JOURNAL OF BALTIC SCIENCE EDUCATION
ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

ASSESSMENT OF CONCEPTUAL UNDERSTANDING IN STUDENT LEARNING OF MOON PHASES

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Abstract. *Many research studies have shown that lower-secondary school students' scientific literacy depends on their understanding of corresponding scientific concepts. Therefore, it is of great significance to model and assess students' conceptual understanding in learning specific scientific concepts, because it can reflect and diagnose students' cognitive characteristics, so as to provide evidence for targeted educational interventions. However, on the topic of Moon Phases, existing research studies have deficiencies in the evaluation and analysis of different levels of students' conceptual understanding, which restrict teachers to take effective educational interventions to help them. Thus, this study explored a new level division and an assessment test for revealing and explaining students' different conceptual understanding in learning Moon Phases. This study was conducted among 768 Chinese lower-secondary school students. Through a variety of quantitative and qualitative analyses, it was found that students' conceptual understanding of Moon Phases can be divided into three levels of continuous improvement, including the mechanical memory of different phenomena of moon phases, the formation of a preliminary mental model of Moon Phases, and the construction of a complete mental model of Moon Phases. Accordingly, this study made some precise suggestions for effectively improving students' conceptual understanding of Moon Phases.*
Keywords: *assessment of conceptual understanding, level division, Moon Phases, quantitative analysis, qualitative analysis*

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Introduction

Basic scientific concepts are one of the main contents of science education in lower-secondary school, so helping students better understand scientific concepts is the key to achieving the corresponding goals of science education. Developing students' scientific literacy has become the fundamental goal of science education worldwide in recent years, and helping students understand basic scientific concepts is undoubtedly the basis and premise for improving their scientific literacy (Murcia, 2009; National Research Council, 2008; Özdem et al., 2010). Many studies have shown that students' ability to solve science-related problems in real situations (the main performance of scientific literacy) depends on their understanding of corresponding scientific concepts (Gerace et al., 2001; Martinez et al., 2021; Nie et al., 2019). Different from the direct, concrete and self-evident daily concepts, scientific concepts usually have the typical characteristics of logic and abstraction (Nersessian, 2002; Yun, 2020). For example, Magnetic Induction Line is not an objective object, but a virtual curve used to describe and explain some relevant magnetic phenomena. This means that students usually need to experience a thinking process of metaphor and modeling when understanding scientific concepts such as Magnetic Induction Line (Barsalou, 1991; Nersessian, 2002). Therefore, it is of great significance to assess students' conceptual understanding in learning specific scientific concepts because it can reflect and diagnose students' cognitive characteristics, especially the cognitive difficulties, so as to provide evidence for targeted educational interventions (Dai et al., 2019; Xu et al., 2020).

The concept topic of this study is Moon Phases, a typical scientific concept that requires modeling process for accurate understanding. After reviewing previous related literature, it was found that students have many difficulties in learning Moon Phases, especially in understanding the nature of Moon Phases, that is, establishing the periodic correspondence among the observed phenomena of moon phases, the relative spatial positions and optical effects of the three celestial bodies (the moon, the earth, and the sun), and the perspectives of human beings on the earth (Chastenay, 2016; Mulholland & Ginns, 2008). However, existing related research studies have deficiencies in the evaluation and analysis of different levels of understanding of students in the process of learning this nature, which restrict teachers to take corresponding effective educational interventions to help them. This

https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

study is a new exploration in this direction. To make a distinction, the "Moon Phases" with uppercase letters in this article refer to the scientific concept, and the "moon phases" with lowercase letters in this article refer to the observed phenomena.

Literature Review (Student Learning of Moon Phases)

In science education, there is a commonly accepted viewpoint that students tend to construct their personal understanding of the things through direct interactions with the world around them (Thouin, 1997). However, such understanding style may sometimes lead to students' misunderstanding of scientific concepts (Chastenay, 2016; Driver, 1981; Thouin, 2004). The phases of the moon are natural phenomena that students can often observe, but Moon Phases is a relatively difficult scientific concept for them (Chastenay, 2016; Ucar, 2014). Relevant research studies have found that students have many mistakes in learning Moon Phases, some of which are caused by their daily observation experience, such as the phases of the moon occur due to 'the shadow of the earth', 'planet or the sun casts a shadow', 'cloud covers the moon', and so on (Baxter, 1989; Chastenay, 2006; Liu, 2005; Schoon, 1992; Stahly, 1999). From these mistakes, it can be seen that the relevant daily experience is not an assistant but an obstacle for students to understand Moon Phases. This fact is consistent with some explanations of the reasons for students' misconceptions in astronomy learning, that is, human beings' exclusively geocentric perspective on the sky, coupled with human beings' inability to judge the characteristics of astronomical systems, is the source of many corresponding misconceptions (Black, 2005; Gazit et al., 2005; Miller & Brewer, 2010; Nussbaum, 1985; Trumper, 2001). There is no exception in the topic of Moon Phases, the misconceptions mentioned above have been reported by relevant surveys in the past decades, which exist not only among lower-secondary school students, but also among college students, and even among science teachers (Jones & Lynch, 1987; Nielsen & Hoban, 2015; Ogan-Bekiroglou, 2007).

Therefore, it has always been the core strategy of the teaching of Moon Phases to help students understand the phases of the moon through constructing corresponding mental models, rather than relying on direct observation experience. For this matter, traditional teaching on Moon Phases usually applies physical three-dimensional models to demonstrate the relative positions of the relevant celestial bodies (the sun, the moon, and the earth) and combines discussion and analysis of the corresponding optical effects and visual effects to help students establish the mental model, so that they can explain the moon phase phenomena they observed (Trundle et al., 2007; Ucar, 2014). Computer-supported teaching is the other major type of teaching that is used to promote students to develop a proper mental model of Moon Phases. The philosophy of this teaching type is similar to that of traditional teaching, but the celestial models, the optical effects, and the visual effects are presented in some digital forms believed to be more effective in the construction of mental models, such as animation, video project, software program, and so on (Barnett & Morran, 2002; Bell & Trundle, 2008; Hobson et al., 2010; Keating et al., 2002; Sun et al., 2009). It can be seen that both traditional teaching and computer-supported teaching are aimed at leading students to overcome the limitation of the geocentric point of view on the sky, and form an allocentric mental model of the moon phase phenomena that is closer to the scientific view. According to Sadler (1992), without establishing a mental model of the periodic correspondence among the observed phenomena of moon phases, the relative spatial positions and optical effects of the three celestial bodies, and the perspectives of human beings on the earth, students will not understand the nature of Moon Phases and will find many related problems virtually impossible to solve (Sadler, 1992).

Previous research studies mentioned above have provided many insightful conclusions about students learning Moon Phases. However, these research studies generally have only made a rough analysis and judgment on whether students understand the nature of Moon Phases after receiving the related lessons, but have not made an accurate and detailed assessment on the different conceptual understanding that students may have in learning Moon Phases (Bell & Trundle, 2008; Chastenay, 2016; Subramaniam & Padalkar, 2009; Ucar, 2014), which makes it difficult for teachers to carry out targeted interventions to help students further improve their conceptual understanding of Moon Phases according to their own existing understanding statuses.

Research Aim

To solve the deficiencies of the assessment on students' conceptual understanding of Moon Phases, this study explored a new level division to present and describe the development of students' conceptual understanding of

https://doi.org/10.33225/jbse/23.22.719

Moon Phases. Meanwhile, based on the division, this study designed and implemented a test among 768 Chinese lower-secondary school students to assess and analyze their actual conceptual understanding status in learning Moon Phases. In addition, based on the research findings, this study conducted some corresponding suggestions and discussions for improving students' conceptual understanding of Moon Phases. In summary, the three goals of this study were: (1) Construct a level division to map out students' conceptual understanding of Moon Phases. (2) Employ an assessment based on the level division to analyze the characteristics of students' conceptual understanding in learning Moon Phases. (3)Make some suggestions for improving students' conceptual understanding of Moon Phases according to the research findings.

The Level Division for Mapping out Students' Conceptual Understanding in Learning Moon Phases

Although the assessment approaches of students' understanding of scientific concepts adopted by the existing research studies were various, most of them reflected a progressive thinking mode (Dai et al., 2019; Liu et al., 2022). In other words, these approaches tended to divide students' understanding of scientific concepts into several different levels from low to high and then developed and used corresponding assessment instruments (such as questionnaires, observation scales, test questions, etc) to analyze and present students' understanding of scientific concepts (Dai et al., 2019; Liu et al., 2022; Xie et al., 2021; Xu et al., 2020). Among them, the most classic was the 'Structure of the Observed Learning Outcome (SOLO)' taxonomy proposed by Professor Biggs of Australia based on Piaget's theory of cognitive development stages. The SOLO theory held that students' understanding of the concept can be divided into five levels from concrete to abstract, from one-dimensional to multi-dimensional, from unordered to ordered: pre-structural, uni-structural, multi-structural, relational, and extended abstract (Biggs & Collis, 1982; Stålne et al., 2016). Similar to the SOLO theory was the Learning Progressions (LPs) theory that has emerged in recent years in US science education reform. LPs theory emphasized that students' understanding of the scientific concept is a gradual development process from one state to another. With the continuous leap of understanding state, students will form a better cognitive structure related to the concept, a clearer way of thinking and a stronger ability to solve situational problems (Alonzo & Steedle, 2009; Battista, 2011). In addition, Linn et al. expressed the students' understanding level of the scientific concept as the degree of knowledge integration, that is, whether and to what extent meaningful links among the concept and other relevant scientific concepts, scientific principles, scientific methods, and scientific thinking have been established in students' cognitive structure (Linn, 2006; Liu et al., 2022).

On the basis of the above theoretical views and literature review of Moon Phases, 3 professors of science education and 3 outstanding science teachers of Chinese lower-secondary school (all the 3 teachers have taught for more than 15 years) were invited to form an expert group to explore the corresponding level division of students' conceptual understanding in learning Moon Phases through consultation and demonstration. The following is the detailed process of the level division.

Consistent with the above-mentioned tendency of students to understand things, the expert group believed that students will give priority to their direct observation experience of moon phases when learning the concept of Moon Phases. In other words, students' original understanding of Moon Phases is to regard it as a series of observed phenomena. Although the teaching of Moon Phases in Chinese lower-secondary school is also committed to helping students construct the mental model, teachers usually provide methods of mechanically memorizing the periodic phenomena of moon phases for those students who cannot think beyond the observation experience. Thus, the expert group determined that the low level of understanding of Moon Phases is that students have mechanically remembered the periodic phenomena of moon phases.

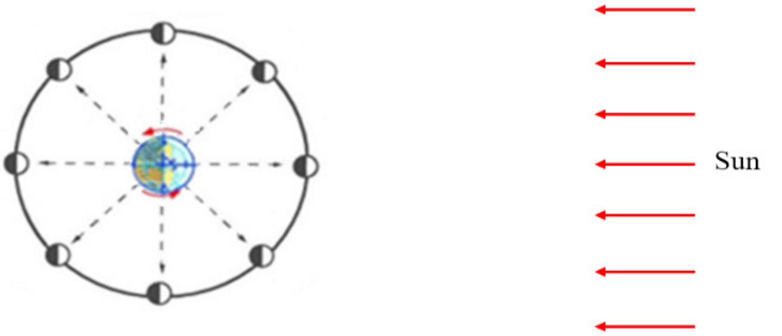
Different from the understanding status of low level students, most of the students will start to construct a relevant mental model in learning Moon Phases. According to the expert group, in the process of a complete mental model construction, students need to build a preliminary mental model of the periodic relative spatial positions of the moon, the earth, and the sun from the cosmic perspective at first (see Figure 1). Meanwhile, students need to analyze and master the optical characteristics in this preliminary mental model. As shown in Figure 1, considering that the relative position of the earth and the sun changes little within one month, it is possible to focus only on the position change of the moon relative to the earth. And considering the great distance between the sun and the earth & the moon, it is possible to equate the sunlight with the parallel light. These two components are consistent with the treatment in the teaching of Moon Phases in Chinese lower-secondary school. To sum up, the expert group determined that the intermediate level of understanding of Moon Phases is that students have

https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

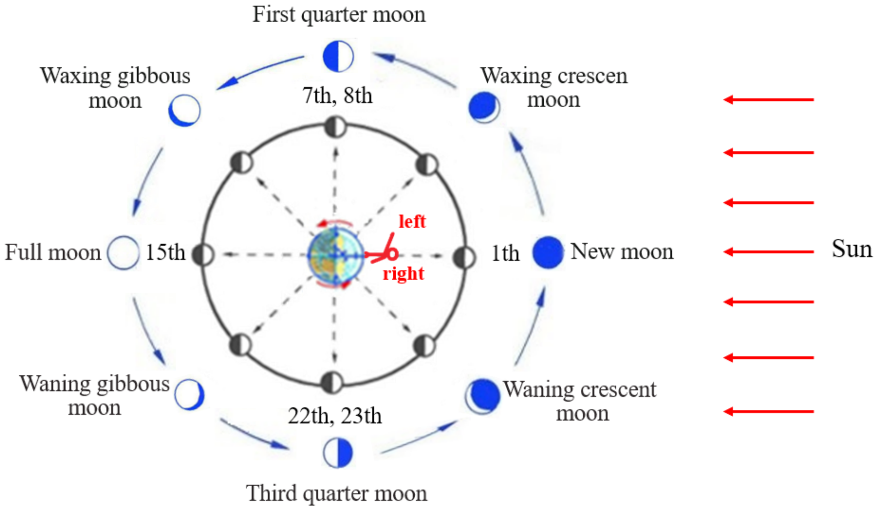
constructed a preliminary mental model as shown in Figure 1, which reflects the periodic relative spatial positions and optical effects of the three celestial bodies corresponding to the periodic phenomena of moon phases from the cosmic perspective.

Figure 1
The Intermediate Level of Understanding of Moon Phases



However, the brightness and darkness of the moon in the preliminary mental model are sometimes different from the observed phenomena of moon phases on the earth. This is because the various phenomena of Moon Phases are a series of visual effects observed by human beings on the earth, while the preliminary mental model lacks the perspective of human beings on the earth. Therefore, in order to form a complete mental model of the concept of Moon Phases, it is necessary to add the human observation perspectives on the earth and the corresponding visual effects to the preliminary mental model. Accordingly, the expert group proposed a mental model as shown in Figure 2 below to present the understanding of the high level students on the concept of Moon Phases. This mental model accurately maps out the periodic correspondence between the observed phenomena of moon phases and the relative spatial positions of the three celestial bodies, and the optical effects contained therein.

Figure 2
The High Level of Understanding of Moon Phases



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Research Methodology

Background

In the procedure of research, considering the representativeness of the sample (which can largely represent the general academic level of Chinese lower-secondary school students), relatively suitable participants were selected. Next, the assessment test was designed according to the above-level division of students' conceptual understanding of Moon Phases. Before and after the Moon Phases lesson, all the participants took the pre-test and post-test. Then, the overview analysis, the scores change trend analysis, the exploratory factor analysis, and the thinking process analysis were carried out to comprehensively and deeply explore the different characteristics of the students' conceptual understanding of Moon Phases.

Participants

The participants of this study were from a lower-secondary school in Jinhua City, Zhejiang Province, China. Jinhua is a moderately developed city in China, and this lower-secondary school is at the medium quality level in Jinhua, so the academic level of the participants largely represents the general academic level of Chinese lower-secondary school students. Chinese lower-secondary school students learn an introductory level integrated science course, and the Moon Phases is arranged to study in the 7th grade. There were 20 classes in the 7th grade of this school, with a total of 768 students. All 768 students participated in this study. This study was approved by the Zhejiang Normal University Review Board, and informed consents were obtained for all participants. The average age of these students was 12.8 years old, including 390 boys and 378 girls. The academic performance of the 20 classes was similar, and the contents and strategies of the Moon Phases lesson adopted by the science teachers of these classes were similar. In late May 2022, all the 768 students attended a 45-minute lesson on Moon Phases in their own class.

Design of the Assessment Test

Based on the above level division, a test consisting of 12 single choice questions (1/4) was designed to assess students' different understanding in learning Moon Phases. All the 12 questions were adapted from the ones that students often encounter in their daily study. For each question, it was tried to avoid the interference of irrelevant information. The questions were put into 3 sets according to the varying degrees of understanding required, including simple set, preliminary set, and integrated set.

The simple set contains 3 questions (Q1, Q6, Q8), which can be solved by mechanically retelling the relevant information about the phenomena of moon phases in memory. For example, Q6 gives the time and location of a specific phenomenon of the moon phase and asks students to choose the correct picture of this moon phase. It was expected that most students can answer these questions correctly after learning the Moon Phases in the related lessons, not to mention the teacher will provide some mechanical memory tricks.

The preliminary set contains 4 questions (Q3, Q7, Q10, Q12), which correspond to the intermediate level of understanding of Moon Phases. In other words, students need to have constructed the preliminary mental model to correctly answer these questions. It was expected that the students at the high level can answer all of these questions correctly, the students at the intermediate level should often be able to answer most of these questions successfully, but the students at the low level can't get the correct answers generally.

The integrated set contains 5 questions (Q2, Q4, Q5, Q9, Q11), which can be solved by students when they have constructed the complete mental model. It was expected that the students at a high level should be able to solve most of these questions, the students at an intermediate level should have difficulty with these questions but may succeed in some of them, and the students at a low level may not be able to answer any questions correctly because they can only guess.

The detailed test questions are attached in the Appendix section. Each question was evaluated with '1' or '0', '1' for the correct answer and '0' for the incorrect answer. Then, the correct rate was used to express the student's score. 160 Chinese lower-secondary school students who have learned the Moon Phases lesson were randomly selected for a preliminary test. Through analysis, it is found that the Cronbach's alpha of the whole test is .89, and the Cronbach's alpha of the three question sets are .87, .85, and .91 respectively, indicating that the test has good structural validity.

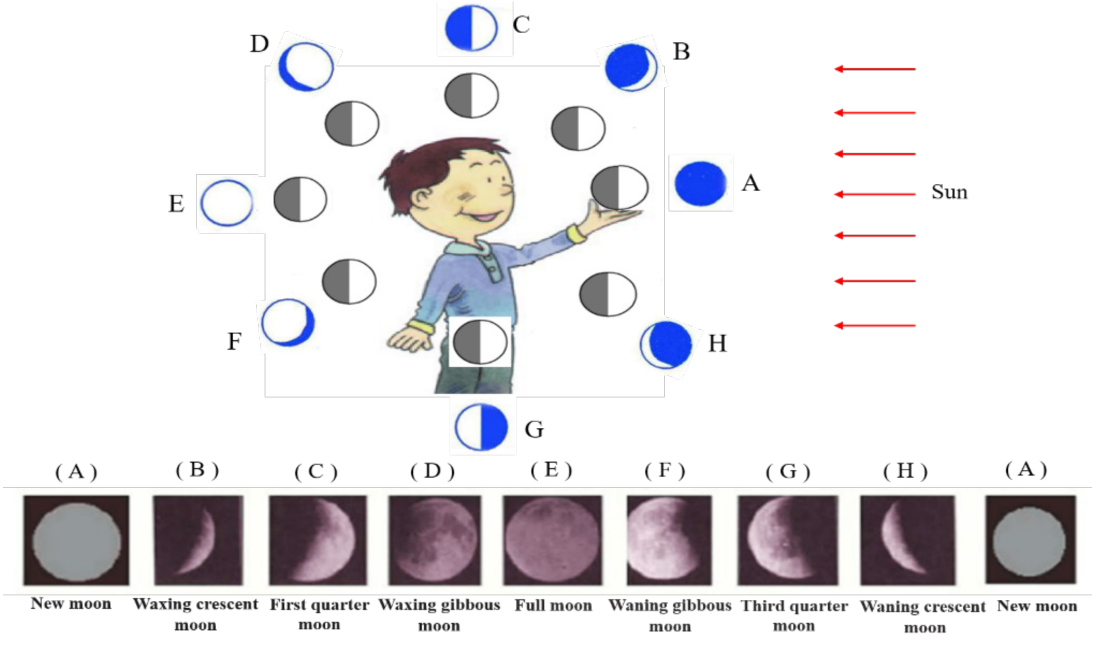
https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The Moon Phases Lesson Received by the Participants

The teaching of Moon Phases in Chinese lower secondary is usually conducted in a 45-minute lesson. At the beginning of the lesson, the teacher presents the students with different phenomena of moon phases, and asks them a question: How do these phenomena of moon phases come into being? After briefly responding and analyzing the students' answers, the teacher guides the students to establish the following hypothesis: different phenomena of moon phases may be formed due to the different visual effects of the different relative spatial positions of the moon, the earth, and the sun. Then, the teacher leads the students to carry out an exploratory activity as shown in Figure 3 below to verify the hypothesis. The detailed operation and analysis of the exploratory activity are as follows: (1) assume the sun is on the blackboard, as the huge distance between the sun and the earth & the moon, the sunlight can be regarded as the parallel light from the blackboard; (2) take a half blackened ping-pong ball as the moon, and make the half that is not blackened (white) always face the sunlight, so as to simulate the brightness and darkness of the moon from the cosmic perspective; (3) take the student as the observer on the earth, and let him/her hold the ping-pong ball and rotate counterclockwise; (4) let the student record the shape of the white part of the ping-pong ball observed at each position from A to H; (5) introduce the name, occurrence time and other relevant information of the moon phase observed at positions A to H; (6) guide the students to construct the mental model through discussing and analyzing the hypothesis and the exploratory activity. In China, there is a special calendar based on the law and period of moon phases change, which is called the lunar calendar, where the first day of each month is the new moon, and the fifteenth day of each month is the full moon, and so on. At the end of the lesson, the teacher provides a memory formula of the periodic changes of the phenomena of moon phases corresponding to the lunar calendar to the students, so that the students can mechanically remember them. One part of this memory formula is 'first first first right right, third second second left left', which means that the first quarter moon appears in the first half of the month, in the first half of the night, in the right half of the sky, and the right half of the moon is bright; the third quarter moon appears in the second half of the month, in the second half of the night, in the left half of the sky, and the left half of the moon is bright. The other part of this formula involves the matching information of the remaining specific moon phases such as the new moon, the full moon, etc. On the whole, in this lesson, the teacher not only tries to guide the students to construct the mental model of Moon Phases through an exploratory activity but also provides the students with the tricks of mechanically remembering the different phenomena of moon phases.

Figure 3
The Activity of Exploring the Causes of Different Phenomena of Moon Phases



https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Data Collection and Analysis

Before and after the Moon Phases lesson, all the 768 students took the pre-test and post-test. Each test was completed in 30 minutes. Additionally, 100 of the 768 students were randomly selected to continue to attend think-out-loud interviews. They were required to explicate the thinking process when dealing with questions in detail, so that their conceptual understanding could be interpreted more clearly. Each interview lasted for about 30 minutes and was audiotaped. (According to similar studies conducted in the past, the selection ratio of 100/768 was sufficient to meet the needs of qualitative analysis. If it failed, more students would be selected for interview and analysis.)

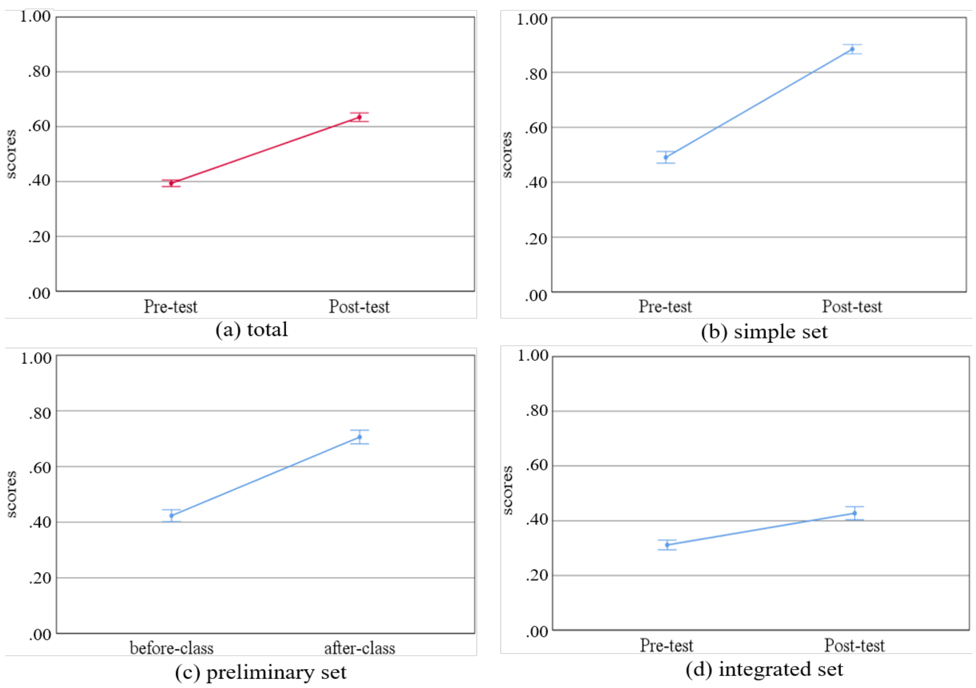
In order to comprehensively and deeply explore the different characteristics of students' conceptual understanding of Moon Phases, some quantitative and qualitative methods were applied (the quantitative analyses were carried out with the aid of Statistical Package for Social Science (SPSS) version 25.0). Specifically, the overview of the pre-test and post-test performances of the students were analyzed to measure the improvement of students' conceptual understanding of Moon Phases after receiving the lesson. The scores distribution for different question sets of different overall performances was analyzed to reveal the development characteristics of students' conceptual understanding of Moon Phases. The exploratory factor analysis (EFA) was carried out on the students' post-test data to explore the structural characteristics of students' conceptual understanding. At the same time, by reference to the level division, students' thinking processes when answering questions were explored through analyzing the interview records to further validate the quantitative outcomes.

Research Results

The Improvement of Students' Conceptual Understanding of Moon Phases

The overview of the pre-test and post-test performances of all the 768 students is given in Figure 4. It can be seen that the overall performances of the students have improved significantly[$.39 \rightarrow .64$, $t\,(767) = 40.111$, $p < .001$, $d = 1.447$], but the degree of improvement in each question set is different. The improvement of the simple question

Figure 4
The Pre-test and Post-test Performances of the Students (with error bars denoting standard error)



https://doi.org/10.33225/jbse/23.22.719

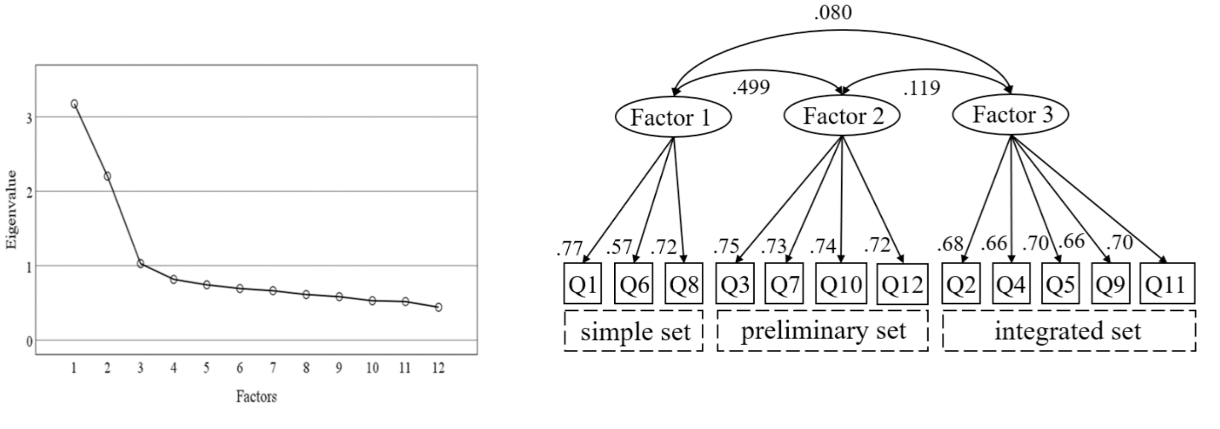
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

set[.49 → .88, t (767) = 35.096, p < .001, d = 1.266] is far superior to that of the preliminary question set[.42 → .71, t (767) = 27.838, p < .001, d = 1.004] and the integrated question set[.31 → .43, t (767) = 15.050, p < .001, d = 0.543], and the improvement of integrated question set is narrowest. These results initially manifest that the level division of students' conceptual understanding of Moon Phases is relatively reasonable. For students, it is the easiest to mechanically memorize the phenomena of moon phases, the second is to construct the preliminary mental model, and the most difficult is to construct the complete mental model.

The Structural Characteristics of Students' Conceptual Understanding of Moon Phases

The results of exploratory factor analysis (EFA) of the students' post-test data are plotted in Figure 5, providing new detailed information for further analysis of students' conceptual understanding after the implementation of the Moon Phases lesson. As shown in Figure 5(a), there are three factors with eigenvalues greater than 1, which explains 53.363% of the cumulative variance (i.e., 20.111%, 19.286%, and 13.966% for factors 1, 2 and 3, respectively). And Figure 5(b) provides the factor loading of all the questions on these three factors. It can be seen that the three factors exactly correspond to the three question sets, factor 1 represents the simple set, factor 2 represents the preliminary set, and factor 3 represents the integrated set. Figure 5(b) also shows that the students' responses on the simple set are moderately correlated to their responses on the preliminary set (.499). However, the students' proficiency in solving the questions of the simple set (.080) and the questions of the preliminary set (.119) is less connected to that of the integrated set. These results represent that the students' conceptual understanding of Moon Phases can be divided into three levels as expected, and it may be the most difficult for them to reach the high level, that is, to construct a complete mental model of Moon Phases.

Figure 5
The EFA Results of all the 768 Students' Post-test Data



The Development Characteristics of Students' Conceptual Understanding of Moon Phases

In order to reveal the development characteristics of students' conceptual understanding of Moon Phases, the score distribution for different question sets of different overall performances was analyzed. The students were assigned to five groups according to their ranking of total scores in the post-test, each containing 20% of the total sample. As shown in Figure 6, the scores on the integrated set are consistently below the scores on the simple set and the preliminary set for all groups. The students with low total scores (<20%) can successfully answer most of the questions on the simple set, but fail to obtain correct answers on the preliminary set and integrated set. This is not different from the expected performances of low level students mentioned above. With the increase of the total scores (20%-60%), the performance gaps between the integrated set and the other two sets are more and more pronounced, while the performance gap between the simple set and the preliminary set is narrower and narrower, indicating that students in this range have begun to establish the preliminary mental model of Moon Phases so that they can perform better and better on the preliminary set. With the further improvement of the total scores (60%-80%), the performance gaps between the different question sets are less and less pronounced,

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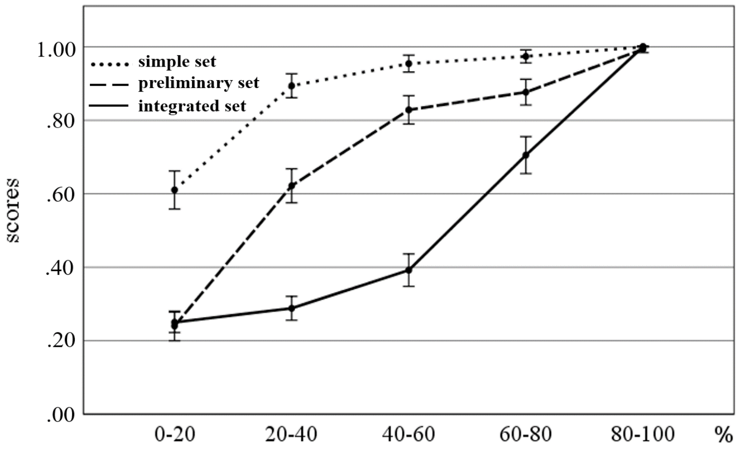
indicating that students in this range have begun to construct the complete mental model of Moon Phases so that they can achieve occasional success in some integrated questions. At last, as for the students with the high total scores (Top 20%), there is no significant difference in their scores on different question sets, indicating that these students have formed a well-integrated mental model of Moon Phases so that all the questions are within their ability. To sum up, these results reveal a general progression of students' development of conceptual understanding about Moon Phases, which is very consistent with our preset.

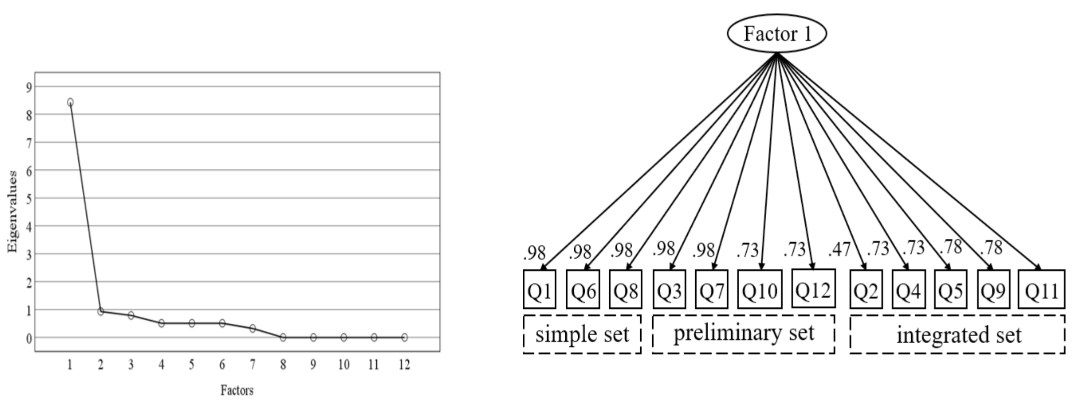
Figure 6
The Scores Distribution for Different Question Sets of Different Overall Performances (with error bars denoting standard error)



The Structural Characteristics of Conceptual Understanding of the Students with the High Total Scores

The structural characteristics of conceptual understanding of the students with the high total scores (Top 20%) were further explored using the exploratory factor analysis (EFA). As shown in Figure 7(a), the first eigenvalue can explain nearly 70.256% of the variance (see Figure 7(b) for the loading of all the questions on the single factor). This indicates that these students' performance can be fully explained by a single salient factor, which means a quite integrated conceptual understanding. When compared to the EFA results of all the students, which have three distinctive factors, this merging effect further indicates that these students with high total scores have formed the complete mental model of Moon Phases. By the way, considering the meaning of EFA analysis of these students' data may be controversial because they answered most of the questions correctly, and the characteristics of their conceptual understanding about Moon Phases need to be further interpreted in combination with the subsequent qualitative analysis.

Figure 7
The EFA Results of the Students with the High Total Scores



https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The Students' Conceptual Understanding of Moon Phases Reflected by Their Thinking Process

According to the responses of these 100 students in think-out-loud interviews, their conceptual understanding of Moon Phases can be divided into three levels as our previous division.

Low Level: Students at this level can only mechanically remember the different phenomena of moon phases without a meaningful reasoning process. It can be said that these students' conceptual understanding of Moon Phases was still at the level of observation experience, and they did not even have an awareness of model construction. For instance, student A and student B were able to correctly solve most of the simple questions using the memorized formula, but they performed poorly on the preliminary questions and the integrated questions.

Student A: To be honest, I still don't understand the cause of the phenomena of moon phases, retelling the memory formula is my unique solution strategy. If I can rely on this formula to get the answer, I will choose that answer, otherwise, I will have to guess.

Student B: Although I know that the phenomena of moon phases are related to the relative spatial positions of the three celestial bodies, it is too abstract for me. I really can't build such a mental model in my mind, so I have no idea about how to deal with many questions in this test, except those that just match the formula.

Intermediate Level: Students at this level have not only established the relationship between the phenomena of moon phases and the memory formula but also constructed the preliminary mental model. However, these students still cannot effectively construct the complete mental model. Therefore, they answered most simple questions and preliminary questions correctly, but they were helpless to solve the integrated questions. The following are excerpts from interviews with students who exhibit this level of conceptual understanding of Moon Phases.

Student C: (For question 7) The sunlight can be regarded as the parallel light, and no matter where the moon is, the half facing the sunlight is illuminated. The answer is A. (For question 5) In this question, the right half of the moon is illuminated by the sunlight, but there is no such option in the answers. I finally chose C because it is closest to the right half of the moon being illuminated. (The correct answer is B).

Student D: (For question 3) The picture shows that the left half of the moon is illuminated by sunlight, so the sun should be on the left side of the moon, and the sunlight can be regarded as the parallel light. The answer is A. (For question 10) The moon phase given in the question is not the standard case where half of the moon is illuminated, which is too difficult for me. Therefore, I just guessed the answer A. (The correct answer is B).

High Level: Students at this level have constructed the complete mental model. In other words, in these students' understanding of the concept of Moon Phases, the phenomena of moon phases, the periodic relative spatial positions and optical effects of the three celestial bodies, and the human observation perspective on the earth and the corresponding visual effects, are not isolated from each other, but logically connected. Therefore, these students were able to correctly solve almost all questions, especially the integrated questions.

Student E: (For question 4) In this question, although the right half of the moon is illuminated by sunlight when a man is in the position shown in the figure, the bright part of the moon he observed should be the left half. The correct answer is D. (For question 5)When the moon is in position d, its right half is illuminated by sunlight, but the visual effect we see on the earth is that the left side of the moon is bright. In addition, due to the angle, we can only see a small part of the moon is bright, as shown in Figure B. So the answer to this question is B.

Student F: (For question 2) When the moon is in this position, the part that is actually illuminated by sunlight is exactly the right half, but when we observe this moon on the earth, the bright part in the visual effect is more than half. It's C. (For question 9) This question is similar to question 2, but the difference is that the bright part of the moon observed on the earth is exactly the right half of the moon that is illuminated by sunlight. The answer is B.

According to the statistics, the number at each level of the 100 interviewed students included 39, 37, and 24, respectively. And their average performances on the post-test are shown in Table 1. It can be seen that the results in Table 1 are basically consistent with some quantitative analysis results above.

https://doi.org/10.33225/jbse/23.22.719

Table 1
The Number and Percentage at Each Level of the 100 Interviewed Students

Conceptual understanding level	Total	Simple set	Preliminary set	Integrated set
Low (39)	.37	.68	.40	.16
Intermediate (37)	.62	.87	.76	.35
High (24)	.97	1.00	1.00	.94

The Preference for Memory Matching of Some Intermediate and High Level Students

In addition, this study also found an interesting common feature among the interviewed students with different understanding levels, that is, quite a few of them prefer to solve problems by memory matching. For the low level students, this feature is predictable because they only mechanically remember the different phenomena of moon phases by reciting the memory formula. Surprisingly, some students at the intermediate and high levels, although they have constructed the mental model of Moon Phases to a certain extent, still gave priority to using the memory formula when answering questions. The followings are descriptions of the thinking processes of two sample students who showed this feature.

Student G (intermediate level): In answering these questions, my basic strategy is to give priority to using the memory formula taught by the teacher. If it fails, I will do other thinking and analysis.

Student H (high level): Before starting to answer the questions, I wrote the memory formula on the edge of the test paper, and also drew the complete mental model of Moon Phases on the edge. In fact, many of the questions in this test were answered by matching. When only a few questions can't be directly matched, I would rethink and reanalyze to find the answer.

Discussion

Moon Phases is Indeed a Difficult Concept to Understand for Students

Consistent with the findings of previous studies (Chastenay, 2016; Subramaniam & Padalkar, 2009; Ucar, 2014), this study also found that Moon Phases are indeed a difficult concept to understand for students. Although students' performances on the test have improved significantly after receiving the Moon Phases lesson, the degrees of improvement are not ideal. The overview of all students' post-test data shows that the total accuracy of students barely exceeds .6. The average score of students in the integrated set is only more than .4, and the average score of students in the preliminary set is only more than .7. These results indicate that most of the students have great difficulties in constructing the mental model of Moon Phases. The EFA analysis of all students' post-test data also fully verifies this point, which shows that students' conceptual understanding of Moon Phases presents three levels of little relevance, meaning that students' understanding of Moon Phases has not yet formed a logical integrated whole. The results of the qualitative analysis also show that only about 24% of the students may really understand the nature of Moon Phases. Put these together, it can be said that students will encounter many difficulties in learning Moon Phases, so as the corresponding precise diagnosis and educational interventions are extremely necessary for improving students' understanding of Moon Phases.

There are Three Levels of Conceptual Understanding in Student Learning of Moon Phases

On the basis of literature review and expert consultation, this study developed a level division and a corresponding test to map out and assess students' different conceptual understanding of Moon Phases. It is found that this approach can effectively identify and present students' understanding of Moon Phases into three different levels, including the mechanical memory of different phenomena of moon phases, the formation of a preliminary mental model of Moon Phases, and the construction of a complete mental model of Moon Phases. Meanwhile, the analysis of scores distribution for different question sets of different overall performances and the EFA analysis of the top

https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

20% of students' data showed that there seems to be a developmental advancement among the three levels of conceptual understanding of Moon Phases. In addition, the qualitative analysis found that some intermediate and high level students also have a preference for memory matching, which is the only strategy for low level students to solve related problems. In view of these findings, it is necessary to carry out different intervention strategies to improve different students' conceptual understanding of Moon Phases.

Different Corresponding Intervention Strategies Should be Adopted

To improve the conceptual understanding of Moon Phases of students with different levels, different intervention strategies should be adopted. For the students at a low level, since they only mechanically remember the periodic phenomena of moon phases and rely on scattered memory matching to solve related problems, helping them form an awareness of model construction in learning Moon Phases is the first thing the teacher needs to strive to do. Specifically, the teacher should remind these students to give up the tendency to learn by rote and guide them to try to construct the connection between the phenomena of moon phases and the corresponding relative spatial positions and optical effects of the three celestial bodies by looking for certain logical relationships and reasoning pathways. Thus, they can solve problems analytically through meaningful reasoning and explanation, rather than through inefficient mechanical memory. For the students at an intermediate level, they seem to be locally connected between the phenomena of moon phases and the preliminary mental model, but they still have not constructed the complete mental model of Moon Phases. Therefore, the teacher should try to make these students figure out the difference between the preliminary mental model and the complete mental model. The core of this difference is that the part of the moon that is actually illuminated by sunlight is not necessarily equal to the phenomenon of moon phases observed by humans on the earth, the phenomena of moon phases are visual effects based on the preliminary mental model. Thus, these students can effectively solve the related problems that need to be solved by applying the complete mental model of Moon Phases. For the students at a high level, they seem to have established effective connections among the phenomena of moon phases, the relative spatial positions and optical effects of the three celestial bodies, and the perspective of human beings on the earth. This means that they have developed a quite deep conceptual understanding of Moon Phases. What the teacher needs to do for these students is to remind them to avoid using memory matching to solve problems any more, and encourage them to explore more logical relationships and reasoning pathways to link more relevant knowledge elements, so as to further expand the formed mental model of Moon Phases and the problem-solving strategies. As a result, they may solve more complex and difficult related problems.

Conclusions and Implications

Overall, this study shows that the method of constructing the level division and the corresponding assessment test is effective in modeling and explaining lower-secondary school students' different conceptual understanding in learning Moon Phases. The results also show that it is necessary to take some precise interventions for effectively improving students' conceptual understanding of Moon Phases accordingly. At the same time, this study can also bring some enlightenment to the learning and teaching of scientific concepts in general. Many research studies have shown that it is necessary to find an effective way to assess the students' actual understanding of the specific scientific concept and advance it to the nature of this scientific concept. In this regard, this study undoubtedly provides a set of strategies for reference both theoretically and practically. This study also has some limitations that need to be duly noted. On the one hand, this study was conducted in China, and the adaptability of the research findings to a broader context needs to be further tested. On the other hand, this study has fully shown that Moon Phases is a very complex and difficult concept for students, so as more diversified assessment approaches need to be further explored and verified to investigate students' conceptual understanding more comprehensively.

Declaration of Interest

The athors declare no competing interest.

https://doi.org/10.33225/jbse/23.22.719

Acknowledgements

The authors would like to express their gratefulness to the students, the science teachers, and the experts for providing support to this study.

Funding

This work was supported by the National Educational Science Planning Project of China (No. BHA210121), the 73rd China Postdoctoral Science Foundation Project (No.2023M733172), and the Zhejiang Educational Science Planning Project (No. 2023SB120).

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Statement

This study was approved by the Zhejiang Normal University Review Board. Informed consent was obtained for all participants.

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https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
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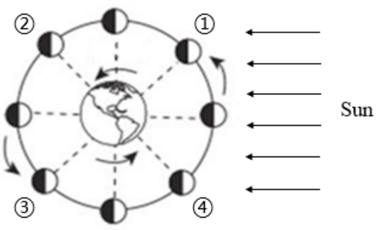
Appendix

The Assessment Questions Used in This Study

1. On the night of March 22 (lunar calendar), what the phenomenon of moon phase can Xiaoming observe in the left half of the sky? (**D**).
A. New moon B. First quarter moon C. Full moon D. Third quarter moon

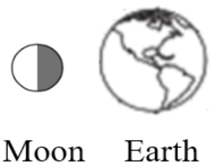
2. As shown in the figure, it is the relative position of the earth and the moon during the moon revolution. When the moon moves to position②, what the phenomenon of moon phase can be observed on the earth? (**C**).



A.First quarter moon  B.Third quarter moon 

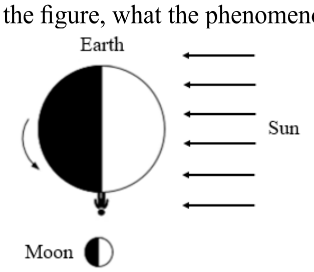
C.Waxing gibbous moon  D.Waning gibbous moon 

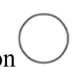
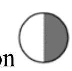
3. As shown in the figure, it is the relative position of the earth and the moon. At this time, the left half of the moon is illuminated by sunlight in the universe, so the sun is located at (**A**).



A. Left side of the Earth & Moon B. Right side of the Earth & Moon
C. Upper side of the Earth & Moon D. Under side of the Earth & Moon

4. As shown in the figure, the sunlight shines on the earth and the moon. When a man is in the position shown in the figure, what the phenomenon of moon phase can he observe? (**D**).

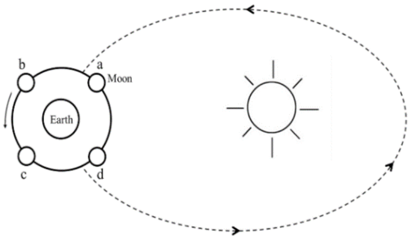


A. New moon  B. First quarter moon  C. Full moon  D. Third quarter moon 

https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

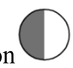
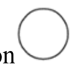
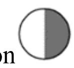
5. As shown in the figure, it is the orbit of the earth and the moon. When the moon is in position d, the phenomenon of moon phase that can be observed on the earth that night is (**B**).



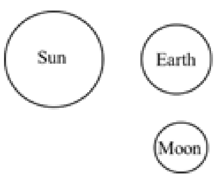
A. Waxing crescent moon  B. Waning crescent moon 

C. Waxing gibbous moon  D. Waning gibbous moon 

6. The Mid-Autumn Festival (August 15 of the lunar calendar) is a traditional festival in China. Please tell me the moon phase you can observe that night is (**C**).

A. New moon  B. First quarter moon  C. Full moon  D. Third quarter moon 

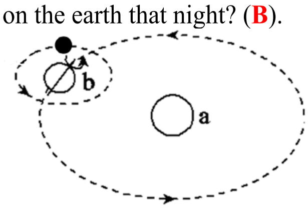
7. The figure shows the relative positions of the sun, the earth and the moon. Which half of the moon in the universe will be illuminated by sunlight at this time? (**A**).

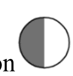
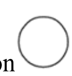
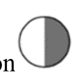


A. Left  B. Right  C. Upper  D. Below 

8. The Qixi Festival (July 7th of the lunar month) is a traditional festival in China. The correct description of the phenomenon of moon phase on the Qixi Festival is (**A**).
A. It appears in the right half of the sky in the first half of the night, and the right half of the moon is bright.
B. It appears in the left half of the sky in the second half of the night, and the left half of the moon is bright.
C. It appears in the left half of the sky in the first half of the night, and the right half of the moon is bright.
D. It appears in the right half of the sky in the second half of the night, and the left half of the moon is bright.

9. As shown in the figure, a is the sun, b is the earth, and c is the moon. When the positions of the sun, the earth and the moon are as shown in the figure, which of the following is the closest moon phase that can be observed on the earth that night? (**B**).

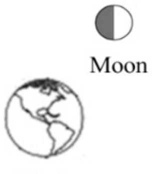


A. New moon  B. First quarter moon  C. Full moon  D. Third quarter moon 

https://doi.org/10.33225/jbse/23.22.719

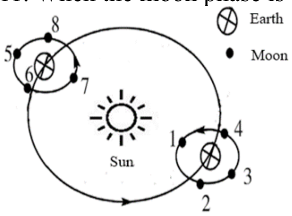
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

10. As shown in the figure, it is the relative position of the earth and the moon. At this time, the right half of the moon is illuminated by sunlight in the universe, so the sun is located at (**B**).



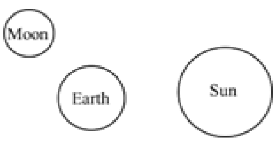
A. Left side of the Earth & Moon B. Right side of the Earth & Moon
C. Upper side of the Earth & Moon D. Under side of the Earth & Moon

11. When the moon phase is waning gibbous moon, where is the position of the moon roughly in the figure? (**C**).



A. between 1 and 2 B. between 2 and 3 C. between 5 and 6 D. between 7 and 8

12. The figure shows the relative positions of the sun, the earth and the moon. Which half of the moon in the universe will be illuminated by sunlight at this time? (**D**).



A. not be illuminated  B. all are illuminated 

C. below side is illuminated  D. right side is illuminated 

https://doi.org/10.33225/jbse/23.22.719

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Received: *May 21, 2023* Revised: *July 01, 2023* Accepted: *July 15, 2023*

Cite as: Zou, Y., Jin, L., Huang, X., & Li, Y. (2023). Assessment of conceptual understanding in student learning of moon phases. *Journal of Baltic Science Education*, *22*(4), 719-736. https://doi.org/10.33225/jbse/23.22.719

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