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Examination of Dynamic Mental Constructs and their Change Regarding Phases of the Moon

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ABSTRACT An immense body of literature on astronomy studies has provided evidence that individuals perceive the lunar phases concept as difficult. Furthermore, many studies have shown erroneous explanations or alternative conceptions of lunar phases. However, there is also a need to understand how individuals construct an explanation of the Moon's phases. This paper aims to explore pre-service science teachers' construction process of their explanations regarding lunar phases through clinical interviews. The data were obtained from fourteen pre-service science teachers and analyzed, identifying their nodes and dynamic mental constructs. The results indicated that most pre-service science teachers did not organize their nodes in a manner consistent with normative scientific explanations. In addition, pre-service science teachers changed their dynamic mental constructs while explaining different lunar phases, utilizing different media such as drawing and three-dimensional models, and responding to prompted questions. It was suggested that different opportunities, including technology-enriched activities regarding phases of the Moon, should be provided for pre-service science teachers to reorganize their nodes.

Keywords Phases of the Moon, Pre-Service Science Teachers, Knowledge in Pieces, Clinical Interview

1. INTRODUCTION

Astronomy is one of the oldest vehicles for people to understand celestial bodies and the celestial phenomena surrounding them. Thirty-thousand-year-old cave paintings show that our ancestors systematically observed celestial bodies (Karttunen, Kroger, Oja, Poutanen, & Donner, 2007). Their observation of lunar phases, eclipses, planets, stars, and other celestial bodies was the initial step of modern astronomy. Today, astronomy presents attractive issues for human beings. People consider questions such as how the universe started, how it will end, whether there is life on distant planets and galaxies, and black holes (De Pree & Axelrod, 2001). Astronomy has also been perceived as an indispensable component of educational programs since it is closely intertwined with human life (Bailey & Slater, 2004). Topics dealing with astronomy, such as lunar phases, eclipses, and the solar system, have been integrated into educational programs in various ways (Pasachoff & Percy, 2009). However, the inclusion of astronomy topics in education programs may not ensure individuals' sufficient understanding. Understanding astronomy topics requires more than knowing appropriate facts; it depends on individuals' imagination, representation, and transformation abilities (Subramaniam & Padalkar, 2009).

Individuals possess a substantial body of astronomy knowledge before instruction, which influences their learning. Studies (e.g., Venville, Louisell, & Wilhelm, 2012) showed that even a three-year-old child knows why we observe different lunar phases. Determining these existing conceptions is important since learning occurs due to the interaction between existing knowledge and new experiences (Posner, Strike, Hewson, & Gertzog, 1982). More specifically, existing knowledge is transformed into new forms that are expected to be consistent with scientific understanding (Sherin, 2006), and this process has been entitled conceptual change (diSessa & Sherin, 1998). Different frameworks exist explaining the structure and development of knowledge. Among these frameworks, the "knowledge in pieces perspective" proposes that the

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knowledge system is constituted by knowledge elements (Minstrell, 1982; Smith, diSessa, & Roschelle, 1993). Accordingly, knowledge elements are bits of a knowledge system, and individuals explain a natural phenomenon by activating and organizing them in a context (diSessa, Gillespie, & Esterly, 2004). An activated group of knowledge elements should fit together in a context and be meaningful to solve a problem or respond to a question (Hammer, Scherr, & Redish, 2005). Researchers studying conceptual change propose a variety of different terminology to clarify knowledge elements as facets (Minstrell & Stimpson, 1996), phenomenological primitives (diSessa, 1993), and node/mode (Sherin, Krakowski, & Lee, 2012). According to the mode-node framework, a node refers to all knowledge elements (e.g., mental images, mental models, general schemas). Nodes are connected, and a group of connected nodes is called a mode. In addition, individuals activate nodes and modes during the sensemaking process. Therefore, an operational and temporal form called a dynamic mental construct (DMC) is constituted.

Clinical interviews are one of the rational methods to understand individuals' conceptual understanding. According to Posner and Gertzog (1982), clinical interviews portray knowledge systems by identifying existing concepts and interactions among them. Participants are exposed to problem situations and attempt to produce feasible solutions during a clinical interview (diSessa, 2007). Clinical interviews provide a comfortable environment for interviewees to speak freely and reconsider their responses. Since this process is dynamic, participants may revise or alter their initial responses without manipulation (diSessa et al., 2004; Sherin et al., 2012). Changes in participants' responses during clinical interviews are perceived as conceptual changes. This change occurs in a short period and is described using various terminologies such as "conceptual dynamics" (Sherin et al., 2012) and "crystallization" (Blown & Bryce, 2006). In this study, pre-service science teachers' conceptual understanding changed during clinical interviews. The aim was to portray the fragmented understanding of pre-service science teachers and examine how their understandings change in different contexts.

To achieve this aim, this research focuses on the following questions.

a) How do pre-service science teachers organize their nodes to explain the Moon's phases during a clinical interview?
b) How do pre-service science teachers change their initial explanations of the phases of the Moon during a clinical interview?

Previous studies on the conceptual change regarding phases of the Moon concepts (e.g., Trundle, Atwood, & Christopher, 2002) were generally designed in light of a classical view. Accordingly, individuals' knowledge was perceived as a coherent structure among different contexts. These studies typically examined responses via a coding schema and categorized participants' responses as scientific or alternative explanations. To illustrate, labeling a participant's explanation as "alternative eclipse" means that s/he believes the Earth's shadow causes the lunar phases (e.g., Hobson, Trundle, & Saçkes, 2010; Trundle et al., 2002; Trundle & Bell, 2010). However, this method cannot fully reflect the participant's conceptual understanding. For instance, it is not clear whether participants consider the orbit of the Moon around the Earth or the illumination of the Moon by the Sun. In addition, these studies presumed that participants propose the same explanation for each lunar phase, and the explanation does not change in different media.

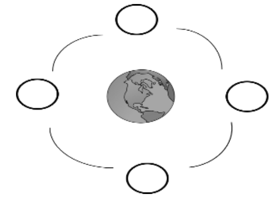
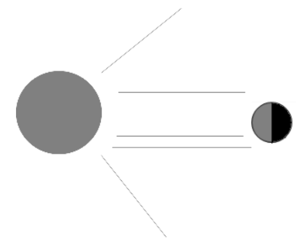
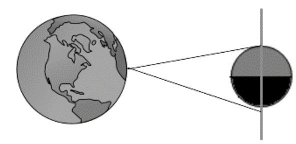
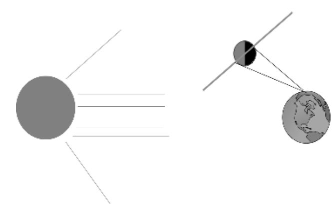
The current study followed the Knowledge in Pieces perspective to predict and understand pre-service science teachers' understanding of the Moon's phases. Knowledge pieces are activated and modified depending on the context (Parnafes, 2007). Since they are not coherent, students' responses may be contradictory or unstable from one situation to another due to a change of context (Parnafes, 2012). Considering these ideas, this study aimed to map pre-service science teachers' conceptual understanding of the Moon's phases in various context. Pre-service science teachers' explanations of Moon phases using different media were examined, as each Moon phase corresponds to a different context. Additionally, it tracked how their explanations changed with different media. Unlike the literature, this study aimed not to determine pre-service science teachers' misconceptions about the Moon's phases but to map the structure of their conceptual understanding. Therefore, the current study's findings present how pre-service science teachers activated knowledge elements and how they produced a DMC regarding the Moon's phases.

1.1 How do Phases of the Moon occur?

The Moon is observed with its eight major phases from Earth. These different appearances result from the Sun/Earth/Moon system. A normative scientific explanation of lunar phases covers four mechanisms (Parnafes, 2012; Trundle et al., 2002). As seen in Table 1, the Moon revolves around the Earth, and half of the Moon is illuminated by the Sun while revolving. In addition, it should be noted that half of the Moon can be seen from Earth. Finally, individuals should visualize these three conditions together and predict that the illuminated part of the Moon is visible from Earth to determine lunar phases.

A scientific explanation regarding the Moon's phases should cover nodes of orbit, illumination, and half. However, individuals may activate unrelated nodes and produce different DMCs. One of the popular nodes activated while explaining the Moon's phases is "shadow". More specifically, the phases of the Moon concept are often confused with the eclipse concept since they are related phenomena (Kanli, 2014; Semercioğlu & Kalkan,

Table 1 Component of scientific understanding of lunar phases

Explanation	Demonstration
The Moon orbits the earth	
Half of the Moon is illuminated by the Sun	
An observer from the earth always sees half of the Moon	
The lighted side of the Moon that is seen from the earth determines the phase	

2021). Furthermore, the location of an observer on Earth (Dunlop, 2000; Stahly, Krockover, & Shepardson, 1999), Earth's rotation (Baxter, 1989), and the distance between the Sun/Earth/Moon (Trundle et al., 2002) are other common conceptions regarding the cause of lunar phases. To arrive at a reasonable conclusion about the normative scientific explanation of lunar phases requires performing spatial abilities. Studies (e.g., Black, 2005; Wellner, 1995) have shown that high abilities in spatial thinking improve students' understanding and explanation of the phases of the Moon topic. To be more precise, spatial characteristics of celestial bodies, such as size, position, or motion, should be visualized by the individual for reasoning on phases of the Moon (Subramaniam & Padalkar, 2009; Wilhelm, Jackson, Sullivan, & Wilhelm, 2013).

2. METHOD

2.1 Research Design

The qualitative research paradigm shaped the current study to obtain detailed information regarding pre-service science teachers' conceptual understanding of the phases of the Moon. This study was designed as a case study. A case study is regarded as examining an issue from one or more cases within a bounded system (Creswell, 2007). Case studies provide holistic descriptions and explanations of situations, settings, or events (Merriam, 2009). Pre-service science teachers who participated in the present study are referred to as cases. Their conceptual understanding of the phases of the Moon is a complex system including different knowledge elements.

2.2 Participants

A total of fourteen pre-service science teachers participated in the current study. The research participants were selected by purposive sampling and consisted of ten juniors and four seniors. These teacher candidates enrolled in astronomy and physics courses in the science teacher education program. Participants were acquainted with the first author of the study. The researcher had assisted in some major undergraduate courses of the participants before the interview. As a result of the rapport between the researcher and participants, they responded to interview questions sincerely without any academic or social concerns. Pseudonyms were utilized to protect confidentiality.

2.3 Data Collection

Pre-service science teachers attempted to find a feasible way to explain why we observe lunar phases, and they tried to show this mechanism using drawings and models. To ascertain the nature and extent of pre-service science teachers' conceptual understanding of phases of the Moon, clinical interviews (Posner & Gertzog, 1982) with a multimedia approach (Blown & Bryce, 2006, 2010) were

Table 2 Interview questions

1	In what ways do you see the Moon when you look at it from the earth? If you looked at the Moon, in what appearances would you observe the Moon?
2	What could be the reasons behind the Moon's different appearances? How would you explain this for each different appearance?
3	Would you draw the explanation of each different appearance?
4	Would you demonstrate the occurrence of each different appearance with three-dimensional models?

Table 3 Description of activated nodes

Nodes	Description
Orbit	The Moon orbits the earth.
Illumination	A star shines on a planet and illuminates half of its surface.
Half	Only half of the Moon can be observed from the earth.
Apparent	The entire illuminated half of the Moon does not always point toward the earth.
Shadow/Blocking	The planets cast shadows in the opposite direction to the Sun. The earth/moon or other celestial bodies can block the light from the Sun.
Location	Observers stand in different locations on the earth's surface to observe different lunar phases.
Distance	Things that are closer look bigger, and things that are farther away look smaller.
Angle*	Earth receives the light from the Moon at a different angle.
Day/night*	The Moon and its phases are apparent only at night.
Tilt*	Earth's axis is tilted.
Reflection*	Different parts of the Moon reflect light to the earth to different extents. The direction of sunlight changes before they receive the earth's surface. (Refraction) Different wavelengths of sunlight scatter before they receive the earth. (Scattering)

*Nodes emerged in the current study.

utilized. Accordingly, pre-service science teachers were asked to respond to different interview questions in various ways (e.g., verbal explanation, drawing, and model demonstration). It was presumed that since the context (e.g., explaining different Moon phases) changes, activated nodes, and DMCs change. Therefore, clinical interviews were conducted to detect various nodes and different DMCs activated by pre-service science teachers during different parts of the interview. Each interview lasted between sixty to ninety minutes. The interview process was flexible, and participants could freely talk and reconsider their responses.

Interview questions were constituted based on examining previous studies on understanding the phases of the Moon. A total of four main interview questions (see Table 2) and many follow-up questions were directed to participants. Initially, pre-service science teachers verbally responded to the first two questions. Then, papers and pencils were provided to pre-service science teachers for the third question. After verbal responses and drawings, they were asked to use three-dimensional models to respond to the fourth question. Pre-service science teachers showed the sequence of the Sun/Earth/Moon for each phase. In addition, they explained how the Moon orbits, how the Sun illuminates, and which part of the Moon is visible using a three-dimensional model.

Obtaining richer and more profound information on the conceptual understanding of pre-service science teachers is a primary goal of the researchers. In addition, researchers aim to elucidate participants' conceptions without any manipulation or instruction. Participants generally do not consider different perspectives of an issue and are unaware of inconsistencies in their explanations (Sherin et al., 2012). Therefore, inconsistencies among their explanations were explicitly pointed out by the researchers and directed as further questions to observe the change in their understanding. For instance, if the waning crescent is explained differently in the model demonstration from their drawing, their drawings are shown again.

2.4 Data Analysis

Data were analyzed to reveal knowledge elements and how these elements constitute a DMC. This research followed the node/mode framework and knowledge in pieces perspectives. First, the activated nodes of the pre-service science teachers were coded. Before the data analysis, previous research on phases of the Moon was examined to determine possible nodes, and most of the nodes were adopted from previous studies (Nielsen & Hoban, 2015; Parnafes, 2012; Trundle et al., 2002). Then, additional nodes emerging from the analysis were added to the node list. A complete list of the nodes and their descriptions are presented in Table 3. Finally, activated nodes and interactions between them were analyzed to generate DMCs.

To establish the reliability of the coding, two additional researchers with experience in phases of the Moon and

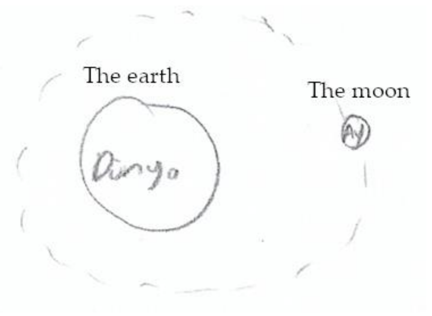


Figure 1 Aykut's drawing of phases of the moon

qualitative research coded 10% of the data. Consistency among the first author and the researchers' coding was 82%. The coders discussed inconsistencies and reached an agreement.

The different sources of data (verbal responses, drawings, and demonstrations) were triangulated on a basis to confirm assertions generated. Pre-service science teachers' responses in three different ways were analyzed independently. Finally, the analysis of each response was compared with others. Sample analysis presented in the following excerpt showed how the study's credibility improved by analyzing different sources. For instance, Aykut verbally explained the phases of the Moon:

> Interviewer: What could be the reasons behind the Moon's different appearances?
>
> Aykut: It is related to being close or away. It moves closer or farther due to the Earth's horizontal axis. Therefore, there is no stable distance between the Moon and the Earth. Therefore, larger shapes occur when it is closer to the Earth.

It might be asserted that phases of the Moon occur because of the Earth's spin on its horizontal axis, considering Aykut's expression, "It moves closer or farther due to the Earth's horizontal axis". Therefore, it was also plausible to infer that the distance between the Earth and the Moon changes due to the Earth's horizontal spin. However, Aykut drew Figure 1, which shows the orbit of the Moon around the Earth. A comparison of these different data sources indicated that Aykut's responses correspond to the Moon's orbit instead of the Earth's spin.

3. FINDINGS

The analysis of pre-service science teachers' responses showed that they activated eleven nodes, four of which - orbit, illumination, half, and apparent - are essential for appropriately explaining the phases of the Moon. The remaining seven nodes - shadow, reflection, location, distance, tilted, day & night, and angle - are not directly related to the phases of the Moon. A DMC includes between two or four nodes. Additionally, fourteen pre-service science teachers produced twenty-five DMCs. The total number of nodes detected from pre-service science teachers' DMCs is presented in Table 4.

Table 4 Knowledge elements activated by pre-service science teachers

Elements	*Number	Element	*Number
Orbit	25	Location	4
Illumination	25	Distance	3
Shadow	8	Tilted	3
Apparent	4	Day & Night	2
Half	4	Angle	1
Refraction	4		

*Total number of nodes detected from all DMC

The DMCs were classified into three groups based on the number of activated nodes: low-level (two nodes), medium-level (three nodes), and high-level (more than three nodes). The total number of activated nodes is presumed to be an indicator of the quality of the DMC due to two factors. Initially, the explanatory power of DMCs increases while the number of activated nodes increases. For instance, a DMC including orbit, illumination, and half explains the Moon's phases more clearly than another DMC including only orbit and illumination nodes. The second factor is related to the consistency among the nodes. While the number of nodes increases, ensuring consistency among them becomes a more challenging task. Pre-service science teachers should be aware of possible discrepancies among the nodes.

The nodes did not contribute equally to the explanations provided by the pre-service science teachers. Different medium-level DMCs were named based on the dominant nodes: angle, distance, shadow, reflection, and location. Table 5 shows the number of DMCs produced by different pre-service science teachers and the eight groups into which the 25 DMCs were categorized.

Table 5 Change of pre-service science teachers' DMC

Name	First DMC	Second DMC	Third DMC
Aytolun	Angle	-	-
Aykut	Distance	High	High
Ayça	Shadow	Reflection	High
Aygun	Shadow	High	-
Ayten	Low	Day & Night	-
Aysil	Reflection	Location	Shadow
Aynur	Shadow	High	-
Aydan	Low	-	-
Aytac	Reflection	Shadow	-
Aybuke	Location	Shadow	-
Aysu	High	-	-
Ayfer	High	-	-
Aybilge	High	-	-
Aysin	High	-	-

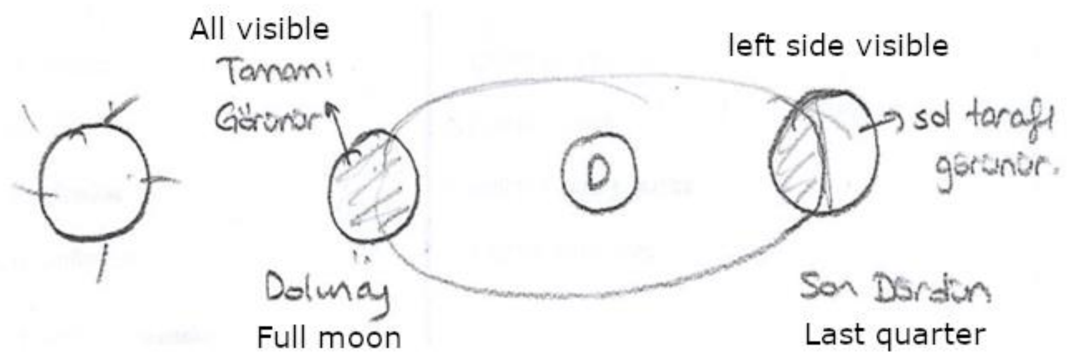


Figure 2 Aynur's drawing of phases of the moon

Table 5 shows that eight pre-service science teachers suggested at least two DMCs. The remaining six pre-service science teachers produced only one DMC during the interview. On the other hand, fourteen medium-level, two low-level, and nine high-level DMCs were detected from pre-service science teachers' responses on phases of the Moon. High-level DMC may not necessarily denote pre-service science teachers' scientific explanation. Although nine high-level DMCs were detected, only four proposed by Aysu, Ayfer, Aybilge, and Aysin were classified as scientific explanations. Although Aykut, Ayça, and Aygun produced high-level DMCs, these DMCs do not include the required nodes to explain the phases of the Moon consistent with scientific explanations.

3.1 The Low-Level DMC

All the pre-service science teachers activated orbit and illumination nodes in their explanations. However, some tried to explain the phases of the Moon only with these two nodes. Since the explanatory power of this explanation was low, they were called low-level DMC. Finally, there were two pre-service science teachers (Ayten and Aydan) who explained the phases of the Moon with illumination and orbit nodes. As seen in the following excerpt, Aydan stated that phases of the Moon occur as a consequence of the illumination of the Moon and the Moon's orbit around the Earth.

> The Moon should be illuminated. However, the Moon does not have its light. The source of the light is the Sun. The Sun illuminates both the Earth and the Moon. Therefore, we observe the Moon phases since the Moon is illuminated while orbiting around the Earth.

Pre-service science teachers produced low-level DMCs at the beginning of the interviews. However, after realizing the shortcomings of their explanations, they changed their DMCs by activating additional nodes.

3.2 The Medium-Level DMCs

In addition to orbit and illumination nodes, pre-service science teachers activated one more node to explain the phases of the Moon. Shadow, location, distance, reflection, and day & night nodes were activated as additional third nodes for explaining the phases of the Moon. Since these additional nodes are more dominant than orbit and illumination nodes, detected DMCs were entitled to considering these additional dominant nodes. These medium-level DMCs are presented in the following sections.

Shadow-dominated DMC

Shadow-dominated DMC means that the phase of the Moon occurs since the Moon is in the shadow cone of the Earth or the Earth blocks the light of the Sun. A total number of six shadow-dominated DMCs were detected. For example, Aynur gave the following explanation:

> Aynur: It occurs there (the Moon is between the Earth and the Sun) since the Moon receives all Sunlight. Therefore, it is the full Moon here. Therefore, no obstacle blocks its surface.
>
> Interviewer: What about the last quarter?
>
> Aynur: The last quarter, the right side of the Moon was blocked. Sunlight…The Earth blocks the right side of the Moon. So the left side of it receives sunlight.

As seen in Figure 2 and the previous excerpt, Aynur explained that the Moon should be full between the Earth and the Sun. According to this viewpoint, the Earth does not prevent the illumination of the Moon in this position. However, it was also revealed that Aynur could not visualize which part of the Moon receives Sunlight and which part of the Moon can be seen from the Earth.

Location-dominated DMC

According to this perspective, phases of the Moon are mainly determined by the observer's location on Earth. Pre-service science teachers determined locations on Earth and then predicted lunar phases from these points. Two pre-service science teachers produced location-dominated DMCs to explain lunar phases. To illustrate, Aybuke explained, "It is important from where we observe the Moon. Simultaneously, someone looking at the Moon from America and I (in Europe) observe differently since they receive lights from different parts of the Moon than me." In addition to this explanation, s/he created a diagram showing that people from different locations can simultaneously observe the Moon as the waning gibbous and crescent gibbous, as shown in Figure 3.

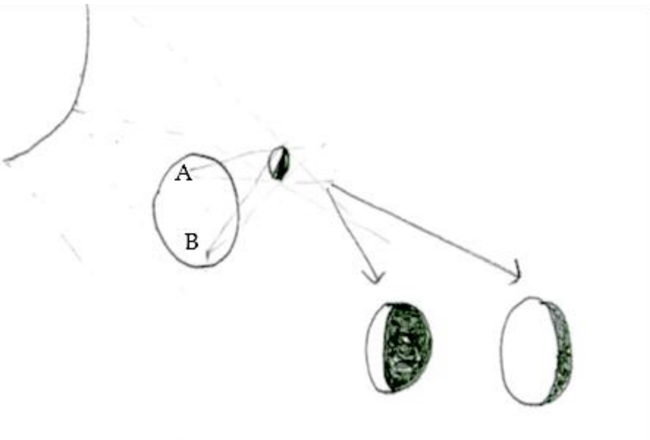


Figure 3 Aybuke's drawing of phases of the Moon

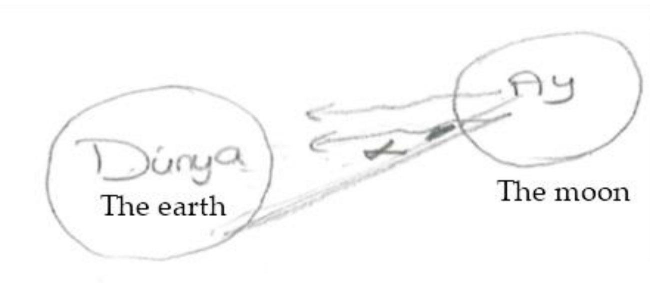


Figure 4 Aytolun's drawing of phases of the Moon

Angle-dominated DMC

There was one pre-service science teacher, Aytolun, who produced angle-dominated DMC. Angle-dominated DMC refers to considering the angle of reflected sunlight to Earth from the Moon. For instance, Aytolun asserted:

> While the Moon rotates and orbits, the light-received from the Moon most probably spreads out. For example, if we observe the new moon when the angle of the light (between the normal of the surface) is ninety degrees. While reducing this degree, the appearance of the Moon changes in the first quarter.

As seen from the utterance, s/he activated three nodes as orbit, illumination, and angle to explain the phases of the Moon. S/he mainly considered the angle of the lights changing while the Moon orbits around the Earth. This drawing also showed the perspective of the pre-service teacher on phases of the Moon. As seen in Figure 5, a normal vector perpendicular to the Moon's surface was drawn, and the α symbol denotes the angle between the normal and the lights.

Distance-dominated DMC

The main perspective behind distance-dominated DMC is that the distance between Earth and the Moon determines the Moon's appearance. Aykut developed distance-dominated DMC, activating distance, orbit, and illumination nodes to elucidate the phases of the Moon. S/he explained:

> It is related to being close or away. It moves closer or farther due to the Earth's horizontal axis. Therefore, there is no stable

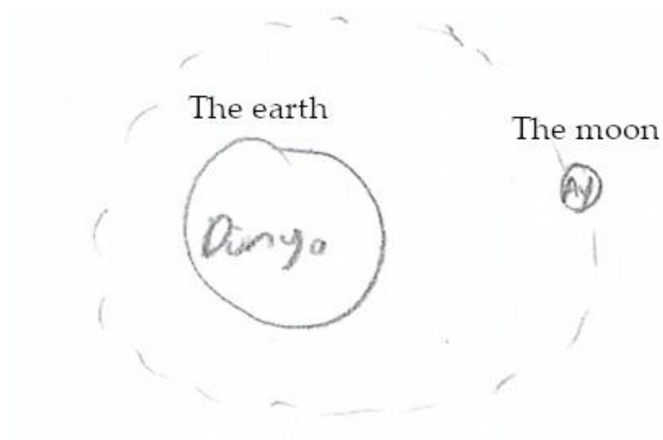


Figure 5 Aykut's drawing of phases of the Moon

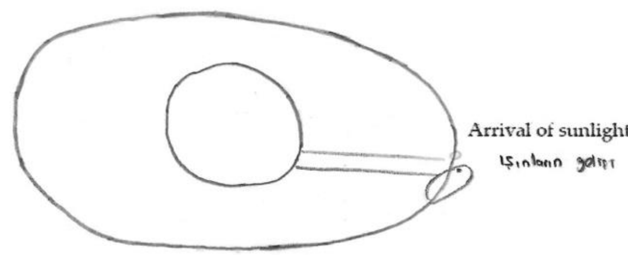


Figure 6 Aysil's drawing of phases of the Moon

> distance between the Moon and the Earth. Therefore, larger shapes occur when it is closer to the Earth.

As evidenced by previous statement and Figure 5, Aykut posited that the distance between the Moon and Earth determines the Moon's phases. Accordingly, as the distance decreases, the visible portion of the Moon from Earth increases.

Reflection-dominated DMC

Pre-service science teachers attempted to explain the Moon's phases using optical principles such as refraction, reflection, or scattering. In brief, reflection-dominated DMC refers to the idea that the Moon reflects light while orbiting Earth; resulting in the observation of different lunar appearances. For example, Aysil drew Figure 6 and explained:

> The Sun is here, and we orbit it. The Moon is here. Since all reflected lights do not reach Earth, we only see a part of the Moon. I may observe the waxing crescent at this point. Scientists know their appearance by calculating. Since the specific angle, the direction of light, and the position of the Moon and Earth are known, the actual phases of the Moon can be calculated. I am just forecasting the phases since I do not have data.

Day and Night-dominated DMC

Pre-service science teachers employed the day and night mechanism to explain lunar phases. Two pre-service science teachers (Aygün and Ayten) activated the day and night nodes. Since Aygün's explanation comprises more than three nodes, only Ayten's explanation was classified as day and night-dominated DMC. S/he generated this DMC

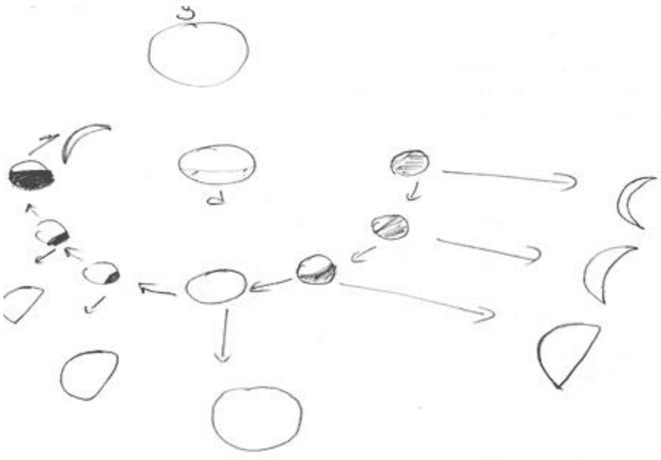


Figure 7 Ayten's drawing of phases of the moon

while displaying three-dimensional models. S/he articulated:

> Ayten: What would happen in this position? Do I observe the Moon? (Silence for a couple of seconds) It is challenging for me to explain. Why do I not observe the Moon? (Silence for 40 seconds). Ah, I see. The phases I examine are present here. In this case, Earth is illuminated. This side of Earth is also in daytime. I need to observe the Moon at the night side. So, do I observe the full Moon in this position? I think… Yes, I observe the full moon in this position. I am sure now. Sunlight receives this part (the part facing the Earth) of the Moon and entirely illuminates this part. This part of Earth is day, and I observe full moon from that side of Earth.
>
> Interviewer: What would happen after this point?
>
> Ayten: Then, the Moon passed the other side. Side of daytime. I could not see the Moon when it was daytime on Earth.

As shown in the excerpt, Ayten attempted to explain the lunar phases by considering day and night mechanisms. Accordingly, the Moon is only visible at night, and its phases change depending on illumination and orbit. After the demonstration, s/he produced Figure 7 to show each appearance of lunar phases.

3.3 High-Level DMC

Analysis of the interview data revealed that eight pre-service science teachers activated nine high DMCs. A total of four DMCs consisted of the scientific explanation of the Moon's phases, as they included orbit, illumination, half, and apparent nodes. Conversely, the other four pre-service science teachers activated four nodes to explain the Moon's phases. For instance, Aykut activated tilted, distance, illumination, and orbit nodes to explain the occurrence of lunar phases, as seen in the following statement.

> Aykut: It is the full moon when in a location close to Earth. It appears as the first or last quarter when it is far from the Earth. We can observe a small portion of the Moon due to its distance. But… I have just noticed… Why do we observe a small portion rather than viewing the complete Moon as small? (Silence for about twenty seconds) I think it is related to the orbit and the Earth's tilt.
>
> Interviewer: How does the Earth's tilt influence the appearance of the Moon?
>
> Aykut: As the Earth has a tilted axis, our angle of view does not cover the whole Moon. Thus, we observe it as first or last-quarter views. However, in a more suitable position, it can be seen as the full Moon.

Here, Aykut activated the tilted node to explain the first and last quarter moon. However, the statement, "Why do we observe a small portion rather than viewing the complete Moon as small?" revealed that the initial explanation is not enough to explain the first and last quarters. Therefore, s/he integrated tilted nodes into the DMC and explained lunar phases. The following excerpts also demonstrated a similar process performed by Ayca.

> Interviewer: Can you explain why we observe waxing crescents using these models?
>
> Ayca: This part is light. The rest of it is dark. (silence for a couple of seconds). I think the Moon can reflect rays only from this illuminated part. I observe it as a crescent Moon since rays reflected from the other part are not enough. For instance, if I vertically expose a lamp to a point, it would be illuminated perfectly. However, if the lamp were tilted, illumination would be reduced in some parts of this point. Since the Moon is tilted, only the crescent part of it is perfectly illuminated. Rays reaching the rest of it are not enough to reach Earth.

Accordingly, s/he articulated that the Moon is tilted; therefore, the illumination of the Moon changes. As a result, the perfectly illuminated part reflects the sunlight better. Considering Ayca's explanation, it was revealed that s/he activated illumination, orbit, tilted, and reflection nodes to explain the Moon's phases.

3.4 Change in Science Teachers' DMC

This part of the research aimed to uncover factors influencing pre-service science teachers' activation of different nodes and changing their DMC. Analysis showed that pre-service science teachers changed their DMCs due to four factors drawing, three-dimensional models, explaining different phases, and prompted questions. Details on the role of these factors in pre-service science teachers' DMCs are presented in this part.

Three-dimensional models

A total of four pre-service science teachers changed their DMC after they were asked to show phases of the Moon using a three-dimensional model. One of the critical points is that utilizing three-dimensional models contributed to their spatial abilities. For instance, in the second DMC, Aysil articulated:

> An observer (pointing to Figure 8) looks at only a quarter of the Moon. However, the observer here has an angle that observes the complete Moon. The position of the Moon and Earth and our location are known. However, the Moon is observed differently from different locations on Earth.

As seen from the previous utterance, Aysil explained the Moon's phases by activating location, orbit, and illumination nodes. However, after using the three-dimensional model, s/he explained:

> … Since this part of the Earth could not receive sunlight, it is night. Another side is day. A person from this side (facing the Moon) of Earth never observes the Moon since Earth blocks the Moon. None of the sunlight reaches the Moon. The Moon is smaller than Earth. Earth covers the place where the Moon is located. After a slight movement of the Moon (s/he moves the Moon's right side in its orbit), it receives light. Therefore, we observe a crescent. Sunlight has an angle. While it moves, I observe an increase in the crescent shape. It becomes thicker. It is more logical.

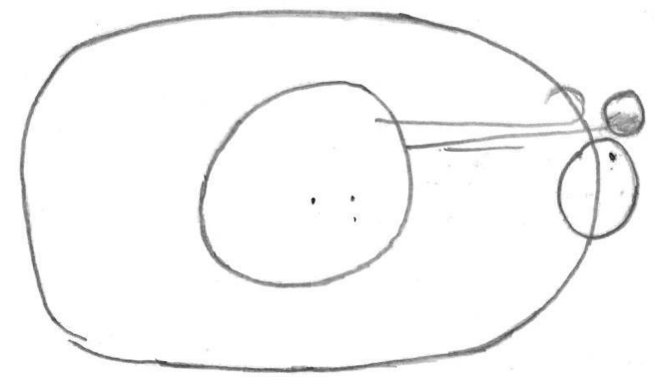


Figure 8 Aysil's initial drawing of phases of the moon

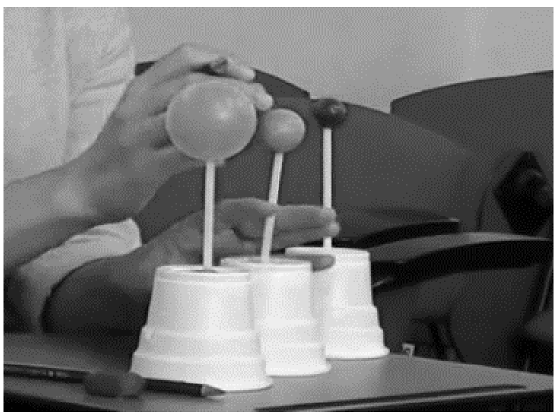


Figure 9 Aysil's demonstration of phases of the moon

With this response and demonstration in Figure 9, Aysil seemed to have shifted to a shadow-dominated DMC from a location-dominated DMC. S/he activated orbit, illumination, and shadow nodes while explaining with a three-dimensional model. Although pre-service science teachers changed their existing DMC, they could not produce a scientific explanation of the phases of the Moon. In other words, the three-dimensional model did not contribute to reaching scientific understanding. Pre-service science teachers activated different nodes and produced different DMCs, which still resulted in inconsistent scientific explanations.

Drawing

Pre-service science teachers changed their initial explanation of the Moon's phases while drawing lunar phases. It was plausible to consider that drawing allowed the pre-service teacher to see all the Moon phases together. In this way, they found an opportunity to compare each lunar phase with one another. For instance, Ayca initially explained, "While moving away from the Sun and revolving around Earth, depending on the sunlight received and shadowing, we observe different phases of the Moon". This explanation showed that s/he initially produced shadow-dominated DMC while activating shadow, orbit, and illumination nodes. However, her explanation changed while demonstrating the phases of the Moon in Figure 10. S/he articulated:

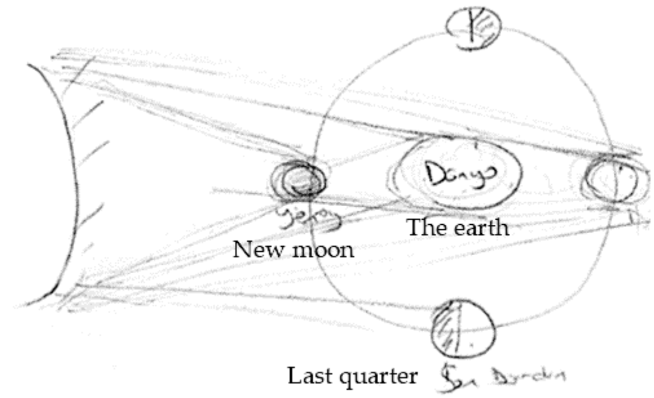


Figure 10 Ayca's drawing of phases of the moon

Interviewer: Could you explain how all these different Moon appearances occur?

Ayça: As I have drawn (Figure 10), while the Moon revolves around Earth, we see it (the new moon position) as dark because of Earth's shadow. Do we see it as dark since the Moon shades it… (silence for a couple of seconds)

Interviewer: Are there any points in your explanation that do not satisfy you?

Ayça: According to my explanation, if it shades it in that position (new moon), we never see the full moon. The Moon completely shades it because Earth is bigger, and the Moon is smaller when compared to Earth. Therefore, the Moon must be completely dark in its full moon phases. Hence, there is no shade of Earth on the Moon.

Interviewer: Alright, why do we see it as dark in the new moon position?

Ayça: It may be related to that… Sunlight is coming from the Sun. It may scatter. Because of scattering, Earth does not receive any sunlight. So Moon's light cannot reach Earth.

Ayça changed their DMC after drawing. S/he considered that a shadow-dominated DMC could not explain both the new and full moon. Therefore, s/he shifted to a reflection-dominated DMC (scattering). It is plausible that pre-service science teachers visualize one of the Moon phases while responding to why we observe different phases. Therefore, the drawing ensured that Ayça considered the new moon and full Mmoon phases together to explain the rationale behind the phases of the Moon.

Different Phases

As noted earlier, pre-service science teachers were asked to explain how we observe each Moon phase. Therefore, they tried explaining the occurrence of the eight Moon phases. Analysis of responses shows that pre-service science teachers activated different nodes while explaining different lunar phases. To illustrate, we return to the interview conducted with Aygün. First, s/he explained phases of the Moon concepts using a shadow-dominated DMC. Then, considering the drawing in Figure 11, the interviewer asked Aygün whether we observe the Moon in the daytime. As seen from the following utterance, Aygün proposed a new model considering the crescent Moon.

Aygün: The lighted part of the Moon was limited (referring to the models seen in Figure 11). Due to its shape, these parts are dark (indicating that part of the Moon does not receive sunlight). Even in this position (Figure on the right).

Figure 11 Aygün's demonstration of phases of the moon

Interviewer: How would we observe the Moon?

Aygün: For this (Figure on the right), it is mostly half-Moon. And for this (Figure on the left), it is crescent.

Interviewer: What would happen at night?

Aygün: These are for daytime. It is different at night. We observe phases due to the shadow of Earth. It is seen in the daytime since the Sun illuminates but at night, it is because of the shadow.

Aygün produced two different models to explain the phases of the Moon. First, s/he explained the crescent Moon with the illumination of the Moon in the daytime while explaining the rest of the phases via shadow-dominated DMC.

Prompted questions

Pre-service science teachers changed their DMCs after the interviewer prompted questions. These questions were generally directed to pre-service science teachers to capture the details of their explanations. While explaining details, they often realized inconsistencies or lacking points. Then they reorganized their DMCs. For instance, Aykut explained the full moon and new moon phases using a distance-dominated DMC. However, s/he explained the first and last quarter phases considering location with three-dimensional models. Finally, the interviewer directed a prompted question, as seen from the following utterance, and Aykut reorganized their DMC.

Interviewer: Is there an equal distance between the Moon and Earth in your demonstration?

Aykut: Because I had explained them, I did not mention distance again.

Interviewer: Could you explain again, considering the role of distance?

Aykut: I consider the Moon approaches Earth in full moon phases. In the case of phases first and last quarter, distance is not close and not away. Therefore, crescent moon is far from the Earth.

Interviewer: What would happen if an observer saw a full Moon when there is a long distance between Earth and the Moon?

Aykut: No way! Humm... It would be possible. We sometimes observe the small full moon and sometimes the big full moon. (Silence a couple of seconds and then smiles). Therefore, it shows me that there is no linkage with distance.

Interviewer: So, what is the factor or factors that influence the appearance of the Moon?

Aykut: Phases of the Moon, how can I explain? Our viewpoint. The location where we observe the Moon.

As shown in the previous excerpt, Aykut changed activated nodes after the interviewer's question. Therefore, Aykut reconsidered DMC and reorganized it.

4. DISCUSSION

This study aimed to understand the process of constructing explanations by identifying nodes and activated DMCs. Results showed that pre-service science teachers activated various nodes during the interview process, attempting to produce a DMC by activating these nodes. On one hand, a total of ten pre-service science teachers sought to explain the lunar phases during the interview. In other words, these pre-service science teachers generated one or more DMCs by activating different nodes. These conceptual structures may quickly change into other forms on short time scales of seconds. Therefore, in alignment with the studies of Sherin et al. (2012), these structures were regarded as DMCs, focusing on their dynamic and temporary features.

On the other hand, four pre-service science teachers confidently and immediately responded to interview questions, providing answers consistent with the normative scientific explanations. These responses were also considered DMCs, as individuals may recall an issue based on their experience. Their experience and familiarity enabled the activation of appropriate knowledge elements (Körhasan, 2021). Sherin et al. (2012) noted that a group of activated nodes might constrain DMCs. To cite an example, this situation resembles asking an astronomer to explain the seasons. Due to their experience with astronomy-related issues, they can quickly activate appropriate nodes to produce a DMC. In the current study, four pre-service science teachers were fourth-grade (senior) students, which may indicate in-depth and considerable experience with the phases of the Moon.

The present study investigated pre-service science teachers' DMCs on Moon phases and tracked changes in their DMCs during a clinical interview without instructional support. The findings demonstrated that individuals might rapidly change their conceptual understanding, consistent with previous research (Parnafes, 2012; Sherin et al., 2012). In this study, pre-service science teachers adjusted and reframed their explanations during a clinical interview. They attempted to provide a more logical explanation of the phases of the Moon after recognizing their shortcomings or researcher's efforts to highlight inconsistencies. Consequently, some suggestions can be made about how to teach Moon phases effectively. For example, asking challenging questions and revealing inconsistencies in their responses may help improve their understanding of a specific topic. Since researchers' prompts triggered shifts in participants' conceptions, instructors or teachers can utilize the same technique to enhance their students' understanding of lunar phases. Furthermore, pre-service science teachers should have the opportunity to explore and ask questions regarding their current conceptual understanding, confronting deficiencies and incompatibility of their explanations. Undergraduate astronomy courses and teaching activities should provide pre-service teachers the opportunity to improve their awareness of their understanding of Moon phases.

The current study showed that 10 out of 14 interviewees did not construct a DMC based on scientific knowledge. This finding is in line with previous studies (e.g., Bayraktar, 2009; Kanli, 2014; Semercioğlu & Kalkan, 2021; Trumper, 2001; Trundle et al., 2002) that indicate individuals harbor misconceptions about phases of the Moon. Nonetheless, explanations not consistent with normative scientific explanations were not considered misconceptions in this study. Following the footstep of the knowledge in-pieces perspective, erroneous interpretations of pre-service science teachers were viewed as a problem of node organization and activation. Accordingly, pre-service science teachers should be provided with different contexts to activate their nodes to achieve a more sophisticated and stable understanding (diSessa, 1993). In other words, pre-service science teachers should develop the skills to present the same phenomena in various contexts. For instance, Ucar (2014) introduced phases of the Earth context for pre-service teachers. Participants attempted to explain how the Earth appears when viewed from the Moon in that study. This approach might be effective, as the same knowledge elements should be activated for explaining both Earth's and the Moon's phases. Moreover, examining the phases of Venus and Mercury could be another effective method for fostering a sophisticated understanding. Pre-service science teachers can predict the appearance of Venus and Mercury by considering the mechanism of Moon phases.

Considering some of the nodes (e.g., reflections, angle) activated by pre-service science teachers, it was revealed that their DMCs were influenced not only by their daily life and astronomy courses they took but also by the physics courses they participated in. Pre-service science teachers activated these nodes, although they were not directly linked to phases of the Moon issues. This situation may suggest that pre-service science teachers do not have a sophisticated understanding of physics subjects, such as the nature of waves. Since pre-service science teachers could not organize their mental constructs concerning these physics subjects, they tend to activate these unrelated knowledge elements when explaining the Moon's phases.

Pre-service science teachers' spatial abilities also shaped their explanations of the phases of the Moon. The finding of this study was consistent with previous research (Cole, Wilhelm, & Yang, 2015; Plummer, 2014; Wilhelm et al., 2013), demonstrating that explaining the Moon's phases requires a certain level of spatial ability. Furthermore, this study clarified why low spatial ability may hinder understanding of the phases of the Moon. It was shown that pre-service science teachers activated unrelated nodes due to their low spatial abilities. For example, they could not visualize how the Moon was illuminated and how it could be seen from a location on Earth. As a result, they activated location, angle, and reflection DMCs to explain the phases of the Moon. Therefore, activities aimed at improving pre-service science teachers' spatial abilities should be designed. Technology resources such as simulations and augmented reality may effectively enhance visualization of lunar phases.

Numerous studies on understanding on phases of the Moon (e.g., Hobson et al., 2010; Trundle et al., 2002) have overlooked potential changes in pre-service science teachers' responses during the data collection process. In the current study, pre-service science teachers' understanding was examined through clinical interviews, and changes in their responses during the interviews were investigated. Results indicated that pre-service science teachers might produce different explanations for different lunar phases. For instance, they explained full and new moon phases by activating shadow and distance nodes while activating angle, tilted, and location nodes for gibbous and crescent Moons. It was revealed that determining activated nodes while considering different phases might be a more appropriate strategy for examining pre-service science teachers' understanding of the Moon's phases. Additionally, instructors should design activities that demonstrate the occurrence of all phases, rather than presenting a general mechanism.

5. CONCLUSION

This paper explored pre-service science teachers' construction of an explanations for the phases of the Moon concept in light of the knowledge in pieces perspective. Data were obtained from clinical interviews conducted with fourteen pre-service science teachers. The results indicated that pre-service science teachers produced eight dynamic mental constructs using eleven knowledge elements. Each dynamic mental construct contained between two and four knowledge elements. In other words, pre-service science teachers activated both related and unrelated nodes. Low spatial abilities and shortcomings in some physics subjects, such as waves and reflection rules, were the chief culprit for activating of unrelated nodes.

This study also demonstarted that pre-service science teachers' explanations changed while explaining different lunar phases, utilizing different media such as models, and responding to interviewers' prompted questions. However, although the explanation of the Moon's phases changed, they could not construct a normative scientific explanation at the end of the clinical interviews. Therefore, pre-service science teachers need different contexts regarding lunar phases to produce a more stable and sophisticated conceptual understanding of the phases of the Moon. It is also interesting to note that some pre-service science teachers construct different explanations for different lunar phases. For example, shadow and distance nodes explained full and new Moon phases, and gibbous and crescent Moons were explained by angle, tilted, and location nodes.

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