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A MULTIDISCIPLINARY ORIGAMI ACTIVITY: FRACTIONS IN THE SOLAR SYSTEM[1]

Okan Arslan[2], Deniz Eroğlu[3], Ercan Tatli[4]

ABSTRACT

A multidisciplinary origami activity that could be used in middle school mathematics and science lessons was designed and implemented. Mathematical purpose of the origami activity is to support students' conceptual understanding and procedural skills related to the concept of fraction. Regarding science, the activity aims to visualize Solar system and support its conceptual learning. The activity was implemented with 7th grade students in order to help them remember the related content and overcome the difficulties they experienced. The implementation process revealed that this multidisciplinary activity can be used by middle school teachers to support students' conceptual understanding of fractions and solar system topics, and to overcome some difficulties they experienced while learning these topics. Details about students' views and approaches that emerged during the implementation of the activity, teacher's views about the implementation, as well as suggestions for teachers who want to implement the activity, are given throughout the paper.
Keywords: origami, multidisciplinary activity, fractions, solar system.

DİSİPLİNLERARASI BİR ORİGAMİ ETKİNLİĞİ: GÜNEŞ SİSTEMİNDEKİ KESİRLER

ÖZ

Bu çalışmada, ortaokul matematik ve fen bilimleri derslerinde kullanılabilecek disiplinlerarası bir origami etkinliği tasarlanmış ve uygulanmıştır. Tasarlanan origami etkinliğinin matematik öğretimi açısından amacı öğrencilerin kesirler konusundaki kavramsal anlamalarının ve işlemsel becerilerinin desteklenmesidir. Fen bilimleri açısından ise Güneş sisteminin görselleştirme yoluyla kavramsal olarak öğretimi amaçlanmaktadır. Tasarlanan etkinlik bu çalışma kapsamında öğrencilerin öğrendikleri konuları hatırlamaları ve varsa bu konularda yaşadıkları zorlukların giderilmesi için 7. sınıf öğrencileri ile uygulanmıştır. Uygulama sonucunda etkinliğin, disiplinlerarası bir origami etkinliği olarak kesirlerin ve güneş sisteminin öğretimi, pekiştirilmesi ve bu konularda öğrencilerin yaşadıkları zorlukların giderilmesi amacıyla kullanılabileceği ortaya konulmuştur. Etkinliğin uygulanması esnasında ortaya çıkan öğrenci görüş ve yaklaşımları ile öğretmen görüşleri, ayrıca etkinliği uygulamak isteyen öğretmenler için çeşitli öneriler detaylı şekilde makalede verilmiştir.
Anahtar kelimeler: origami, disiplinlerarası etkinlik, kesirler, güneş sistemi.

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[2] Dr., Burdur Mehmet Akif Ersoy University, Faculty of Education, Department of Mathematics and Science Education, oarslan@mehmetakif.edu.tr, ORCID: https://orcid.org/0000-0001-9305-2961
[3] Asst. Prof. Dr., Burdur Mehmet Akif Ersoy University, Faculty of Education, Department of Mathematics and Science Education, deroglu@mehmetakif.edu.tr, ORCID: https://orcid.org/0000-0001-7863-5055
[4] Dr., Burdur Mehmet Akif Ersoy University, Faculty of Education, Department of Mathematics and Science Education, etatli@mehmetakif.edu.tr, ORCID: https://orcid.org/0000-0002-4235-059X

INTRODUCTION

Origami, which is known as the art of paper folding, is a very convenient tool to be used in education since it allows students to be active in the learning process and supports their cognitive and affective development (Tuğrul & Kavici, 2002). Therefore, origami has been used for various purposes in teaching mathematics and science and its positive effects have already been well documented (Boz, 2015; Budnitz, 2002; Çelikler et al., 2017; Georgeson, 2011; Güneş, 2012). However, it is noteworthy that there are not enough resources in the literature for teachers to effectively benefit from origami in their lessons (Boz, 2015). Therefore, a multidisciplinary origami activity that can be used in middle school mathematics and science lessons was designed and implemented in this study.

In mathematics education studies, it is observed that the use of origami is mostly carried out in geometry. These studies revealed the positive effects of origami in improving students' knowledge and spatial skills in geometry subjects (e.g., geometric shapes and objects, symmetry, angles, volume) (Arıcı & Aslan-Tutak, 2015; Çakmak et al., 2014; Kandil & Işıksal-Bostan, 2019). In addition, previous studies have shown that origami can be used to help students to explore algebraic patterns (Higginson & Colgan, 2001; Georgeson, 2011). The fold lines make origami a useful tool in the teaching of fractions since they allow dividing the paper into equal parts (Coad, 2007; Russell, 2017). Although some origami models are quite suitable for teaching fractions, it is noteworthy that there are not enough resources and sample uses of origami to be used by teachers in teaching fractions (Carter & Ferruci, 2002), and this continues to be an area that needs further investigation in the current literature as well.

A fraction is a concept that has both conceptual and operational dimensions. In the literature, it has been found that students have many conceptual and procedural difficulties with fractions: determining equal parts of a fraction (Okur & Çakmak-Gürel, 2016), dividing the whole into equal parts on the number line and selecting a certain number of parts (Önal & Yorulmaz, 2017), operating according to the numerator and denominator in fraction comparisons (Hansen, 2020), and strictly complying to the rules when adding and subtracting fractions (Önal & Yorulmaz, 2017). Therefore, the origami activity designed in this study aims to support students' conceptual and procedural understanding of fractions. The activity is designed in line with the following standards in the middle school mathematics curriculum: 6.1.5.1. To compare and order fractions, and to place fractions on the number line, and 6.1.5.2. To add and subtract fractions (Ministry of National Education [MoNE], 2018a).

The other dimension of the designed multidisciplinary origami activity is related to science education. The use of origami in science education has mostly been on modeling various concepts by means of origami. The following concepts were modeled in the related studies: nucleic acids (Güneş, 2012), tetrahedral molecular geometry (Ünan et al., 2016), metamorphosis stages of some animals, DNA and mitochondria, various elements and compounds (Çelik et al., 2017), and developmental stages in organisms (Budnitz, 2002). In the activity designed within the scope of this research, it is aimed to gain a conceptual understanding of the Solar system by developing a visual model, which is among the goals of the science course.

The related studies focusing on astronomy concepts have revealed that students have various difficulties in understanding the dimensions of the Universe, calculating interplanetary distances (Gali, 2021), and showing the order of the planets according to the position of the Sun (Comins, 2000). In accordance with these findings, the aim of this activity is to remedy students' difficulties with visualization of the Solar system by means of origami.

The activity has the potential to enable students to reach the following science curriculum standards: 6.1.1.1. To compare the planets in the Solar system with each other, 6.1.1.1.a. To know the basic properties of planets, 6.1.1.1.c. To understand the sizes of planets spatially, 6.1.1.1.ç. To order the positions of the planets according to their distance to the Sun, 6.1.1.1.d. To know the concepts of meteor, meteorite, and asteroid, 6.1.1.2. To model the Solar system by ordering the planets according to their distance to the Sun (MoNE, 2018b).

ACTIVITY IMPLEMENTATION

Activity

In this study, the Solar System Scroll activity developed by Jet Propulsion Laboratory (JPL) (JPL, 2021) is adapted to origami. During the adaptation process, the solar system model was developed with origami folds, and various questions related to the model were prepared to support students' knowledge of fractions (Appendix 1).

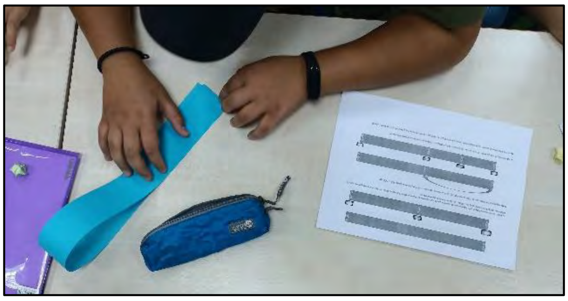
Implementation Group

This activity, which targets the curriculum standards of the sixth graders, was organized at a state university in Turkey in the 2021-2022 academic year. It was implemented in the "Science Education Program for Children", which aims to overcome the conceptual and procedural difficulties of the students through fun science activities. The participants were 12 male and 18 female seventh grade students who enrolled in public middle schools. These students voluntarily participated in the program as well as in this research study. In accordance with the characteristics of the participant students, the activity aimed to support their conceptual understanding of fractions and remedy the difficulties they might have had in the previous year when they learned this topic in school. Ethics committee approval for the study was obtained from Burdur Mehmet Akif Ersoy University Non-Interventional Clinical Research Ethics Committee with the document dated 06.10.2021 and numbered GO-2021/322.

Activity Implementation Steps

In the activity, the students developed the Solar system model. In the first step of the activity, the students were told that a solar system model would be developed; thus, this enabled them to be aware of the purpose of the activity. Then, they were asked to define the notion of the planet in order to activate their prior knowledge. Students stated various properties of planets with expressions, such as "they are celestial bodies revolving around themselves" and "they revolve around the stars", to name a few. The teacher continued the activity by defining the planet as "celestial bodies of a certain size that revolve around itself and the star it is connected to". Afterwards, the students were asked about the number of planets in the Solar system, and the majority of them answered "eight". In this activity, the students were given the worksheets in Appendix 1 and the rectangular paper strips of 5 cm x 70 cm. Students were asked to write the word "Sun" on the left-hand side and "Pluto" on the right-hand side of the rectangular paper strip. At this stage, it was emphasized that Pluto is not accepted as one of the eight planets in the Solar system, is called as a dwarf planet, and is only used as a reference point in the activity.

The next stages of the activity were continued by associating fractions with the positions of the planets. The students were asked to represent the whole paper strip with a fraction. Students gave the correct answer such as "one" or "one over one". Then, the students were asked which points the Sun and Pluto would correspond to by considering the paper strip as a number line. They were also asked to write the numbers on each side. The students said that the Sun can be denoted by 0 and Pluto by 1. At this point, one side of the paper strip was used to place the planets, while the other side was used to place fractions. Students were asked to turn the rectangular paper strip upside-down and write 0 for the corresponding place of the Sun, and 1 for the corresponding place of Pluto. The same procedures were followed by the teacher in front of the students, and also in the model drawn on the board. As the first folding step, the students were asked to fold the paper strip so that the Sun and Pluto stand on top of each other and to write Uranus on the fold line (Photograph 1).



Photograph 1. Student Work in the First Folding Step

Students were asked to represent the fold line with a fraction, and they answered as "one-half", "one over two", and "two-fourths". The students were asked to express their reasoning for finding fractions and they emphasized that there were two equal parts on the model. After a short in-class discussion, it was agreed that the students' answers represent equal fractions. It was decided that the relevant fraction should be shown as $\frac{1}{2}$ which is the simplest form. When the strip is considered as a number line model, the fold line corresponds to $\frac{1}{2}$. At this stage, the students wrote $\frac{1}{2}$ on the worksheet and on the fold line on the other side of the model (paper strip).

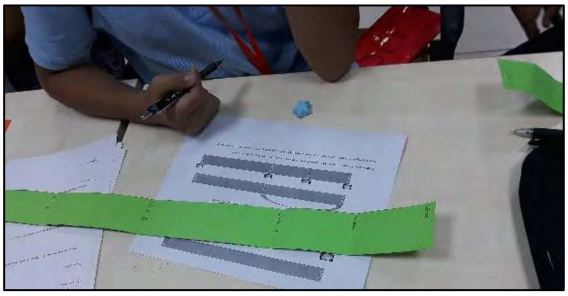
In the second folding step, the students were asked to fold the Sun side onto Uranus formed in the first step and to write Saturn on the fold line. Similar to the first step, the students were asked to represent the position of Saturn with a fraction. While the majority of the students correctly answered as "a quarter" or "one-fourth", some other students answered as "one-half". The teacher asked questions such as "Why do you think it is one-half?", "What is the whole here?", "How many pieces are there in the whole after the last fold?" in order to support these students to realize their incorrect answers. The part corresponding to the half is divided into two, thus it is concluded that the part up to Saturn should be expressed as a quarter. On the fraction side of the model, $\frac{1}{4}$ was written on the corresponding fold line.

In the third folding step, the same procedures were followed by folding Pluto side onto Uranus. At this stage, Neptune was written on the fold line. Part of the classroom discussion about fractions corresponding to the fold lines is exemplified below:

> Teacher: Does everyone have the Sun, Saturn, Uranus, and Pluto now? Then, let's move on to the next step. This time we fold Pluto onto Uranus. We write Neptune on that fold line. Then, how can we represent Neptune with a fraction?
> Student [1]: Three over four.
> Student [2]: Three-fourths.
> Student [3]: Six-eighths.
> Teacher: How did you find three-fourths?
> Student [2]: One, two, three, four (counting the $\frac{1}{4}$ parts). The third of four pieces.
> Teacher: Well, how did you find six-eighths?
> Student [3]: I thought of each piece as two pieces, thus I said six-eighths?
> Teacher: So, which one do you think is correct?
> Students [Together]: Both are the same, correct.
> Teacher: Then, how do we write this fraction ($\frac{3}{4}$)?
> Students [Together]: Three above, four below (the fraction line).

In the fourth folding step, the students were asked to fold the Sun onto Saturn and to name the fold line as Jupiter (Photograph 2). Some students had difficulty in representing $\frac{1}{8}$ which is the correct answer:

> Teacher: Well, what was the distance between the Sun and Saturn?
> Students [Together]: One-fourth.
> Teacher: What am I doing now (showing the relevant fold on the model)?
> Students [Together]: I doubled it.
> Teacher: What did I find?
> Students [Some]: One-eighth.
> Teacher: How do I know that I got one-eighth, Student [1]?
> Student [1]: Teacher… Ummm…



Photograph 2. Student Work in the Fourth Folding Step

At this point, the class discussion proceeded with the guidance of the teacher as in the dialogue below, and the students wrote $\frac{1}{8}$ on both the worksheets and the fold line on the other side of the paper strip.

> Teacher: What did I say about the distance between the Sun and Saturn? A quarter. What did I do now? I divided the quarter into half. So, how far is it from Saturn to Uranus?
> Students [Together]: One-fourth.
> Teacher: How far is it from Uranus to Neptune?
> Students [Together]: One-fourth.
> Teacher: How far is it from Neptune to Pluto?
> Students [Together]: One-fourth.

Teacher: Well, I divided [the part of] one-fourth into half (showing the relevant folding on the model).
Student [Together]: One-eighth.
Teacher: How do you decide that it is one-eighth?
Student [2]: Since we fold [the paper], we multiply four by two.
Teacher: If I equally divide each part into two, how many equal parts are there on the whole here?
Students [Together]: Eight. [In addition to the discussion about the number of equal parts of a whole when unit fractions are divided into two equal parts, a discussion can also be carried out about the number of the parts of a whole when dividing the unit fractions into different numbers such as three, four, and five.]
Teacher: Then, how do I denote Jupiter [by fraction]?
Students [Together]: One-eighth.
Teacher: Student [1], can you explain why it is one-eighth?
Student [1]: This is one-fourth. Dividing each part into half makes eight parts. That is one-eighth.
Teacher: Eight equal parts, right? That is why we say one-eighth (writing $\frac{1}{8}$ in the relevant place on the board and model).

However, implementations in the classroom may not always happen as in the dialogue above. Students may express fractions without paying attention to equal partitioning. For example, students may denote the point where Saturn is located by $\frac{1}{5}$ since not all the folded parts are equal in this model. In such cases, teachers can ask questions about the meaning of fractions such as "Why did you express it as one-fifth?", "What does one-fifth mean?" in order to help students realize that the whole fraction should consist of equal parts.

In the fifth folding step, the Sun was folded onto Jupiter, which was formed in the last step, to form Asteroid Belt. Similar to the previous step, it was concluded that Asteroid Belt can be represented by $\frac{1}{16}$ with the help of questions asked by the teacher:

Teacher: How can we represent [it] with fractions?
Student [1]: We divided this into eight. If we divide it like this (showing with his hand the division of all parts into two), would not it be one-sixteenth?
Teacher: Yes, right?
Student [1]: We multiply (the number of parts) by two, we get sixteen.
Teacher: I divided the whole into eight, right? If I divide all the parts into half again, how many parts will there be on the whole?
Student [2]: It was eight, now if we divide it by two, it becomes sixteen.
Teacher: Yes, then how do I denote Asteroid Belt by a fraction?
Student [2]: One-sixteenth.

In this discussion, the students easily noted that the fold line corresponds to $\frac{1}{16}$ when the part represented with $\frac{1}{8}$ is divided into two equal parts. However, if there were students who struggled with equipartitioning, the paper strip could be repeatedly folded over the smallest piece to enable students to realize that the whole consists of 16 equal parts. At this point, the discussion can be taken a step further to enable students to explore some equivalencies between different fractions (for example, $\frac{1}{8}$ equals to $\frac{2}{16}$). In the current implementation, after the discussion given above, some students explored the pattern between the folding steps and the fractions:

Student [3]: It is constantly increasing as much as its value, four became eight.
Student [4]: Yes, it increases in multiples.
Teacher: How is it increasing in multiples?
Student [3]: Then it becomes sixteen, then it becomes thirty-two.
Teacher: Yes, right? Did everyone notice this? Student [4], do you want to explain?
Student [4]: It increases in multiples of two.
Teacher: Yes, when I divide each fraction part into half, the number of parts, namely the denominator, also doubles.

At this stage, the students were asked what asteroid means. Upon receiving students' responses such as "stone" and "rock", the teacher informed the students about asteroids: They revolve around the Sun and themselves, they are pieces of rocks that are much smaller than the planets, there are millions of them in the Solar system, and a significant part of them are located between Jupiter (folded in the last step) and Mars (will be folded in the next step). Afterwards, the teacher said that Asteroid Belt divides the Solar system into inner (terrestrial) and outer (gaseous) planets. For this reason, the teacher emphasized that the planets (Jupiter, Saturn, Uranus, and Neptune) that have been determined by folding steps until now are called outer planets, in other words, gaseous planets.

In the sixth folding step, the Sun side was folded onto Asteroid Belt, and Mars was written on the fold line. The teacher asked the following two questions to the students: "If the folds of the previous step are made, how many parts will the whole be divided into?", "Which fraction corresponds to the new fold line?" The students answered that Mars can be represented with $\frac{1}{32}$.

In the next steps, due to the difficulty of folding the paper strip, the order of the inner planets was expressed by the teacher as Mercury-Venus-Earth-Mars, and the students were asked to write the inner planets on the model in accordance with this order. According to this order, students were asked to estimate the possible fractions for Mercury, Venus, and Earth. Students are expected to determine fractions between 0 and $\frac{1}{32}$ and identify fractions according to the planetary order—the largest for Earth and the smallest for Mercury.

Some students, who noticed the pattern explained in the discussion above, continued the pattern they found and denoted Earth by $\frac{1}{64}$, Venus by $\frac{1}{128}$, and Mercury by $\frac{1}{256}$. Some other students, on the other hand, represented the planets with different fractions by denoting Earth by $\frac{1}{40}$, Venus by $\frac{1}{50}$ and, Mercury by $\frac{1}{60}$. When determining the fractions for these planets, the students rounded the denominator to the nearest ten (such as rounding 32 to 40). At this stage, some questions can be asked to explore students' justifications for their estimations: "What did you consider in determining the denominator of fractions?", "What is the smallest integer that we can use to express the denominator for the Earth's position?". In addition, some further question(s) can be asked students to realize that when the denominator of the fraction gets larger, it approaches to zero and, the planet gets closer to the Sun: "Have you noticed a relationship between the distances of the planets from the Sun and the fractions expressing the positions of the planets?". In this activity, an in-class discussion about the magnitude and order of fractions was conducted as follows:

Teacher: So, how do I know that one sixty-fourth is greater than one over one hundred and twenty-eighth? Which one is greater?
Student [1]: One sixty-fourth.
Teacher: Why?
Student [1]: The one with a smaller denominator is greater.
Teacher: Why is a fraction with a smaller denominator greater?
Student [2]: It is divided into larger pieces.
Student [3]: If we divide it into fewer pieces, as happens in cake [partitioning], one person eats more.
Teacher: Yes, if I divide it into fewer pieces, my piece will be larger. What if I divide it into more pieces?
Student [3]: It gets smaller. [Students' knowledge can also be supported by showing the piece sizes by folding the paper strip. For example, it can be noticed that the paper strip gets smaller as the denominator gets larger, by showing that the $\frac{1}{4}$ paper strip is larger than $\frac{1}{8}$, and the $\frac{1}{8}$ paper strip is larger than $\frac{1}{16}$.]
Teacher: So, I could say that Earth, Venus, and Mercury can be represented in this way. (According to the order in the model, the estimations of those using the fractions $\frac{1}{64}$, $\frac{1}{128}$, and $\frac{1}{256}$)

As a result of the folding steps, the Solar system model was developed by considering the distances of the planets from each other. At this stage, in order to increase the visual attractiveness of the model, the planets and the Sun, the photographs of which were prepared in advance by the researchers, were distributed to the students. The students were asked to stick these photos on the fold lines. The sizes of the planets were considered while preparing the relevant photographs. Consequently, the model was developed in which the planets in the Solar system are located on the one side of the paper strip and the fractions corresponding to the positions of the planets are on the other side (Photograph 3). The teacher emphasized that the distances between the planets and the planet sizes were approximately represented on this model. At this stage, the students were asked questions about the biggest/smallest planets, the closest/farthest planets to the Sun, and the correct answers were obtained from the students.

Photograph 3. Solar System Model Examples

Following the completion of the solar system model, the students started to work on the eighth step of the worksheet. At this stage, the students were requested to compare the relative distances among the planet pairs given in the worksheet and to decide which planet pair has a greater distance. This part of the activity is about ordering and comparing fractions. Furthermore, addition and subtraction of fractions are used to calculate the distances between the planets. At this stage, the students were asked to compare the distance between Neptune-Jupiter and the distance between Mars-Uranus. Students offered various ideas for the use of the paper strip as an area model in order to make this comparison:

> Student [1]: Both are the same (equal distance).
> Teacher: How did you know that it is the same?
> Student [1]: There are two planets between them.
> Teacher: Any other opinions?
> Student [2]: There are two pieces between Mars and Uranus (showing the $\frac{1}{4}$ part and the part between $\frac{1}{32}$ and $\frac{1}{4}$). So, I thought that [the answer is] Neptune and Jupiter. It is because there are two whole (referring to the $\frac{1}{4}$ parts) and one-half parts (referring to the $\frac{1}{8}$ part) between them.

This discussion was concluded by emphasizing that the distance should be determined by considering the sizes of parts between planets rather than the number of planets between the planet pairs. Following this discussion, the students came up with the idea of subtracting the fractions corresponding to the positions of the planets on the paper strip. However, if this idea is not proposed, teachers may ask the question(s) that enable students to focus on the meaning of the subtraction: "If we knew the distance of the planets from the Sun in kilometers, how would we find the distances between the planets?". Since the positions of the planets are expressed as fractions in this activity, teachers can continue the discussion with questions such as "How do we calculate the distances between the planets when their distance from the Sun is expressed as a fraction?", Then, they can move on to the stage of subtraction with fractions.

In order to make comparisons by using fractions in the activity, the students wrote the fractions corresponding to the related planets on the worksheet. It was essential to determine the planets that have a greater fraction in planet pairs to perform the subtraction operation. At this stage, upon students' thinking of the paper strip as a number line, a discussion to support students to realize that a fraction gets greater as it moves away from the Sun, which is the zero point of the model, was carried out:

> Teacher: According to your model, which one is farther away [from the Sun], Uranus or Neptune?
> Students [Together]: Neptune.
> Teacher: Well, which fraction is Uranus denoted by?
> Students [Together]: One-half.
> Teacher: And, Neptune?
> Students [Together]: Three-fourths.
> Teacher: Then, which fraction would be greater? The farther one or the closer one?
> Students [Together]: The farther one, three-fourths are greater.
> Teacher: So, how does the fraction change as the planets move away from the Sun?
> Students [Together]: It gets greater.

In the cases where such reasoning cannot be made, teachers can enable students to see on the model that $\frac{3}{4}$ consists of three $\frac{1}{4}$ parts, and $\frac{1}{2}$ consists of two $\frac{1}{4}$ parts. Thus, students can realize that $\frac{3}{4}$ is greater than $\frac{1}{2}$ by the help of the model they have. As a result, students will be able to derive the conclusion that the fraction will be greater as the planets move away from the Sun, which is the zero point of the model.

The students were given a certain amount of time to work on their own to make the comparisons by using fractions, and then, the activity continued with discussions. Here is an excerpt from the discussion at this time:

> Teacher: Which fraction is Neptune denoted by?
> Students [Together]: Three-fourths.
> Teacher: Well, Saturn?
> Students [Together]: One-fourth.
> Teacher: Well, how did you find the distance between them?
> Student [1]: By subtracting one-fourth from three-fourths (showing the operations on the worksheet).
> (The teacher performed the operation on the board).
> Teacher: How did you find the distance between Mars and Uranus?
> Student [2]: I equated the denominators and subtracted one over thirty-two from one-half. I expanded it by sixteen (the student expanded $\frac{1}{2}$ by 16 and showed it as $\frac{1}{32}$ on the worksheet).
> Teacher: Your friend expanded one-half by sixteen and said one over thirty-two, does anyone think otherwise?
> Student [3,4]: It is sixteen over thirty-two (other students confirm).
> Student [2]: I forgot to multiply one by sixteen.
> Teacher: Yes, we multiply both the numerator and denominator by the same number when expanding fractions.
> Student [3]: When we subtract, we find fifteen over thirty-two (The student shows the operation $\frac{16}{32}-\frac{1}{32}$ on the worksheet, the teacher recorded the operation on the board).
> Teacher: Yes, we find fifteen over thirty-two. Which one is greater, two over four or fifteen over thirty-two?
> Student [5]: We will equate (the denominator).
> Student [4]: Two over four, becomes sixteen over thirty-two. Sixteen pieces would be greater.
> Teacher: So, which two planets are farther away from each other?
> Students [Together]: Neptune and Jupiter.

As exemplified in the dialogue above, the students had prior knowledge of subtraction in fractions which enabled the discussion to proceed smoothly. However, in the first implementations of teaching fraction subtraction conceptually, it is important for the teacher to relate the developed model with the operation. For example, in the dialogue above, it can be explained that $\frac{3}{4}$ consists of three $\frac{1}{4}$ parts on the model, and when one $\frac{1}{4}$ is removed from these parts, two $\frac{1}{4}$ parts ($\frac{2}{4}$), will remain. Likewise, the model provides opportunities for students to understand the underlying meaning of making the denominator equal. For example, by asking questions, such as “How many one over thirty-two pieces are there in a half?”, teachers can help students to realize that there are 16 pieces of $\frac{1}{32}$ in $\frac{1}{2}$. Afterwards, by asking the question “How many one over thirty-two pieces are there between Uranus and Pluto?”, students might be realized that Uranus is represented by $\frac{16}{32}$ when the whole is divided into 32 equal parts. At this stage, the reason for multiplying both the numerator and denominator in equating fractions should be explored by using the model. Teachers can also lead discussions on the equivalence of $\frac{1}{2}$ and $\frac{16}{32}$. Such discussions might enable students to conclude that the numerator and denominator should be expanded by 16 when each part of the model is divided into 16 equal parts. Teachers can ask the following questions in discussions: “Which operation did I perform on the half?”, “What is the relationship between the number I used in this operation and the number of divisions I have made on the model?”, “Why do I need to multiply both the numerator and the denominator?” After discussing such questions in making the denominators equal, the activity can be continued with subtraction of fractions with the help of questions explained in the previous steps.

In the next step, the distances between the planet pairs, Mars-Uranus and Neptune-Saturn, were compared. The students compared the distances between the planets by using both fraction parts and subtracting fractions. Below is a discussion in which two different methods are explained:

> Student [1]: There is a one-fourth between Mars and Uranus, and a one-eighth between

Jupiter and Saturn (showing the part between Jupiter and Saturn on the model)

Student [2]: Should not it be Neptune and Saturn? There are two [parts of] one-fourth between them.

Teacher: Well, how much is there in the other pair (between Mars and Uranus)?

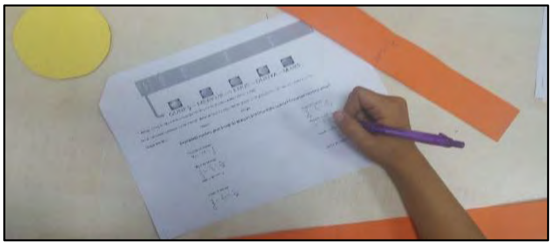
Student [2]: There is a one-fourth between Mars and Uranus, [plus] the second part is one over thirty-two less than one-fourth. The second one-fourth [part] is not complete. So, Neptune and Saturn are farther away.

Teacher: How did you do it?

Student [4]: By operation (describing the operations $\frac{1}{2}-\frac{1}{32}=\frac{15}{32}$ and $\frac{3}{4}-\frac{1}{4}=\frac{2}{4}$ on the worksheet. At the same time, the operations were recorded by the teacher on the board).

Teacher: So, with both methods, Neptune and Saturn are farther from each other than Mars and Uranus (Students approved).

The same procedures were repeated for the other planetary pairs in the worksheet (Photograph 4).



Photograph 4. A Student's Operations on the Worksheet

In the following sections, the students were required to make comparisons using fractions and to find the farther distance using subtraction. Although it was observed that the students easily compared fractions by using the model they had, it was noted that some students had difficulties in operations such as equating denominators and subtracting fractions. In such cases, the students' conceptual learning was supported by asking various questions. For example, the following questions were asked to a student who forgot to expand the numerator of the fraction while equating the denominator in order to make him realize his mistake: "How many parts did we divide the whole into?", "How many parts are there up to this planet?", "Which fraction can we denote this planet by?"

The implementation of the activity took approximately 60 minutes. After the end of the activity, a questionnaire consisting of open-ended questions was given to the students to explain their opinions about the activity, and they were given 10 minutes to complete the questionnaire (Appendix 2). Since personal information is not asked in the relevant document, it is assumed that the students express their sincere views without being influenced.

The Students' and Teacher's Views about the Activity

The first question was about students' opinions about the origami activity. Most of the students stated that they enjoyed the activity: "It was fun, it was very interesting.", "Super", "It was quite enjoyable, I liked it.", "It was very good, I like activities like this.", "Folding paper is very enjoyable." Most of the students said that they wanted to participate in other origami activities, on the other hand, only two students stated that they do not want to participate in origami activities similar to the current activity. These students thought that the activity was difficult and boring.

The second question was about whether the activity helped the students with fractions. Students stated that the activity helped them to recall the concepts they forgot about fractions and to understand fractions better: "I understood better.", "I learned the type of pieces and their closeness [to zero]; math was fun this way.", "I don't understand fractions very well, but I understood it now thanks to this activity", "I remembered fractions.", "We found results and also remembered fractions, and it was fun."

Similar to the second question, the third question was about whether the activity helped the students with the Solar system and the planets. As in the responses of the previous question, the students stated that the activity contributed to their learning about the planets: "We relearned the planets.", "I learned the properties of the planets.", "I remembered the order (of the planets' positions).", "I learned their positions.", "There were planets that I did not know, I learned [them].", "I was very curious about the planets, [it was] a very useful activity.", "I learned the order of the planets.", "I didn't know many of the planets.", "We learned about the asteroid and learned that Pluto is not a planet."

The teacher also shared his views about the activity as follows: (1) The students found various opportunities to express themselves because of the use of an inquiry-based learning approach in the activity. (2) The students participated a lot because of the interesting nature of the activity. (3) Developing a model enabled to support students' understanding on both mathematics (in terms of visualizing fraction comparison and subtraction) and science (in terms of visualizing the Solar system by considering the order of the planets' positions). (4) The implementation of the activity can be easily repeated since the materials are accessible and economical, and the folding steps are easy. On the other hand, he stated that he needed preliminary preparation for the science-related part of the activity since he was a mathematics teacher. Therefore, he emphasized that it would be more beneficial if science and mathematics teachers collaborate to implement the activity.

CONCLUSION AND SUGGESTIONS

In this study, a multidisciplinary origami activity that can be used to teach fractions and the Solar system concepts was designed and implemented. During the implementation of the activity, the students experienced some difficulties and the teacher helped them to overcome these difficulties. At the end of the activity, the students stated that they learned new concepts about fractions and astronomy, they remembered some concepts about these topics, and they enjoyed the activity. It has been concluded that the activity designed and implemented in this study can be used with middle students in mathematics and science lessons.

Seventh grade students participated in this activity, which targets the sixth-grade curriculum standards, to recall the concepts and to overcome their difficulties, if any, regarding the related concepts. Although the area model is the most common model used in teaching fractions (Lamon, 2005), simultaneous use of multiple models is suggested (Samsiah, 2002). Therefore, the use of the paper strip in the current activity as both area and length (number line) models can be seen as one of the strengths of the activity. In addition, the use of this model allows students to visualize the Solar system which they often have difficulties with (Comins, 2000; Gali, 2021). In this activity, it was revealed that the visualization of both fractions and the Solar system using the model had a positive effect on the students' learning. In line with the findings of this study, it is concluded that this activity can also be used as a teaching activity for the related concepts in the sixth grade's mathematics and science lessons. In this respect, this origami activity provides a resource for mathematics and science teachers.

It is important to bear in mind that students learn the concepts presented in this multidisciplinary activity at different times in the middle mathematics and science lessons. For this reason, it is recommended that teachers who want to use this multidisciplinary activity should schedule their fractions and solar system lesson planning in a parallel manner. In addition, mathematics and science teachers need cooperative preparation and implementation for effective teaching because of the multidisciplinary nature of the activity.

Teachers who aim for effective teaching need preliminary preparations to enable students to use the activity materials conveniently. Accordingly, it is highly recommended that teachers should create the paper strips, print and cut the pictures of the planets, and obtain stationery (such as glue and pencils) before the activity. In addition, since the students in this study had prior knowledge about fractions and the Solar system, the teacher did not need an extensive amount of time for the classroom discussions during the activity implementation. However, if the activity is to be used as a teaching activity when students do not know the concepts, it should be taken into account that the classroom discussions will take longer. Therefore, it is suggested for teachers to devote more time to the activity.

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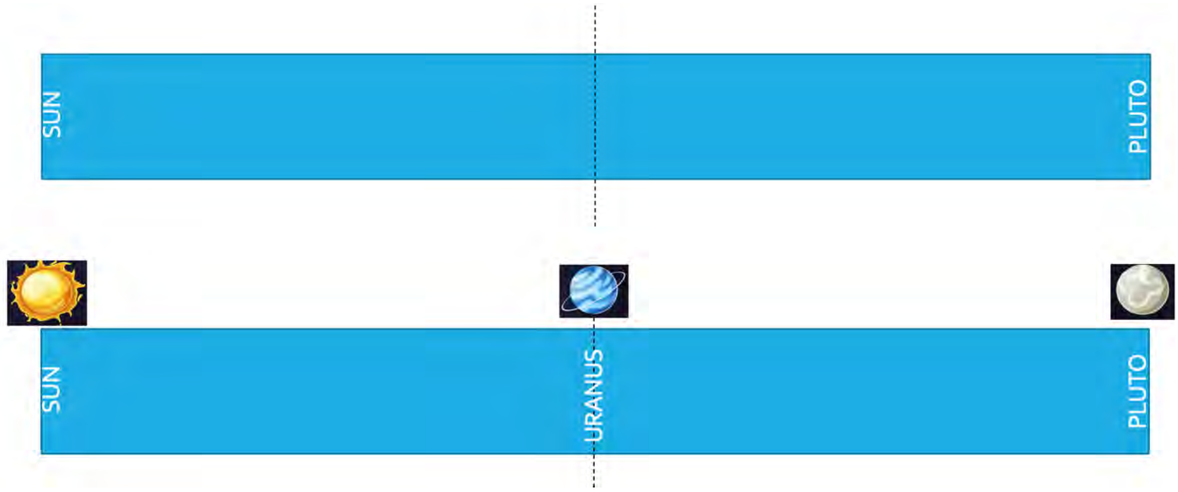
Appendix 1

Planets Worksheet

Step 1: Write the *Sun* on the left side and *Pluto* on the right side of our rectangular paper strip. Then, fold the paper as in the figure so that the *Sun* and *Pluto* are on top of each other. Now, unfold the paper and write *Uranus* on the fold line.

Question: If we consider this paper strip as a whole, which fraction represents the fold line, that is the location of Uranus?

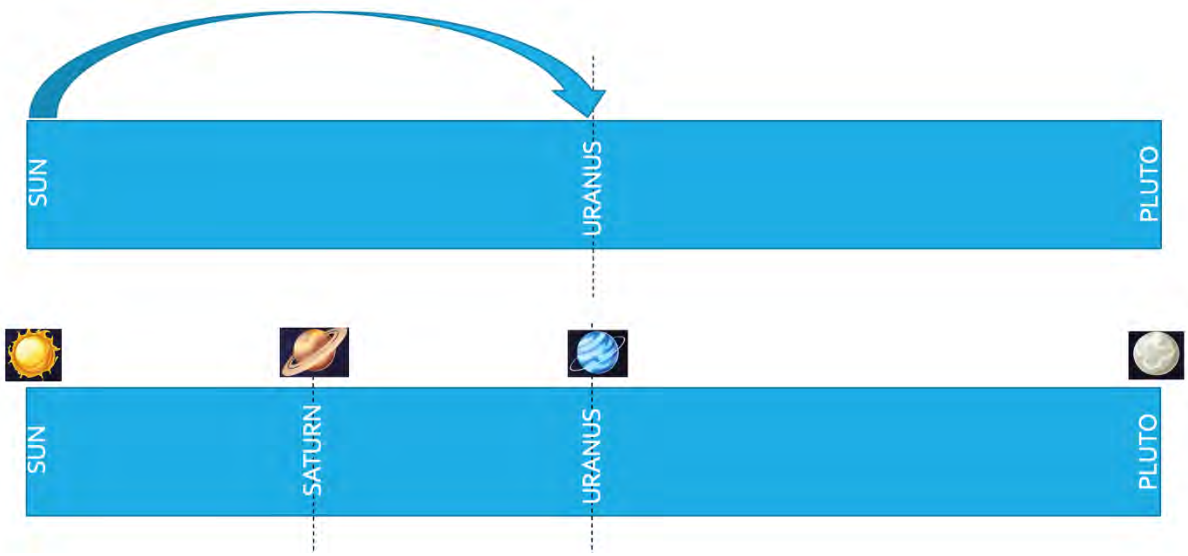
Answer:



Step 2: Fold the *Sun* side onto *Uranus*. Write *Saturn* on the fold line.

Question: If we consider the paper strip as a whole, which fraction should be written on the fold line formed in this step, that is the location of *Saturn*?

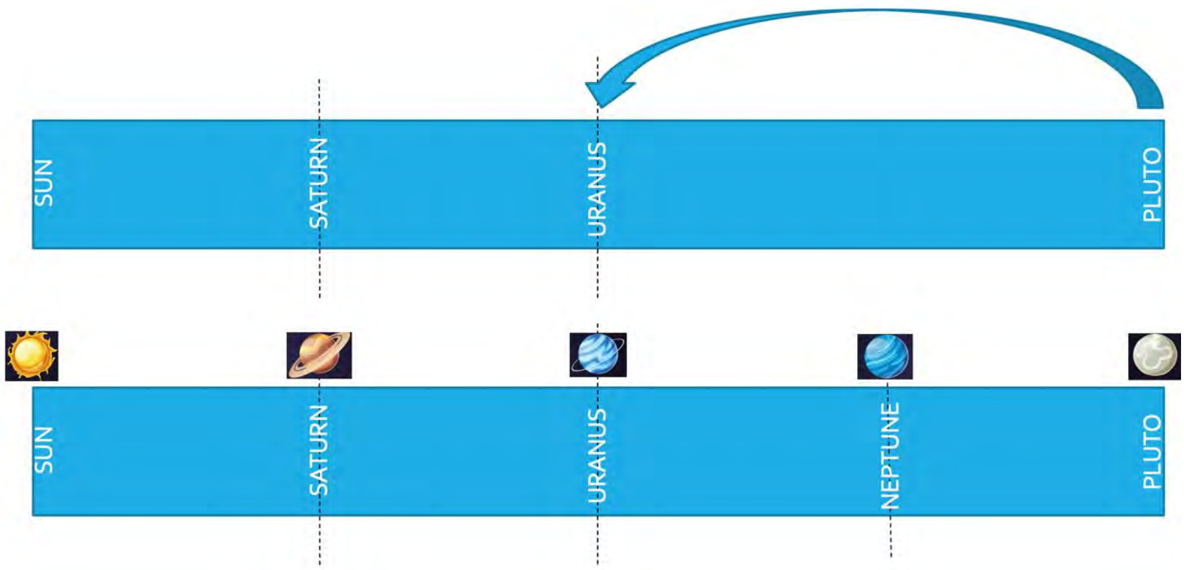
Answer:



Step 3: Fold *Pluto* side onto *Uranus*. Write *Neptune* on the fold line.

Question: Which fraction represents the fold line formed in this step, that is the location of *Neptune*?

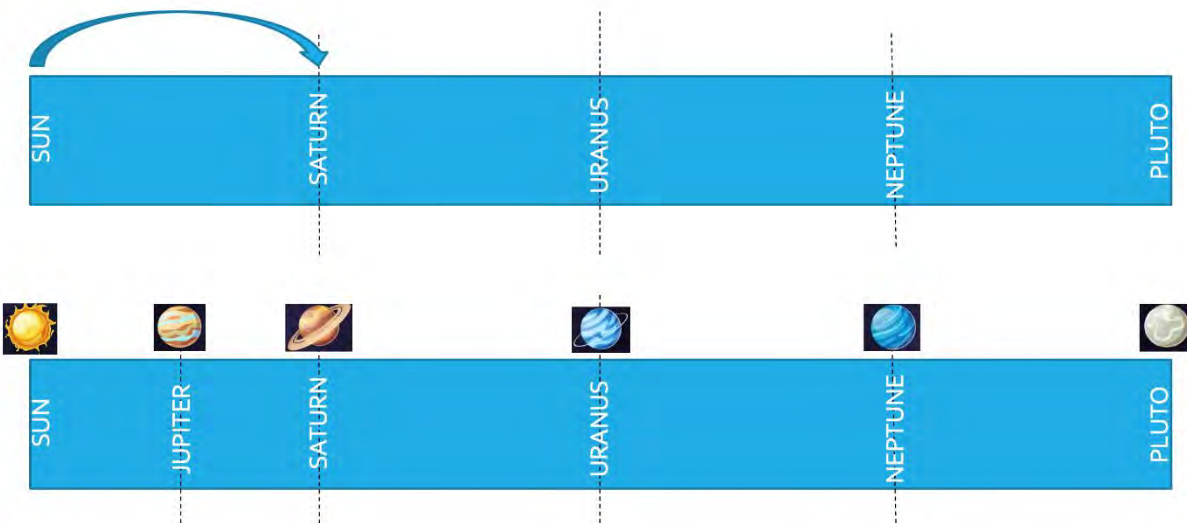
Answer:



Step 4: Fold the *Sun* side onto *Saturn*. Write *Jupiter* on the fold line.

Question: Which fraction represents the fold line formed in this step, that is the location of *Jupiter*?

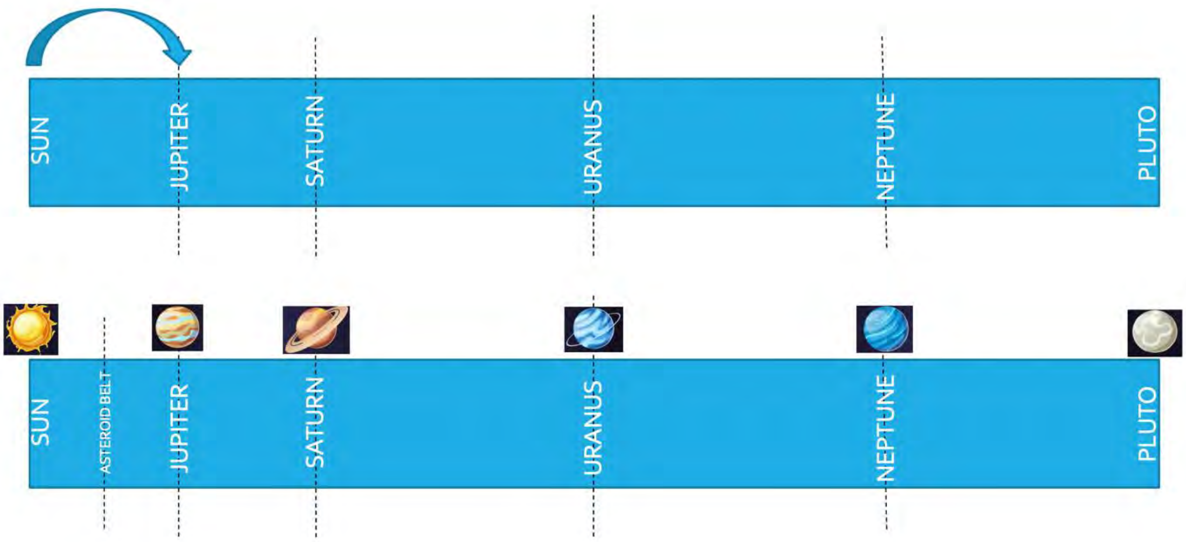
Answer:



Step 5: Fold the *Sun* side onto Jupiter. Write *Asteroid Belt* on the fold line.

Question: Which fraction represents the fold line formed in this step, that is the location of *Asteroid Belt*?

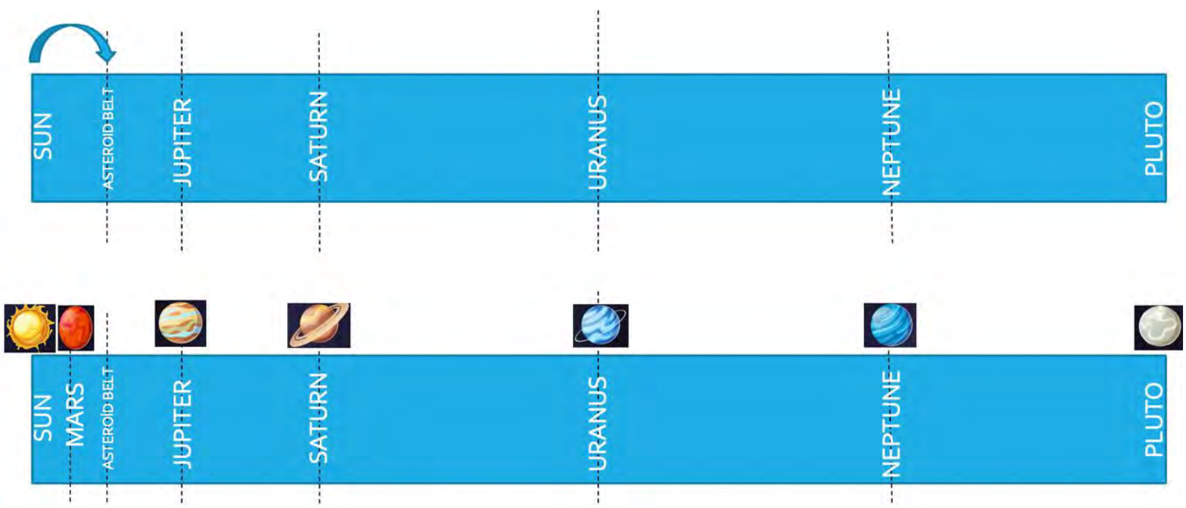
Answer:



Step 6: Fold the *Sun* side onto *Asteroid Belt*. Write *Mars* on the fold line.

Question: Which fraction represents the fold line formed in this step, that is the location of *Mars*?

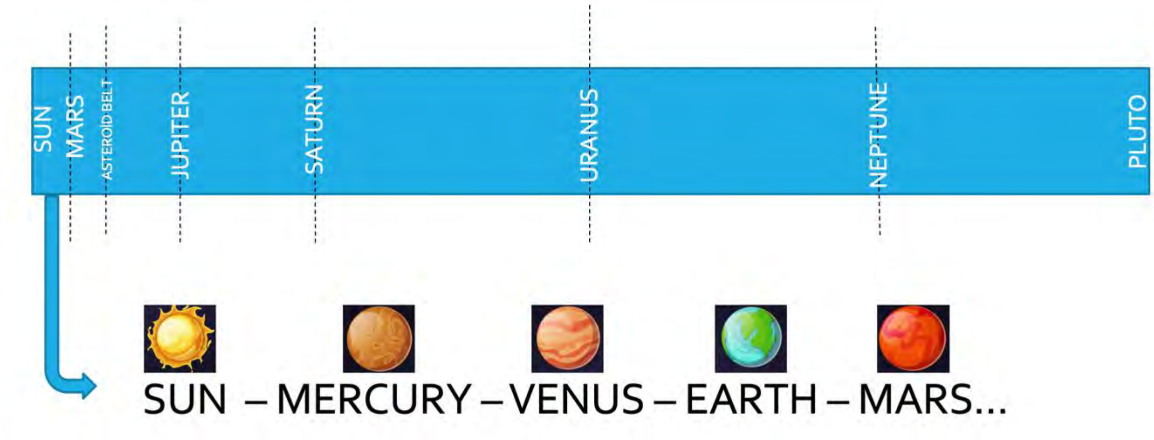
Answer:



Step 7: Write *Mercury*, *Venus*, and *Earth* between the *Sun* and *Mars*, respectively.

Question: According to the order of the planets, estimate which fractions can Mercury, Venus, and Earth be denoted by. Write your estimations below.

Answer:
Mercury: Venus: Earth:



Step 8: According to our model, which two planets are farther apart? (Circle the pair of planets you think are farther away).

Neptune and Jupiter Mars and Uranus

Mars and Uranus Neptune and Saturn

Earth and Saturn Saturn and Uranus

Mars and Jupiter Jupiter and Saturn

Appendix 2

Activity Evaluation Form

- What do you think about the origami activity we completed today?

- Would you like to participate in other origami activities like this one?

☐ Yes, because …

☐ No, because …

- What did you feel during the activity? (Entertainment, boredom, curiosity, fear, etc.)

- Do you think the activity was useful for you to understand fractions?

☐ Yes, because …

☐ No, because …

- Do you think the activity was useful for you to understand planets?

☐ Yes, because …

☐ No, because …