury compress the air in the short leg of the tube?
Student 8: As Boyle's assistant pours mercury from above, the mercury pushes the air inside the tube and compresses it.
Teacher: Does anyone have a different opinion?
Teacher: Okay, you all think the same. Now, let's look at the chart again. The first data in this column is zero. What do you think this means?
Student 9: Then the mercury height is zero.
Teacher: Which mercury height?
Student 9: The mercury height that compresses the air. I mean, the mercury levels are the same.
Teacher: Correct. Then I will ask a very important question: how did Boyle manage to measure the height of the mercury column that compresses the air in the short leg of the J tube?
Student 10: By subtracting the mercury level in the long leg from the one in the short leg. That is by subtracting.

Fifth Phase: What Does Boyle's Data Say? Analyze and Understand

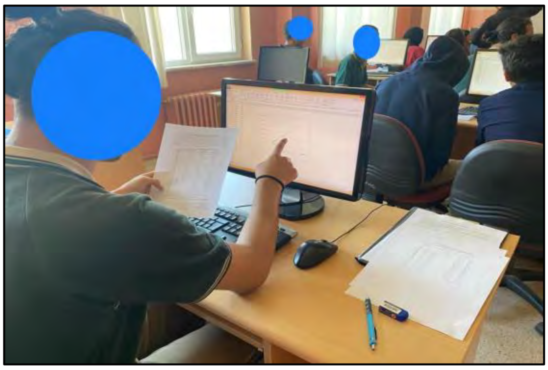
The fifth phase of the activity was carried out on a computer because EXCEL is required. Firstly, the students were asked to reanalyze Boyle's data. Then the worksheet that include the questions that would help the students understand the data were distributed (Appendix 5). The students were asked to work first individually and then in pairs to find the answer to the questions on the paper using Boyle's data. The students said that this was the first time they encountered data this way, so they examined the questions one by one. For example, the students answered the first question by working individually and writing their answers on paper. Then, they worked in pairs, revised their individual decisions, and recorded their group decision (Photograph 5).



Photograph 5. An Example of the Answers Students Gave to the Questions Given in Appendix 5

Afterward, every group shared its decision; in this way, they tried to reach an accurate and acceptable conclusion under the guidance of the teacher. This procedure was applied to every question. The students were asked to use EXCEL on a computer for the questions that required a graph. Students first recorded the data using EXCEL, did the necessary calculations, and then created graphs using the data (Photograph 6). In this phase, the students who had never used EXCEL were provided with support on how to enter data, make calculations and draw a graph. A part of the data analysis conducted with the students is given below:

Teacher: Okay, let's talk about your answers to the first question. What is the type of data Boyle gathered?
Group 1: Quantitative.
Teacher: Does any group have a different opinion?
Seeing all groups have the same opinion
Teacher: Alright, why do you think that?
Group 1: There are numbers. The data is numerical.
Teacher: Can't it be qualitative?
Group 1: No, because there are no characteristics or qualities, it is only the numbers.
Teacher: Does everyone think the same way? Does anyone have a different opinion?
Students [Together]: No.
Teacher: Yes, the type of Boyle's data is quantitative. Numerical data. And they are gathered as a result of measurement. They are not qualitative data because they do not describe qualities or characteristics.
…
Teacher: If you have entered pressure and volume data on the EXCEL sheet, you can continue with the graph drawing.
Students [Together]: We completed it and are now onto the next one.
After completing drawing the graph:
Teacher: What does your graph say to you? Discuss as a group and share your decision with us.
Group 3: It is an inverse proportion graph. Pressure is inversely proportional to volume.
Group 4: Likewise, we think the same as well. As one increases, the other decreases.
Groups [All together]: We also think like that.
Teacher: Can you give an example?
Group 5: For example, while the volume is 25.4, the pressure is 89.7; while it is 17.8, the other is 127.8.



Photograph 6. Calculations and Graph Drawings of the Students Using Boyle's Data

The document titled "Guide for the Applicators" that includes the possible answers to the questions in Appendix 5 is given in Appendix 6. The references are provided in the continuation of the document.

Sixth Phase: What Does Boyle's Data Say? Express It

In the sixth phase, which is the last, the activity was completed, and the students were asked to express for the last time what Boyle's data said. Therefore, Boyle's law was defined based on Boyle's experimental data, and the relationship between the pressure and volume of gases was expressed:

Teacher: Okay, you have analyzed Boyle's data. What did Boyle's data say, can you explain it one last time?
Student 1: Gas volume is inversely proportional to pressure.
Teacher: Can you show it on the board with mathematical expressions?
Student 1: Of course. (Writes on the board) $P \propto 1/V$
Teacher: Great, thank you. Then, does Boyle change the amount of gas in the short leg of the J tube during his experiments?
Students [Together]: No.
Teacher: Then what can we say about the amount of gas?
Students [Together]: It is constant.
Teacher: Good. Well, what was our conclusion in terms of temperature?
Student 2: He did not record any data on the temperature. Which means he did not make any changes in terms of the temperature. So, we thought that he conducted his experiments at the same temperature.
Teacher: Exactly. Then, what can we say about the temperature?

Student 2: It is constant.
Teacher: Let's express the conclusion we draw from here with what we have talked about so that nothing is missing.
Student 3: The volume of the gas is inversely proportional to the pressure of the gas at a constant temperature.
Teacher: Good, does anyone else want to add something else?
Student 4: In constant temperature, as the pressure of gas increases, volume decreases or vice versa.
Teacher: Good, what else?
Student 5: Teacher, we did not say anything about the mass.
Teacher: Exactly, well done, what could we say about that?
Students [Together]: ... (Thinking)
Teacher: We have very little time left guys; we can say it altogether if you like.
Teacher and students [Together]: The pressure of a fixed amount of gas maintained at constant temperature is inversely proportional to the volume of the gas.
Teacher: That's it!!! You have explored Boyle's Law, congratulations! (Applause).

EVALUATION OF THE ACTIVITY

The students were asked to state their opinions on the activity after completing it. A written opinion form consisting of five open-ended questions was prepared to achieve this. The questions were prepared by the researcher and the last version was submitted by taking into consideration the opinions of an expert in science education and a chemistry teacher. The data gathered from the opinion form was analyzed with content analysis. Codes were therefore created according to the concepts gathered from the data; and using these, themes that can describe the data in the general sense were created (Strauss & Corbin, 1990). At the end of the process completed with an expert's opinion, the data was transferred into a table.

The first open-ended question directed at the students for the evaluation of the activity was "When examining Boyle's data, what do you have to say about the meaning of the variables and your understanding of the relation between the variables?" All students answered this question by saying that they had a hard time understanding Boyle's data. It is identified that the explanations of the students can be classified as "unit difference (1)" and "relation between variable (2)" codes that are categorized under the theme of "Understanding Boyle's data." (Numbers are written at the end of the codes specifically. The numbers are given so that it is easier to make connections between the codes and student explanations examples. This is also preferred for other data representations). Examples from student responses are given below.

- At first, I did not understand it when analyzing Boyle's own data. At first, I didn't get it because they were in inches, and it was hard. S1 (1).
- At first, I found it hard. For instance, I couldn't really grasp the relationship between the variables. S14 (2).

The students were asked "Did you have any difficulty understanding the topics such as the type of data, what it was about, the context of data, the pattern of data, outliers, and differences?" to reach more detailed findings on how well the students understood Boyle's data. The explanations of the students were classified as "the context of data (1)", "pattern in data (2)", "what the data was about (3)" and "outliers and differences in data (4)" codes that are categorized under the theme of "recognize data." Examples of student explanations are given below.

- At first, I determined the type of data while examining the data myself. However, I couldn't understand what the data was about, the context of the data, the pattern in the data, and the outliers and differences. I understood these when I dealt with them one by one with the teacher and classmates. S14 (1, 2, 3, 4).
- I didn't understand what the context of data means. But I understood the topic as we talked about it and after the explanations. S7 (1).

Another open-ended question was "How was the “What Does Boyle's Data Say?” activity?" The explanations of the students were classified as "working with real data (1)", "based on application (2)", "far from rote learning (3)", "understandable (4)", "ensuring effective learning (5)", "fun and enjoyable learning (6)", "working with graphs (7)", "using history of science (8)", and "feeling like a scientist (9)" codes that are categorized under the theme of "evaluating the activity." Some examples of the students' explanations are given below.

- It was very exciting to work with real data. S12 (1).
- I think the best part about the activity was to work with real data. It made it easier to understand. We were engaged with the data while doing it. It was application based. It was very productive. S3 (1, 2, 5).
- We had the real data, we had something real. At first, I found it hard to understand the real data, but it got easier as the activity went on. I effectively learned Boyle's law. The activity is far from rote learning; therefore, I think it is important because the activity turns students from memorizers to observers. S14 (1, 3, 5).
- The activity was good. Having the history of science included in it enabled us to feel the conditions of the time and helped us understand how Boyle conducted his experiments. S7 (8).
- It is an activity that teaches you to learn in a fun way, so you can practice many things. I effectively learned Boyle's law. It is a smooth and practical activity. It was an interesting experience for me, it was one of the unforgettable moments of my life. It is very interesting, I felt like Boyle himself while doing the activity. S11 (2, 5, 6, 9).

Another open-ended question was "Do you think the activity supported your data literacy skills or not?" All students responded to this question by saying that the activity did effectively support their data literacy. The explanations of the students were classified as "data comparison/relation (1)", "data analysis (2)", "visualizing data (3)", "improving thinking skills (4)", "interpreting data (5)", and "using data (6)" codes that were categorized under the theme of "supporting data literacy." Some examples of the students' explanations are given below.

- I think it supports data literacy. Since no one told us that this is this and that is that, we ourselves found the connection between the data. S14 (1).
- I definitely think that it supports the skills because I think that comparing and analyzing data contributed to data literacy. S1 (1, 2).
- I think it contributed to data literacy. I believe that analyzing data, creating tables, and drawing graphs contributed to data literacy skills. S4 (3).
- I think that it contributed to data literacy. It improved my logic and the way that I think. S12 (4).
- I think working on data, interpreting it, and making inferences contributed to data literacy and it was fun. S5 (5).
- I learned how data is used. S9 (6).

The last question was "Do you recommend using this activity while learning the topic of Boyle's Law? And why or why not?" Fifteen students answered "Yes" and one student said "No". The affirmative explanations of the students were classified as "based on application (1)", "permanent learning (2)", "student-oriented (3)", "far from rote learning (4)", "working with real data (5)", "facilitation of understanding (6)", "deep learning (7)", "learning the history of science (8)", " learning how to work with data (9)", "fun (10)" codes, and the negative response of the student saying no were classified as "the chance of students not taking the activity seriously (11)", and " not having a computer (12)" codes that are categorized under the theme of "recommend the use of the activity." Some examples of students' explanations are given below.

- I recommend it, it is very useful. I think the application was very useful for me because we only hear these in classes, but there is no such goal as to prove these laws; however, in this activity, we almost proved it with our own work and observations. I felt like I was a university student while doing the activity. S1 (1).
- Of course, I recommend it. It covers the pressure and volume relations, and we worked with the real data, that is, the ones that are gathered at that time. It's been so permanent. S6 (2, 5).
- I recommend it. I believe it is more effective and permanent because it enables the students to use their own capacity. It was really so much fun examining, calculating, and analyzing the data. I believe it really taught the topic instead of making you memorize it. S5 (2, 3, 4).
- Yes, I understood the topic much easier in a shorter time than the ordinary, boring curriculum. I wish it was always like this. Learning by application makes us like the course and also it helps the course to be more productive. S8 (1, 6).

- Yes, because we made a journey to the history of science, we learned how Boyle's Law came about. It is more meaningful this way. S9 (7, 8).
- No, because not everyone might not take the activity seriously and may not contribute to the class, and the full application of the activity might not happen, that is, it cannot be fully done. Additionally, not every school has computers, and this might be a problem. S4 (11, 12).

CONCLUSION and SUGGESTIONS

In this study, an activity based on the use of Boyle’s real data was designed and implemented for teaching Boyle's law. The activity was designed both for teaching Boyle's law and for improving data literacy. The activity showed that the real data of Boyle is incomprehensible, but the rearranged version was more comprehensible for the students. The main reason why the data was incomprehensible had to do with the length measurement used in Boyle's original data, which is inches. Considering the students had never encountered inches, the data was subsequently rearranged by converting inches into centimeters. This helped the students comprehend the data without issue. The first objective was to get to know Boyle’s data in a way to improve data literacy. The students expressed that they had a hard time specifying the context of the data, the pattern in the data, what the data was about, and the outliers and differences in the data. It can be said that recognizing data is the most basic data literacy competency (Hunter-Thomson, 2019; Temel Aslan, 2022, pp. 1-26). The students stated that the subjects within the scope of this competency became understandable when they were examined interactively using Boyle's data.

Upon examining students’ opinions about the activity, all of them submitted positive feedback about the activity and thought that it supported data literacy. All except one student recommended the use of the activity while learning Boyle's law. The explanation of the student that did not recommend the use of the activity showed that he thought that some students either may not take the activity seriously or may not have access to computers at school. The explanation of this student is as follows: "... however, everyone who gets the chance should try it because it was a really good activity to understand the topic. We were excited to find the P-V relation on our own and also it helped us understand the topic." These explanations show that when the students are motivated to both take the application seriously and to take personal responsibility for learning, the activity can be applied more effectively and productively. In this study, it can be stated that the students' voluntary participation, taking the practice seriously, and exhibiting attitudes and behaviors showing that they take responsibility for learning supported the applicability and implementation of the activity. In fact, it can be said that this observation regarding the activity is valid for every in-class application (Aslan, 2015). Looking at the views of the students on the activity, the one aspect that stands out the most is their appreciation for working with real data and its application. The literature also encourages the improvement of data literacy by using real data (Ellwein et al., 2014; Data Nuggets Project, 2022). Authentic data was provided for the students in this activity. However, it is still possible for the students to comprehend the topic and improve their data literacy using the data they gather via data collection (Gibson & Mourad, 2018; Wolff et al., 2016). The literature has been in need of applications designed to support the improvement of data literacy in chemistry teaching. The results of this study also seem to support the idea of designing and applying activities that include different steps in order to improve data literacy.

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Appendix 1

Worksheet Used in the First Part

WHAT DOES BOYLE'S DATA SAY?

Would you like to learn chemistry with real data? You can do the following activity to experience how educational and fun it is. You will first make a journey to the history of science. Then, you will have the opportunity to work with Boyle's experimental data. Please follow the steps given below while doing the activity.

1st STEP

1) Read the text titled "A Journey to the History of Science" below. You are expected to do an active reading.

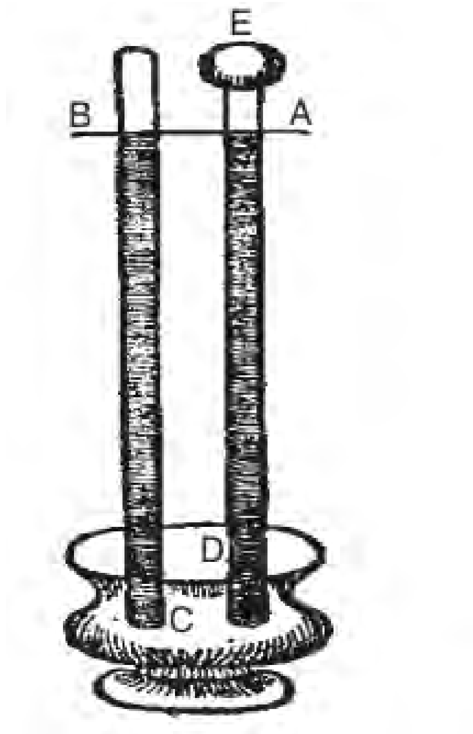
Reminder: Active reading requires you to take the text seriously. It constitutes active thinking and learning, which includes activities that show an interaction with the text such as note-taking, and underlining the sentences or words (O'Hara, 1996; akt. Inie & Barkhuus, 2021).

A JOURNEY TO THE HISTORY OF SCIENCE

The studies on air have an important place in chemistry. Many observations have been carried out on the physical and chemical properties of air. Studies about air showed that air (or gas) has pressure.

Let's remember the experiment where Italian physicist and mathematician Evangelista Torricelli vertically placed a one-meter-long, closed-ended, mercury-filled tube into another mercury-filled container.

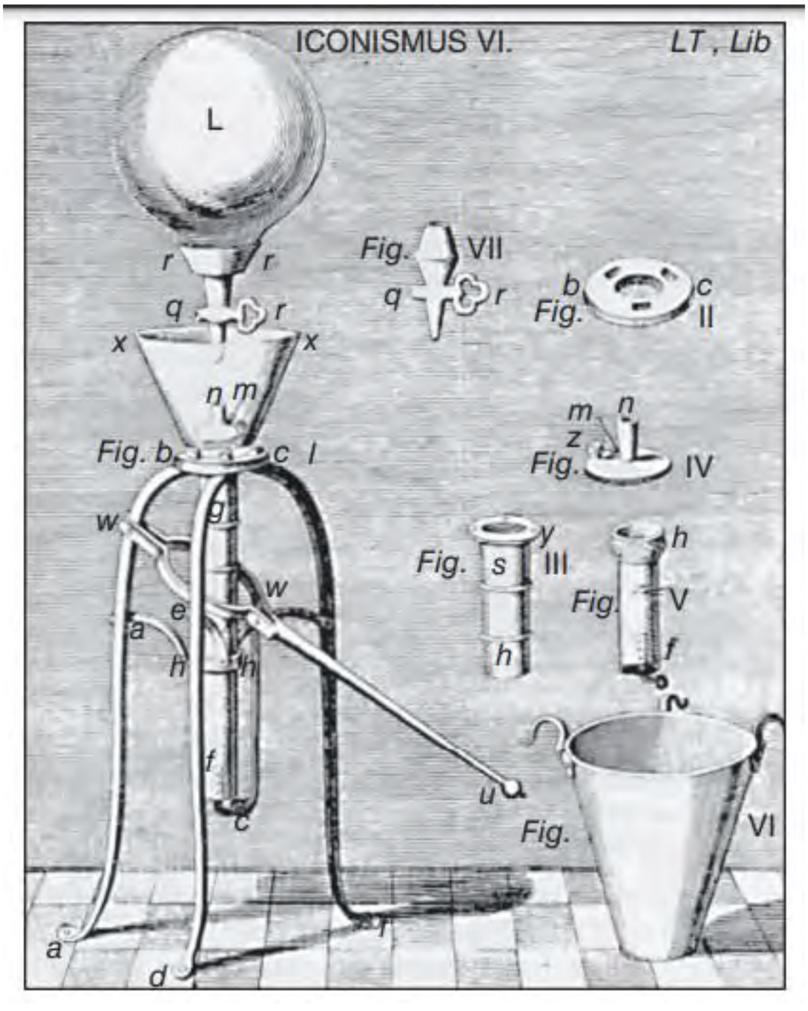
The picture was taken from the cover page of Torricelli's work titled "Lezioni accademiche di Evangelista Torricelli" (Torricelli, 1823).



Picture: Torricelli's vacuum experiment in 1644. A and B mercury levels in C and D tubes are equal regardless of the additional volume E in tube D (Jousten, 2016).

We know that the level of mercury in the tube is about 30 inches[1] when measured from the surface of the mercury in the container, and a space void (vacuum) forms at the top (this void is later called the Torricelli vacuum). In fact, this experiment included a mechanism that had the first feature of a barometer, and also it led to the disappearance of the Aristotelian idea that "nature abhors a vacuum" which was accepted until that time. According to the Aristotelian idea which had not been questioned much for almost 2000 years, it was not possible for an absolute void, that is, a void without matter, to exist because it would immediately be filled with the matter surrounding it. Torricelli's experiment showed that it is possible to form a vacuum. In fact, a vacuum was the key element to a barometer. Besides it being the first successful attempt to form a vacuum, the experiment was also quite important because it showed that the atmospheric air has a weight and exerts pressure.

Later on, the German politician[2], physicist, engineer, and natural philosopher Otto von Guericke invented the first air pump to form a vacuum. The air pump of Guericke could pump the air directly out of a container and create larger volumes of vacuum than Torricelli tubes.



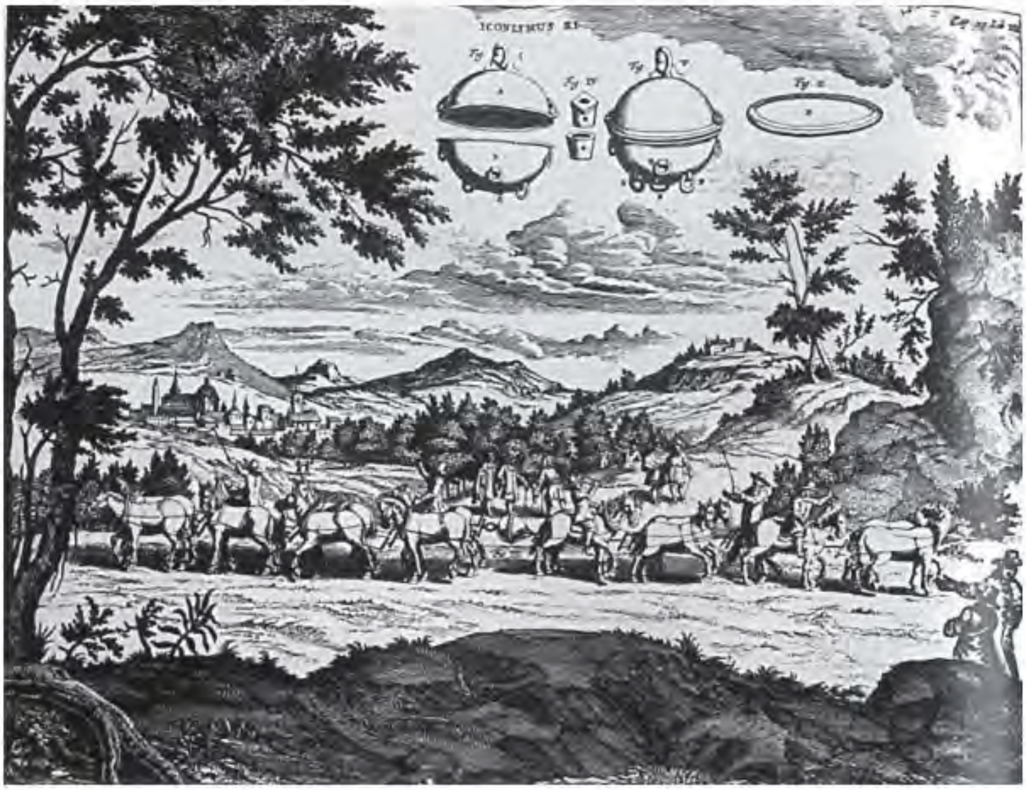
Picture: The air pump of Guericke (Jousten, 2016).

Guericke conducted experiments with these pumps many times. He conducted his most famous experiment that displayed his new vacuum technique in 1657 in Magdeburg. In the experiment, two thick metal hemispheres in the diameter of 40 cm (Magdeburg hemispheres) are used and a leather

[1]inch: Inch is an English measure of length more commonly used in the past. 1 inch equals 2.54 cm. In this case "approximately 30 inches" approximately equals 76 cm.

[2]He was the mayor of Magdeburg, Germany.

ring dipped in candle and turpentine is placed between these hemispheres. He then evacuated the air in the ring by attaching the faucet he fastened to one of the hemispheres beforehand to the vacuum pump. In tis way, when he closed the faucet he managed to form a vacuum inside the container consisting of two hemispheres. Then he tied the rings he attached to the hemispheres beforehand to eight horses on one side and another eight horses on the other. But these groups consisting of eight horses on each side could barely detach the hemispheres after emptying the enclosed volume.



Picture: The picture of Guericke showing the experiment he conducted with hemispheres to the German Emperor Kaiser Ferdinand III (Jousten, 2016).

Guericke clearly demonstrated the existence of a vacuum, and that it is possible to form a vacuum with the air pump he invented, and the existence of atmospheric air pressure. Guernick's air pump is deemed to be one of the biggest technical inventions of the seventeenth century.

Appendix 2

Worksheet Used in the Second Part

2nd STEP

1) Read the text titled "Boyle's Experiments" below. You are expected to do an active reading here as well.

BOYLE'S EXPERIMENTS

All of these studies on air (explained in the previous step) drew the attention of the Irish natural philosopher, chemist, and physicist Robert Boyle. With his assistant Robert Hooke, he designed and produced an air pump superior to Guericke's. Boyle named this air pump "pneumatic engine". With this, he evacuated the air inside many containers (glass spheres, jars, etc.). He showed that as the air pressure on the mercury-filled container in which the tube of Torricelli was placed decreases, the mercury level in the tube decreases. Therefore, he showed that the barometric height of the mercury in Torricelli's barometer depends on outside pressure.

An important question needed to be clarified after Torricelli showed that a vacuum was possible. Why did the empty volumes need to fill up, why a vacuum was a temporary and rare occurrence? While Guernick was working on the vacuum pump, he found that he could not fully get a vacuum in the sphere he was evacuating the air in his first trials. He realized that there was an air leakage into the sphere through the pistons and valves of the pump. With arrangements he made on the air pump (in the third version of the pump) he managed to solve this problem. Right here the question of "why did the void volume (vacuum) filled with air?" became significant. According to Boyle, the magnificent spread power of air filled the space void. For him, the air had “elasticity” and it could be compressed or expanded according to the pressure exerted on it. Boyle furthered his studies on compressing and expanding air and carried out his experiment that led to Boyle's law, which is noteworthy among gas laws. For this, he got a long tube. The two ends of the tube were open. He closed one end airtight by heating it. Then again using heat, he bent the tube in a way that one side is shorter than the other, and the two are almost parallel to one another. In fact, what he had at the end was a J-shaped pipe.

Fig. 7. R. BOYLE, *New Experiments Physico-Mechanical*, London, 1662; *Works*, vol.1, End-plate Fig. 16. BOYLE's J-tube apparatus

The figure was taken from Charles Webster's "The discovery of Boyle's Law, and the concept of the elasticity of air in the seventeenth century" paper (Webster, 1965, p. 485).

The long leg of the tube was open to the atmosphere. This way, Boyle's assistant could pour mercury inside the tube from this end. Therefore, he could increase the pressure on the trapped air in the short leg of the tube. Then he stuck a paper strip to the side of the tube divided into inches fractions so that he could measure the data in terms of length for both mercury and the air. Boyle followed this path to calculate the volume of the trapped air in the short leg of the tube: Assuming that the tube he was working with had a uniform diameter, he thought about calculating the volume of the short leg of the tube, that is the volume of the cylinder, by considering $\Pi.r^2.h$. In this case, the volume is proportional to the length (h) of the short tube. Moving from that, in his data Boyle expressed the volume in length units of inches. On top of this, he noted the mercury levels on both the short and the long legs of the tube and recorded the difference as the pressure in his data. Then, his assistant added mercury from the long and open leg of the tube. In fact, the length of the long leg was more than three meters. Therefore, the tube was placed in a stairwell. As a safety precaution, the bottom part of the tube was placed in a wooden box. This way, if the tube was broken, the mercury would spill into the wooden box (the tube actually did break in one of the trials).

The mercury that Boyle's assistant poured first filled the U-shaped part of the tube. He kept pouring mercury until the mercury level on the two sides of the tube were even. Meanwhile, Boyle took care to bend the tube frequently so that the air could pass freely from the sides of the mercury from one leg of the tube to the other. An equal level of mercury in both legs of the tube meant that the air pressure in the closed short leg of the tube was equal to the atmospheric pressure. Then the assistant kept adding mercury from the long and open leg of the tube. As he added mercury, the mercury in the shorter closed-end leg of the tube pushed the air upward. The volume of air in the short leg gradually decreased. During this process, both Boyle and his other assistant locked their eyes on the measuring strip. They recorded the data they gathered from this point. They did not record any data regarding the temperature.

Appendix 3

Worksheet Used in the Third Part

3rd STEP

1) The data Boyle and his team gathered is given below. Examine the data. Write down what the data in each column is about, whether there is a relationship between the data, and what you understood from the data.

THE REAL DATA OF BOYLE

The data Boyle and his team gathered through their experiments is as follows (Boyle, 1662, p. 60):

Table 1. A Table of the Condensation of the Air

A	*A*	*B*	*C*	*D*	*E*
48	12	00	Added to	$29^{2}/_{16}$	$29^{2}/_{16}$
46	$11^{1}/_{2}$	$01^{7}/_{16}$	$29^{1}/_{8}$	$30^{9}/_{16}$	$30^{6}/_{16}$
44	11	$02^{13}/_{16}$	makes	$31^{15}/_{16}$	$31^{12}/_{16}$
42	$10^{1}/_{2}$	$04^{6}/_{16}$		$33^{8}/_{16}$	$33^{1}/_{7}$
40	10	$06^{3}/_{16}$		$35^{5}/_{16}$	35
38	$9^{1}/_{2}$	$07^{14}/_{16}$		37	$36^{15}/_{19}$
36	9	$10^{2}/_{16}$		$39^{4}/_{16}$	$38^{7}/_{8}$
34	$8^{1}/_{2}$	$12^{8}/_{16}$		$41^{10}/_{16}$	$41^{2}/_{17}$
32	8	$15^{1}/_{16}$		$44^{3}/_{16}$	$43^{11}/_{16}$
30	$7^{1}/_{2}$	$17^{15}/_{16}$		$47^{1}/_{16}$	$46^{3}/_{5}$
28	7	$21^{3}/_{16}$		$50^{5}/_{16}$	50
26	$6^{1}/_{2}$	$25^{3}/_{16}$		$54^{5}/_{16}$	$53^{10}/_{13}$
24	6	$29^{11}/_{16}$		$58^{13}/_{16}$	$58^{2}/_{8}$
23	$5^{3}/_{4}$	$32^{3}/_{16}$		$61^{5}/_{16}$	$60^{18}/_{23}$
22	$5^{1}/_{2}$	$34^{15}/_{16}$		$64^{1}/_{16}$	$63^{6}/_{11}$
21	$5^{1}/_{4}$	$37^{15}/_{16}$		$67^{1}/_{16}$	$66^{4}/_{7}$
20	5	$41^{9}/_{16}$		$70^{11}/_{16}$	70
19	$4^{3}/_{4}$	45		$74^{2}/_{16}$	$73^{11}/_{19}$
18	$4^{1}/_{2}$	$48^{12}/_{16}$		$77^{14}/_{16}$	$77^{2}/_{3}$
17	$4^{1}/_{4}$	$53^{11}/_{16}$		$82^{12}/_{16}$	$82^{4}/_{17}$
16	4	$58^{2}/_{16}$		$87^{14}/_{16}$	$87^{3}/_{8}$
15	$3^{3}/_{4}$	$63^{15}/_{16}$		$93^{1}/_{16}$	$93^{1}/_{5}$
14	$3^{1}/_{2}$	$71^{5}/_{16}$		$100^{7}/_{16}$	$99^{6}/_{7}$
13	$3^{1}/_{4}$	$78^{11}/_{16}$		$107^{13}/_{16}$	$107^{7}/_{13}$
12	3	$88^{7}/_{16}$		$117^{9}/_{16}$	$116^{4}/_{8}$

AA. The number of equal spaces in the shorter leg, that contained the same parcel of air diversely extended.
B. The height of the mercurial cylinder in the longer leg, that compressed the air into those dimensions.
C. The height of a mercurial cylinder that counterbalanced the pressure of the atmosphere.
D. The Aggregate of the two last columns B and C, exhibiting the pressure sustained by the included air.
E. What that pressure should be according to the hypothesis, that supposes, the pressures and expansions to be in reciprocal proportion.

Appendix 4

Worksheet Used in the Fourth Part

4th STEP

1) Below is the text titled "The Rearranged Version of Boyle's Data". Read the text and examine the rearranged version of Boyle's experimental data. Then show every variable the data belongs to on the figure by drawing Boyle's experiment mechanism (J-shaped pipe with mercury) figure. (For example, the first column has the variable of the air height in the shorter closed-end leg. Show the height of air in the figure.)

THE REARRANGED VERSION OF BOYLE'S DATA

Boyle used inches as the unit of length. Today the use of inch is not preferred. Instead, the International System of Units (SI) proposed by the experts who came together at the General Conference on Weights and Measures in 1960 is used. The unit of length in the SI metric system is determined as m (meter). With the prefixes used in SI units, subunits such as cm (centimeters) can be used as well. Because the SI system of units is used in schools and students are familiar with it, the inch was converted into cm to make the experimental data of Boyle clearer. The version in which this conversion was made and Boyle's data was rearranged in a clearer way is given below (the numbers are rounded up so that there is one digit after the comma).

Table 1: The rearranged version of Boyle's data

The height of the air in the shorter closed-end leg (cm)	The height of the mercurial cylinder compressing air (cm)	The height of a mercurial cylinder that counterbalanced the pressure of the atmosphere (cm)	The pressure of the air in the shorter closed-end leg (cm)	The pressure according to the hypothesis (cm)
30.5	0.0	74.0	74.0	74.0
29.2	3.6		77.6	77.2
27.9	7.1		81.1	80.6
26.7	11.1		85.1	84.2
25.4	15.7		89.7	88.9
24.1	20.0		94.0	93.4
22.9	25.7		99.7	98.7
21.6	31.7		105.7	104.4
20.3	38.2		112.2	111.0
19.1	45.5		119.5	118.4
17.8	53.8		127.8	127.0
16.5	64.0		138.0	136.6
15.2	75.4		149.4	148.0
14.6	81.7		155.7	154.4
14.0	88.7		162.7	161.4
13.3	96.3		170.3	171.6
12.7	105.6		179.5	177.8
12.1	114.3		188.3	186.9
11.4	123.8		197.8	197.3
10.8	136.3		210.3	208.9
10.2	147.6		221.6	221.9
9.5	162.4		236.4	236.7

8.9	181.1		255.1	253.6
8.3	199.8		273.8	273.1
7.6	224.6		298.6	295.9

1st Column: Represents the volume of the trapped air in the shorter closed-end leg of the J tube.
2nd Column: The difference in the mercury levels in two legs of the J tube.
3rd Column: Represents the barometric pressure in the room.
4th Column: The total pressure acting on the trapped air in the short leg of the J tube.
5th Column: This is the theoretical calculation for the pressure based on the data set and PxV=k[3].

[3] The first data set is the data gathered when the mercury levels on both legs of the J tube are even, that is, the pressure of trapped air in the short leg equals the atmospheric pressure. Accordingly, V=30.5; P=74.0. Then, the total pressure acting on the trapped air in the short leg, in other words the pressure of the trapped air is theoretically calculated from the $P_1xV_1=P_2xV_2$ equation and the last column is created this way. Such as 30.5x74.0= P_2x29.2 from here P_2=77.2. Please note that because the numbers are rounded so that there is one digit after the comma to make them easier to work with, there may be some minor errors in the rounded up measurement results.

Appendix 5

Worksheet Used in the Fifth Step

5th STEP

1) Reexamine the rearranged version of Boyle's experimental data given in the 4th step and try to find the answers to the questions given below. State your answers in writing. Examining data with questions will help you better understand the data, produce information from the data, and reach beneficial inferences.

WHAT DOES BOYLE'S DATA SAY? ANALYZE AND UNDERSTAND

1) ***What is the type of data Boyle gathered?***
2) ***What is the context of the data?***
3) ***What does the data in the table relate to?***
4) ***How could the variables in the table be defined? What kind of a path did Boyle take to measure these variables?***
5) ***How does every single one of the variables change?***
6) ***What is the pattern in the data?***
7) ***Are there any outliers/differences in the data?***
8) ***What is the pressure in the lowest volume of the trapped air in the short leg of the J tube?***
9) ***What is the pressure in the highest volume of the trapped air in the short leg of the J tube?***
10) ***What is the pressure when the volume of the trapped air in the short leg of the J tube is approximately halved?***
11) ***What is the pressure when the volume of the trapped air in the short leg of the J tube is reduced to about one-third?***
12) ***How could the data distribution on the volume and pressure of the trapped air in the short leg of the J tube be associated?***
13) ***Transfer the data on the volume and pressure of the trapped air in the short leg of the J tube to EXCEL. Draw a P-V graph in EXCEL.***
14) ***What could be said regarding the pattern in the data based on the graph you drew in Question 13?***
15) ***Calculate the inverse volume (1/V) value from the volume (V) values in the table using EXCEL and draw a P - 1/V graph.***
16) ***What could be said regarding the pattern in the data based on the graph you drew in Question 15?***
17) ***Calculate the multiplication of the volume (V) and pressure (P) values in the table using EXCEL. Compare and evaluate your results.***
18) ***Draw the PxV - P and PxV - V graphs using EXCEL.***
19) ***What could be said regarding the pattern in the data in PxV – P and PxV – V graphs?***
20) ***Calculate and interpret the percent error using Boyle's pressure data (data in the last two columns of the data table) in EXCEL.***

Percent error = |true value-experimental value| / true value x 100%

Reminder: There may be errors in the data obtained from the measurements made during the experimental studies. There are many reasons leading to these errors. While some of the error sources can be eliminated (such as tool or method errors), some may not be eliminated. Even the sources of these errors might not be identified. What path should we take in such cases? How can we evaluate the measurement results? We can make error calculations for this reason. For example, we can calculate percent error. Because accuracy indicates the closeness of a result to the real value, and it is possible to express it with percent error. Lastly, when interpreting the percent error results, if the value is below 5%, you can consider the measurement results, that is, the data, acceptable.

21) What kind of an argument based on the data could you put forward considering all the studies we did while examining Boyle's data?

Appendix 6

Worksheet Used in the Sixth Step

A GUIDE FOR THE APPLICATORS

Examine the experimental data of Boyle. Try to find the answers to the questions below to help you understand the data.

1) What is the type of data Boyle gathered?

Data is quantitative data when it indicates numbers, in other words, quantity.

2) What is the context of the data?

Boyle obtained his data during his studies on compressing and expanding air. He gathered 3 different data regarding 25 different trials (measurement) in the studies he conducted. The data was related to the height of mercury added to the J tube, the height of the trapped air in the shorter closed-end leg of the tube as the mercury is added, and the pressure of trapped air. The height of a mercurial cylinder that counterbalanced the pressure of the atmosphere is 74 cm. So the barometric pressure of the room is 74 cm-Hg. There was no data regarding the temperature in the experiment the data was gathered from (It can be assumed that the temperature is the same for 25 trials).

3) What does the data in the table relate to?

First, there is the height of the trapped air in the short closed-end leg of the J tube in the table. The height of the trapped air is in inches in the original data. The second data was the mercury height which represents the mercury level difference in the long and short legs of the tube after adding mercury from the long leg of the tube. In the table, this data is indicated as the mercury height that compresses the air and is again measured in inches. The third data was the height of a mercurial cylinder that counterbalanced the pressure of the atmosphere. It was barometric pressure of the room. The fourth data was related to the pressure of the trapped air in the short closed-end leg of the J tube and again is measured in inches. The last data was the pressure according to the hypothesis (The hypothesis, that supposes, the pressures and expansions to be in reciprocal proportion). Inch was converted into centimeter for easier comprehension.

4) How could the variables in the table be defined? What kind of a path did Boyle take to measure these variables?

<u>Independent variable:</u> The height of the mercurial cylinder compressing air (This actually represents the pressure of the mercury compressing the air).

<u>How the independent variable is observed:</u> It is observed by measuring the length (inch) difference of the mercury levels between the long and short legs of the tube based on every time the mercury is added from the long opened-end leg of the J tube.

<u>1st Dependent variable:</u> The height of the trapped air in the short closed-end leg of the J tube (This actually represents the volume of the trapped air in the short closed-end leg of the J tube).

<u>How the 1st dependent variable is observed:</u> It is observed by measuring the length (inch) of the height of the trapped air in the short closed-end leg of the tube as the mercury is being added from the long opened-end leg of the J tube.

<u>2nd Dependent variable:</u> The pressure of the trapped air in the short closed-end leg of the J tube.

<u>How the 2nd dependent variable is observed:</u> The data regarding this variable is obtained via calculations. Boyle found the pressure of the trapped air in the short leg of the tube by adding the pressure of the environment where the experiment was conducted to the pressure that the mercury added to the tube exerts.

In his experiment, Boyle recorded the height of a mercurial cylinder that counterbalanced the pressure of the atmosphere was 29(1/8) inches; therefore, he added the value of 29(1/8) inches to each height observed in the long leg to obtain the pressure that the air exerts, and this total was reflected on the table as the pressure that the air in the short leg exerts.

To be clearer 29(1/8) inches is accepted as 29.125 x 2.54 = 73.9775 ≈ 74.0 cm.

5) How does every single one of the variables change?

The height of the trapped air in the short closed-end leg of the J tube decreases as mercury is added from the long opened-end leg of the tube. The height of the mercury that compresses the air (the height of the mercury level differences between the long and short legs of the tube) increases as mercury is added from the long leg of the tube. The pressure of the trapped air in the short leg of the J tube increases as the mercury is added from the long leg of the J tube. The value of the barometric pressure in the room was fixed (74 cm-Hg).

6) What is the pattern in the data?

There is a negative relationship between the height of the mercury level difference between the long and short legs of the J tube (as mercury is added from the long leg) and the height (volume) of the trapped air in the short end of the J tube. In other words, as the height of the mercury level difference between the legs of the tube increases, the height of the trapped air in the short leg of the tube decreases. These decreases are not regular/linear. For example, when the height of the mercury level difference between the legs of the tube approximately doubles, the height of the trapped air in the short leg of the tube does not fall half.

There is a positive relationship between the height of the mercury level difference between the long and short legs of the J tube and the pressure of the trapped air in the short leg of the tube. In other words, as the height of the mercury level difference increases, the pressure of the trapped air in the short leg of the tube increases. These increases are not regular/linear. For example, when the height of the mercury level difference between the legs approximately doubles, the pressure of the trapped air in the short leg of the tube does not double.

When the height (volume) and the pressure of the trapped air in the short leg of the J tube are evaluated together according to the height of the mercury level difference between the long and short leg of the tube, that is, as mercury is added from the long leg of the tube, as the height (volume) of the trapped air decreases, its pressure always increased. We can say that the relationship between the decrease in the volume of the trapped air and the increase in its pressure is proportional. When the volume of the trapped air is approximately decreased by half (decreased from 30.5 cm to 15.2 cm), the pressure of the gas approximately doubles (increases from 74.0 cm to 149.4 cm).

7) Are there any outliers/differences in the data?

No. As the height of the mercury that compresses the air increases, the height of the trapped air in the short leg decreases. There is no data that breaks this negative relationship between the data. In other words, there is no data showing that as the height of the mercury that compresses the air increases, the height of the trapped air in the short leg increases. As the height of mercury compressing the air increases, the pressure of the trapped air in the short leg increases as well. There is no data that breaks this positive relationship between the data. In other words, there is no data showing that as the height of the mercury increases, the pressure of the trapped air in the short leg decreases. When the data of the height and pressure of the trapped air in the short leg is evaluated, as the height of the trapped air decreases, its pressure increases. There is no data that breaks this relationship between the data of the height and pressure of the trapped air. In other words, there is no data indicating that as the height of the trapped air in the short leg decreases, the pressure of the trapped air in the short leg decreases. The height of the trapped air in the short leg represents the volume of the trapped air.

8) What is the pressure in the lowest volume of the trapped air in the short leg of the J tube?

298,6 cmHg

9) What is the pressure in the highest volume of the trapped air in the short leg of the J tube?

74,0 cmHg

10) What is the pressure when the volume of the trapped air in the short leg of the J tube is approximately halved?

149,4 cmHg

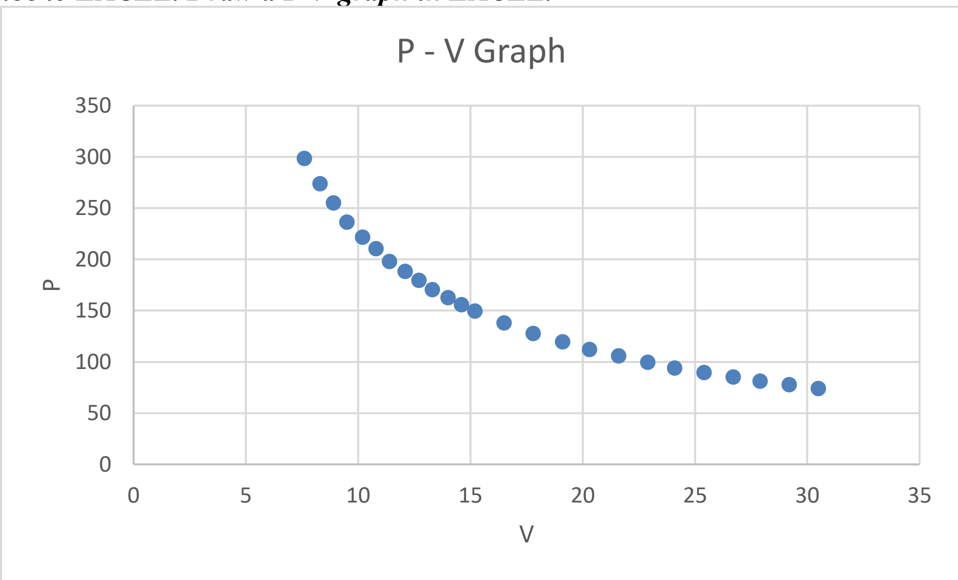
11) What is the pressure when the volume of the trapped air in the short leg of the J tube is reduced to about one-third?

221,6 cmHg

12) ***How could the data distribution on the volume and pressure of the trapped air in the short leg of the J tube be associated?***

As the volume of the trapped air in the short leg of the J tube decreases, its pressure increases. It can be said that this negative relationship is proportional because as the volume approximately halves (from 30.5 to 15.2), the pressure doubles (from 74.0 to 149.4); and as the volume decreases to one-third (from 30.5 to 10.2), the pressure almost triples (from 74.0 to 221.6).

13) ***Transfer the data on the volume and pressure of the trapped air in the short leg of the J tube to EXCEL. Draw a P-V graph in EXCEL.***



14) What could be said regarding the pattern in the data based on the graph you drew in Question 13?

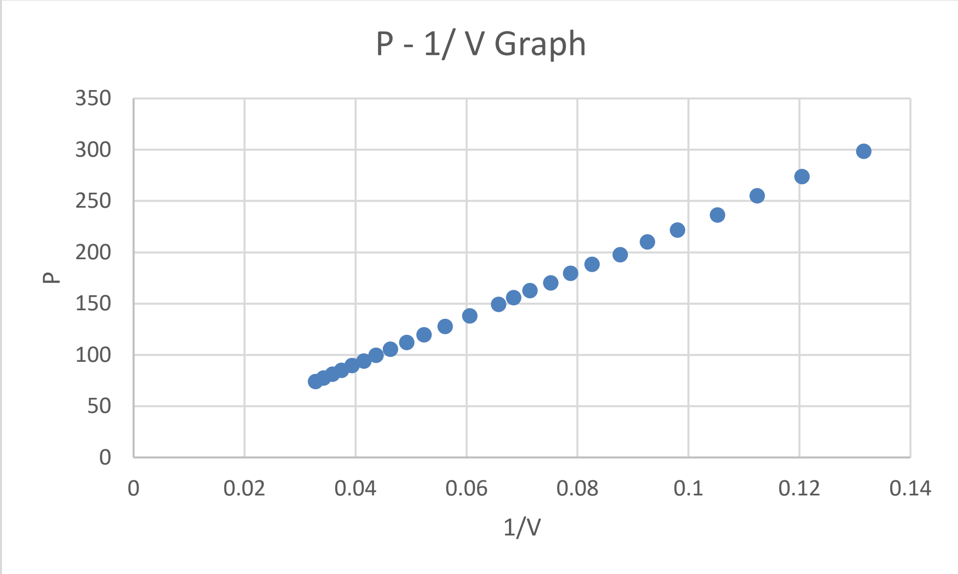
There is a negative relationship between the volume of the trapped air in the short leg of the J tube and its pressure. The graph goes downwards. That is, as the volume of the trapped air decreases, its pressure increases. However, the relationship between the two variables is not linear (nonlinear relationship) because the line in the graph is not linear but curved. However, when the data of the graph given below is examined in the table, it is evident that as the volume of the trapped air halves (from 30.5 cm to 15.2 cm), the pressure of the trapped air doubles (from 74.0 cm to 149.4 cm); as the volume of the trapped air decreases to its one third (from 30.5 cm to 10.2 cm), the pressure of the trapped air triples (from 74.0 cm to 221.6 cm). This relationship seems proportional. In conclusion, the graph of pressure versus volume shows that as volume decreases, pressure increases (and vice versa), indicating an inverse relationship. We can say that the pressure and the volume are inversely proportional.

The height of the air in the shorter closed-end leg (cm)	The pressure of the air in the shorter closed-end leg (cm)
30,5	74,0
29,2	77,6
27,9	81,1

26,7	85,1
25,4	89,7
24,1	94,0
22,9	99,7
21,6	105,7
20,3	112,2
19,1	119,5
17,8	127,8
16,5	138,0
15,2	149,4
14,6	155,7
14	162,7
13,3	170,3
12,7	179,5
12,1	188,3
11,4	197,8
10,8	210,3
10,2	221,6
9,5	236,4
8,9	255,1
8,3	273,8
7,6	298,6

15) Calculate the inverse volume (1/V) value from the volume (V) values in the table using EXCEL and draw a P - 1/V graph.

V	1/V
30,5	0,032787
29,2	0,034247
27,9	0,035842
26,7	0,037453
25,4	0,03937
24,1	0,041494
22,9	0,043668
21,6	0,046296
20,3	0,049261
19,1	0,052356
17,8	0,05618
16,5	0,060606
15,2	0,065789
14,6	0,068493
14	0,071429
13,3	0,075188
12,7	0,07874
12,1	0,082645
11,4	0,087719
10,8	0,092593
10,2	0,098039
9,5	0,105263
8,9	0,11236
8,3	0,120482
7,6	0,131579



16) What could be said regarding the pattern in the data based on the graph you drew in Question 15?

There is a positive relationship between the 1/V and P values of the trapped air in the short leg of the J tube. The graph goes upwards. That is as the 1/V value increases, the P value constantly increases. There is a linear relationship between these two variables. The graph is a straight-line graph. (Reminder: If the straight line in the graph passes from the origin, this represents a proportional relationship. It is important to decide whether the first data point is in origin (0, 0) or not. It is obvious that here the line should pass over the origin. If there is no volume, there is no pressure either.)

1/V	P
0,032787	74,0
0,034247	77,6
0,035842	81,1
0,037453	85,1
0,03937	89,7
0,041494	94,0
0,043668	99,7
0,046296	105,7
0,049261	112,2
0,052356	119,5
0,05618	127,8
0,060606	138,0
0,065789	149,4
0,068493	155,7
0,071429	162,7
0,075188	170,3
0,07874	179,5
0,082645	188,3
0,087719	197,8
0,092593	210,3
0,098039	221,6
0,105263	236,4
0,11236	255,1
0,120482	273,8
0,131579	298,6

As the 1/V increases, P increases, and 1/V and P are proportional. When the value of 1/V approximately doubles (from 0.032787 to 0.065789), the P value also doubles (from 74.0 to 149.4).

When the value of 1/V triples (from 0.032787 to 0.098039), the P value also almost triples (from 74.0 to 221.6).

The pressure-volume graph made us think that the two variables are inversely proportional. In this case, the variables in the pressure-inverse volume graph (P, 1/V) are expected to have a proportional relationship, and the obtained graph confirms that.

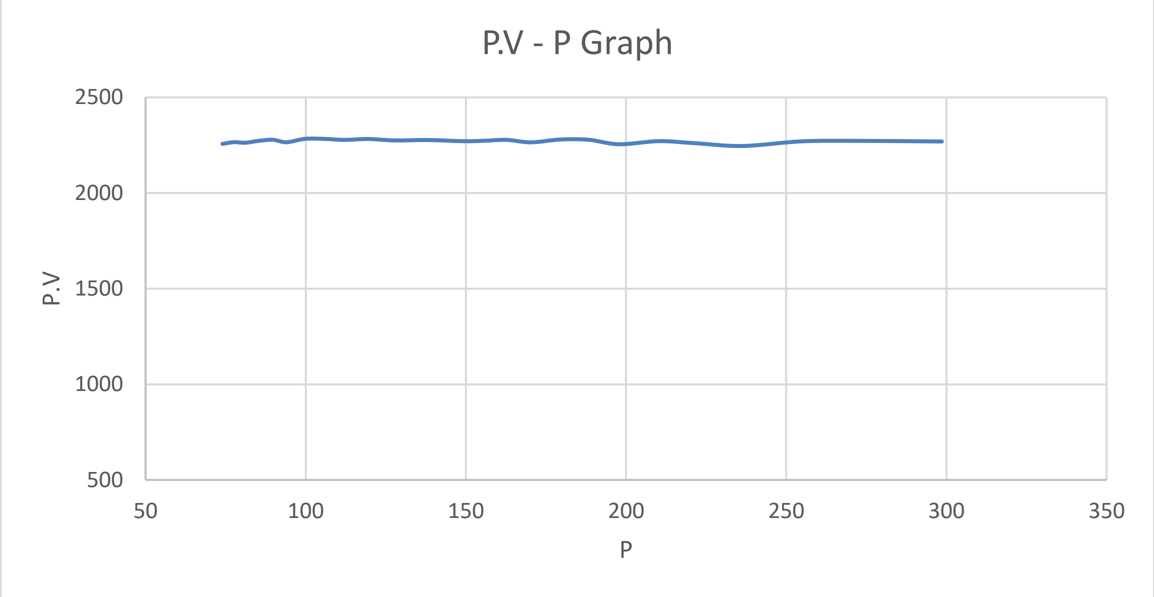
17) Calculate the multiplication of the volume (V) and pressure (P) values in the table using EXCEL. Compare and evaluate your results.

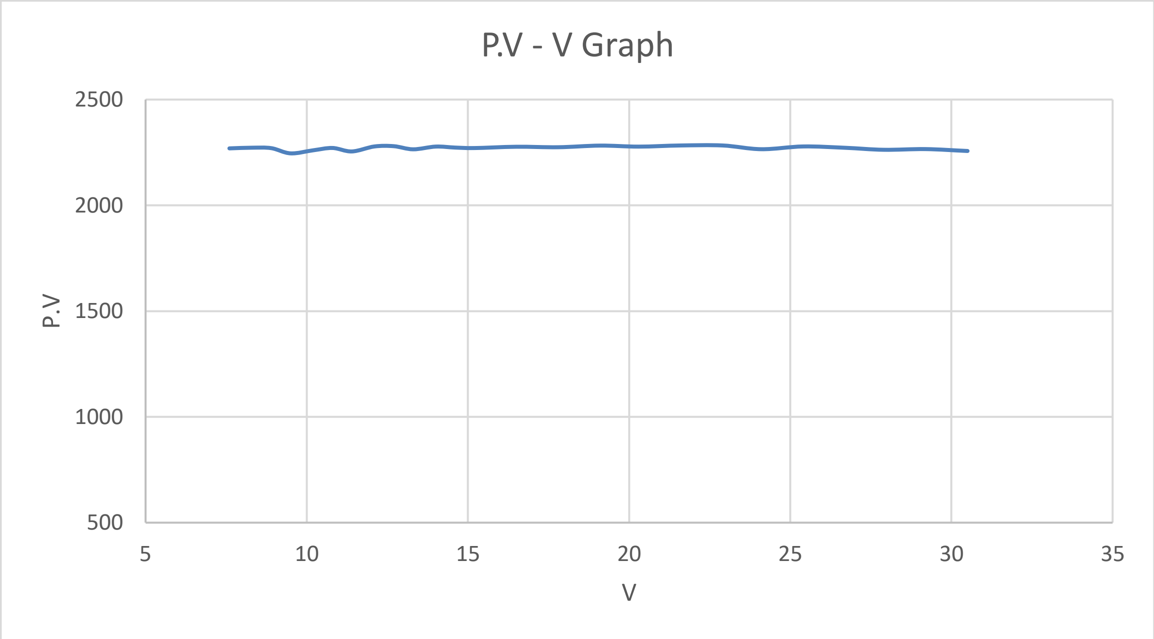
(The PxV results were transferred to the table by rounding a single step after the comma.)

P	V	PxV
74,0	30,5	2257,0
77,6	29,2	2265,9
81,1	27,9	2262,7
85,1	26,7	2272,2
89,7	25,4	2278,4
94,0	24,1	2265,4
99,7	22,9	2283,1
105,7	21,6	2283,1
112,2	20,3	2277,7
119,5	19,1	2282,5
127,8	17,8	2274,8
138,0	16,5	2277,0
149,4	15,2	2270,9
155,7	14,6	2273,2
162,7	14	2277,8
170,3	13,3	2265,0
179,5	12,7	2279,7
188,3	12,1	2278,4
197,8	11,4	2254,9
210,3	10,8	2271,2
221,6	10,2	2260,3
236,4	9,5	2245,8
255,1	8,9	2270,4
273,8	8,3	2272,5
298,6	7,6	2269,4

Every PxV value in Boyle's data is very close to the others. In other words, the multiplication of the volume and the pressure of the gas in any measurement and the volume and the pressure of the gas in another are very close values. (Here, it is possible to accept multiplications equal in the experimental error. In addition, we should remember that the data has been rounded up.)

18) Draw the PxV - P and PxV - V graphs using EXCEL





19) ***What could be said regarding the pattern in the data in P.V – P and P.V – V graphs?***
In the PxV - P graph, as the P value increases, the PxV value almost remains constant. The same case applies to the PxV - V graph.

20) ***Calculate and interpret the percent error using Boyle's pressure data (data in the last two columns of the data table) in EXCEL.***
Percent error = |true value-experimental value | / True value x 100%

The pressure of the air in the shorter closed-end leg (cm)	The pressure according to the hypothesis (cm)	Percent error (%)
74,0	74,0	0
77,6	77,2	0,518
81,1	80,6	0,620
85,1	84,2	1,068
89,7	88,9	0,899

94,0	93,4	0,642
99,7	98,7	1,013
105,7	104,4	1,245
112,2	111	1,081
119,5	118,4	0,929
127,8	127	0,629
138,0	136,6	1,024
149,4	148	0,945
155,7	154,4	0,841
162,7	161,4	0,805
170,3	171,6	0,757
179,5	177,8	0,956
188,3	186,9	0,749
197,8	197,3	0,253
210,3	208,9	0,670
221,6	221,9	0,135
236,4	236,7	0,126
255,1	253,6	0,591
273,8	273,1	0,256
298,6	295,9	0,912

We can say that the accuracy of the data is high because the percent error of Boyle's data is reasonably and acceptably low (less than 5%), that is, the measurement results are quite close to the true value. Because accuracy indicates the closeness of a result to the real value, and it is possible to express it with percent error.

21) What kind of an argument based on the data could you put forward considering all the studies we did while examining Boyle's data?

According to the data of Boyle's experimental study in 1662, the volume and the pressure of a certain amount of gas (air) in an enclosed environment are inversely proportional. In other words, if the volume of a certain amount of gas increases, its pressure decreases, or if the volume decreases its pressure increases. The multiplication of the volume and pressure of the gas is constant. Such as P.V = k.

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