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Exploring students' understanding of “Earth's Movement” with OMC project

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Abstract: *The setup of test questions should be effective in conveying diagnostic information and exploring potential valid information. In this study, we focused on the important “Earth's Movement” in secondary school geography, constructed a construct map of “Earth's Movement” based on students' cognitive development and the OMC program, and developed a hierarchical multiple-choice assessment based on the construct map to empirically investigate students' geography understanding. Understanding. Based on the results of the assessment, it is suggested that students should be assessed before and after instruction to determine where they are in the construct of latent interest, that answers to test questions should be developed to map a larger domain of knowledge, and that observable motion should be integrated with actual motion.*

Keywords: *Earth movement; Constructed maps; OMC*

1. Introduction

Learning concepts involves not only acquiring more knowledge and skills but also advancing to higher levels of capability through the integration of new knowledge with existing understanding and the development of deeper insights that replace earlier ones (National Research Council, USA). The National Geography Curriculum Standards for Ordinary High Schools (2017 Edition, Revised in 2020) emphasizes that cultivating core geographical competencies requires focusing on the cognitive development of students throughout the learning process. This involves assessing students' thinking development by analyzing learning outcomes at different levels.[1]

This paper draws on the OMC (Ordered Multiple-Choice) project developed by Briggs et al., and associates it with student cognitive development models. It designs a construct map representing middle school students' progressive understanding of "Earth Movement" and develops corresponding Ordered Multiple-Choice questions for assessment. The aim is to assist in diagnosing and explaining students' responses, providing a reference for frontline geography teachers. Ordered Multiple-Choice questions offer greater diagnostic utility compared to classic multiple-choice questions and provide faster feedback than open-ended questions, benefiting schools, teachers, and students.

2. Characteristics of Ordered Multiple-Choice

Compared to traditional multiple-choice questions (TMC) that are either right or wrong and cannot effectively assess higher-level cognitive processes, Ordered Multiple-Choice (OMC) questions retain the high reliability of TMC while linking each option to students' cognitive development models. This approach maximizes the use of potentially useful information discarded in the distractors, thereby providing schools, teachers, and students with meaningful feedback quickly and reliably.[2]

The design of Ordered Multiple-Choice questions mainly involves two steps: First: Designing Construct Maps: A typical construct map consists of two components: "respondents" and "item responses."Second:Develop Ordered Multiple-Choice questions Based on the Construct Maps: After completing the construct map, create Ordered Multiple-Choice questions based on it. Each option of the item is aligned with different levels in the construct map, integrating the item options with the levels of the construct map Figure 1.

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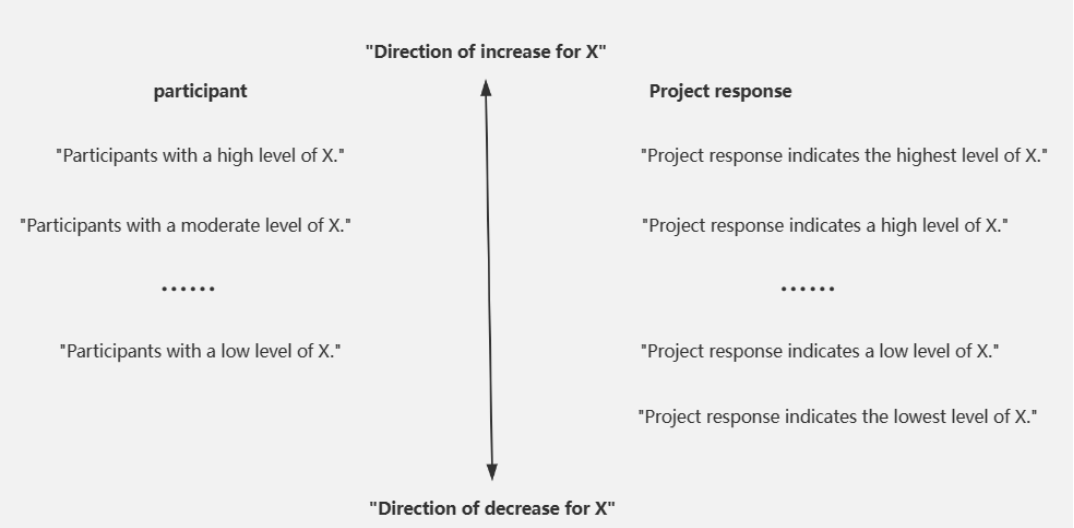

Figure 1: General Construct Map

3. Ordered Multiple-Choice questions on "Earth's Movement"

3.1 Selection of Test Concepts

"Earth's Movement" is fundamental in geography and has been extensively studied by scholars both domestically and internationally. Earth's Movement profoundly affects climate, rivers, vegetation, soil, and human activities. To truly understand geographical environments and the reasons for changes in environmental factors, students must grasp the knowledge related to Earth's Movement. In China, the "Earth's Movement" section is part of the compulsory curriculum for high school students in the first chapter of the first semester. This section is concentrated in knowledge points (see Figure 2) and demands high spatial thinking, reasoning, and analytical skills. Therefore, shifting students' thinking and applying knowledge flexibly are key challenges in teaching. The high level of challenge, advanced cognitive requirements, and extensive research literature are the main reasons for selecting this as a test concept Figure 2.

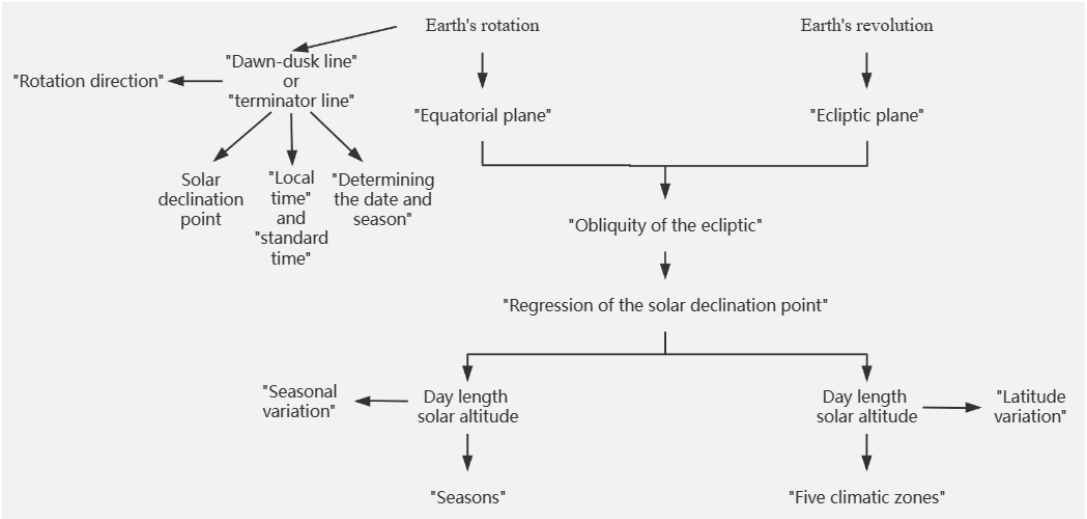

Figure 2: Summary of Key Concepts in Earth's Movement

3.2. Test Design

3.2.1. Construction Diagram Design

The Ordered Multiple-Choice questions are developed based on potential construction diagrams, which are central to their design and interpretation. A construction diagram categorizes students'

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understanding of knowledge into different levels, assessing students' positions on some potential constructs. Each level in the construction diagram reflects a stage of understanding, with levels representing continuous rather than discrete variables. Thus, the construction diagram represents the continuous understanding of knowledge content by secondary school students.

This paper utilizes the OMC project developed by Briggs and colleagues, selecting two questions related to "Earth's Movement" to create and modify the construction diagram for "Earth in the Solar System." This construction diagram outlines the overall structure of students' understanding of "Earth's Movement," representing the continuous comprehension of this concept by secondary school students (Table 1).

Table 1:Contruct map of ESS

Level	description
5 (High School Standard)	Students are able to translate the movements of the Earth and the Moon into a complete description of the solar system's motion and demonstrate it, explaining the geographic significance of Earth's Movements. Examples include: ·Day-night cycle ·Seasons ·Climate zones (five belts) ·Noon solar altitude
4 (Middle School Standard)	Students are able to coordinate the observable movements of celestial objects with their actual movements, explaining: ·The Earth both revolves around the Sun and rotates on its axis ·The Earth revolves around the Sun once per year ·The Earth rotates on its axis once per day, causing day-night alternation and the apparent movement of the Sun in the sky ·A basic explanation of how the Sun's direct rays and the variation in day length form seasons and climate zones ·Demonstration of the movement of the Sun's direct rays causing changes in day length, and summarizing the patterns of day length variation.[3] Common Error: Seasons are caused by the change in distance between the Earth and the Sun.
3	Students understand: ·The Earth revolves around the Sun ·The Earth rotates on its axis However, students have not integrated this knowledge with observable movements to form explanations and may not recognize that the Earth both rotates and revolves. Common Error: Nighttime gets dark because the Earth revolves around the Sun in a day.
2	Students recognize: ·The Sun appears to move across the sky daily ·Students may think that the Sun revolves around the Earth Common Errors: ·All movements in the sky are caused by the Earth's rotation on its axis ·The Sun revolves around the Earth ·Nighttime gets dark because the Sun revolves around the Earth in a day ·The Earth is the center of the universe
1	Students do not understand the systematic nature of celestial objects' appearance. Students may not recognize that the Earth is spherical. Common Error: The Sun is below the Earth at night.
0	No evidence or deviates from the expected path.

3.2.2. The construction diagram consists of five levels

Except for Level 0, the five levels progress incrementally, with each level reflecting a cognitive

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stage and embodying the "developmental perspective" principle of the Berkeley assessment system. Since students' understanding of Earth System Science (ESS) develops throughout their school years, it is important to use the same continuum to describe the understanding of fifth and eighth-grade students.The top level, Level 5, represents the expectations set forth in the "General High School Geography Curriculum Standards (2017 Edition)" for the selective compulsory course, indicating a comprehensive scientific understanding of "Earth's Movement" at the secondary school stage. Level 2 reflects the expected understanding according to the "Compulsory Education Junior High School Geography Curriculum Standards (2011 Edition)." To define the lower levels of our construction diagram, we also reviewed literature and past exam data related to students' misconceptions about "Earth's Movement."

In addition to defining students' understanding at each level of the continuum, typical student misconceptions are represented as "common errors" in the construction diagram of "Earth's Movement." The concept of common errors helps clarify the differences between levels. A misunderstanding represented as a common error at one level will be addressed and corrected in the next level of the construction diagram. For example, students at Level 3 might believe that it gets dark at night because the Earth orbits the Sun every day (a common error at Level 3), whereas students at Level 4 will no longer hold this belief but will have a scientific understanding that the Earth orbits the Sun on an annual basis.

3.2.3. Hierarchical Multiple-Choice Question Design

Once a construction diagram with ordered understanding levels is created, Ordered Multiple-Choice questions can be developed with answer options linked to each level. This involves aligning question options with the construction diagram's levels. [4]The specific process for designing Ordered Multiple-Choice questions for "Earth's Movement" is as follows: First, divide the knowledge to be tested into several levels based on the learning development process and describe the characteristics of each level qualitatively. Second, create options for each level, with each option representing a level in the learning development process. Thus, hierarchy allows us to connect students' answers to the broader "Earth's Movement" domain represented in the construction diagram, rather than just gathering information related to students' understanding of specific contexts described in the questions. In summary, students' responses to a set of Ordered Multiple-Choice questions can estimate their level of understanding.

Based on the expected understanding and common errors described for each level in the "Earth's Movement" construction diagram, a set of classic questions from the OMC project was selected and modified, with pilot testing and preliminary testing conducted in the fall of 2023.

Q1:

Nights are likely colder because:

A. The Earth is at the farthest point in its orbit around the Sun. Level 3
B. The Sun has rotated to the other side of the Earth. Level 2
C. The Sun is below the Earth, and the heat emitted by the Moon at night is less than that of the Sun. Level 1
D. The Earth has rotated to the side away from the Sun, resulting in nighttime in that region. Level 4

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Q2:

Which of the following best explains why we experience different seasons (summer, winter, etc.) on Earth?

A. The Earth's orbit around the Sun causes summer to be closer to the Sun and winter to be farther away. Level 4
B. The Earth's orbit around the Sun makes us face the Sun in summer and awayfrom it in winter. Level 3
C. The tilt of the Earth causes regions in summer to be closer to the Sun's direct rays Level 5
D. The tilt of the Earth makes us closer to the Sun in summer than in winter. Level 4

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The two example questions aim to explore students' understanding of knowledge, so the questions are clear and straightforward to avoid any reading or comprehension difficulties. The literature refers to

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graded scoring questions, where each option corresponds to a specific level in the conceptual framework, addressing topics related to "Earth's rotation" and "revolution." The first question involves concepts such as "Earth's rotation," "geocentric theory," "perihelion," "aphelion," and "diurnal temperature variation," while the second question involves "Earth's orbital characteristics," "Sun's direct rays," "perihelion," and "aphelion."

To select the option representing the top level of the conceptual framework, students need to explain in detail through diagrams: ① how Earth's rotation causes day and night cycles, ② how the tilt of the Earth creates an angle between the rotational axis and the orbital plane, known as the obliquity of the ecliptic, which causes the movement of the Sun's direct rays and resulting changes in day length. As the Sun's direct rays move toward a hemisphere, that hemisphere experiences longer days and shorter nights, and when the rays are in the opposite hemisphere, it has longer nights and shorter days, indicating the respective season with more sunlight.

4. Analysis of Test Results

After an initial test of 42 students, this study selected 463 students from Jinan, Shandong Province for a formal assessment. Among them, 225 were first-year high school students with less than 30 days of enrollment, and 238 were second-year students who had chosen geography as an elective. Based on the analysis, first-year students, who have not yet begun systematic learning of "Earth's Movements," should reach Level 4 in their understanding, according to the "National Curriculum Standards for Junior High School Geography (2011 Edition)." Second-year students, having completed the "Earth's Movements" section in their elective geography course, should ideally reach Level 5 in terms of understanding and cognitive development.

To delve into the results, it's noted that the responses to Question 1 were categorized into 4 levels and 4 types, while responses to Question 2 were categorized into 3 levels and 4 types. The frequency and percentage of each option for these questions are detailed in Tables 2 and Tables 3.

Table 2.OMC-1

"Level of Earth's Movements"	Option	Frequency and percentage(high school)		All
		First-year student	Second-year student	
4	C	72.4%(163)	78.60%(187)	75.6%(350)
3	B	7.10%(16)	4.30%(4)	4.30%(20)
2	A	7.60%(17)	7.10%(17)	7.30%(34)
1	D	12.9%(29)	12.6%(30)	12.7%(59)

Table 3.OMC-2

"Level of Earth's Movements"	Option	Frequency and percentage(high school)		All
		First-year student	Second-year student	
5	C	38.20%(86)	50.80%(121)	44.71%(207)
4	D	6.68%(15)	10.09%(24)	8.42%(39)
4	A	44.78%(100)	25.21%(60)	34.56%(160)
3	B	10.70%(24)	13.90%(33)	12.31%(57)

Students at Level 5 in understanding "Earth's Movements" (Question 2, option C) make up 44.71% of the total, with a frequency of 207. These students demonstrate high comprehension, accurately explaining the causes of the seasons, the geographic significance of Earth's revolution, and that the seasons result from the movement of the Sun's direct rays. In contrast, 38.20% of first-year students who have not systematically studied "Earth's Movements" reach this level, while 50.80% of second-year students who have studied it systematically still show incomplete understanding.

For Level 4 understanding of "Earth's Movements" (Question 1, option D; Question 2, options A and D), the distribution is as follows: 75.60% of students selected option D for Question 1, 8.42% selected option D for Question 2, and 34.56% selected option A for Question 2. Data indicates that both first-year (72.4%) and second-year (78.6%) students have a high level of understanding in the domain of "Earth's rotation and its significance," clearly recognizing the day-night cycle caused by Earth's daily rotation around its axis.Students who chose option A confused the relationship between "perihelion and

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aphelion" and "the origins of the seasons," mistakenly believing that seasons are caused by the changing distance between Earth and the Sun. This confusion is particularly evident among first-year students who are still in the advanced stage of middle school learning. Among second-year students, 25.21% have moved on to a more in-depth study of relevant concepts, but this has not significantly improved their understanding of the geographic significance of Earth's Movements.[5]

Students at Level 3 in understanding "Earth's Movements" (those who selected option A for Question 1 and option B for Question 2) make up less than 15% of each grade. Notably, second-year students are more prone to falling into the trap of option B in Question 2 compared to first-year students (10.70% for first-year versus 13.90% for second-year students).At this level, students often confuse the geographic significance of Earth's revolution and rotation. Many have processed information from their middle school studies on Earth's revolution and rotation, managing to bypass the pitfalls of the questions based on these concepts. However, interviews with a few students revealed that those at Level 3 understand the concepts of "Earth orbiting the Sun" and "Earth rotating on its axis" but have not effectively integrated these concepts with observable phenomena. They might not fully grasp the simultaneous nature of Earth's rotation and revolution. A common misconception among Level 3 students is that "nightfall occurs because Earth completes an orbit around the Sun every day," reflecting their persistent, simplified thinking.

For students at cognitive levels 1-2 in understanding "Earth's Movements" (those selecting option B for Question 1 or option C for Question 2), the proportions across both grades are relatively stable: Level 2 students are 7.6% and 7.1%, while Level 1 students are 12.9% and 12.6%, respectively. Interviews revealed that some students misunderstood the questions, while others rejected the heliocentric model based on their everyday experiences. A common error among these students is attributing all observable sky movements to Earth's rotation alone. This indicates that students at lower cognitive levels do not deepen their understanding of "Earth's Movements" as they progress through their education. These students have not reached the learning objectives for their grade level, highlighting the need for educators to reconstruct their cognitive framework around the core concepts of "Earth's Movements."[6]

5. Conclusions and Future Directions

5.1. Conclusions

5.1.1. Assess Students' Position in Constructing Potential Interests Before and After Teaching

Students' understanding is defined as a developmental continuum rather than a binary state. If learning is a developmental process, it is essential to assess a student's position in constructing potential interests. This is why constructing diagrams should be designed before creating Ordered Multiple-Choice questions. Before high school teaching, the differences in content taught by middle school teachers vary, and Ordered Multiple-Choice questions designed with construction diagrams can be used for both pre-tests (such as assessing high school freshmen's understanding of "Earth's Movement") and post-tests (assessing sophomores after teaching). This helps target specific teaching needs. In this study, the most significant difference in choice rates before and after teaching was between the knowledge points of "Earth-Sun Distance" and "Origins of Seasons." Therefore, teachers should consciously emphasize the significance of these two knowledge points during new lesson introductions and high school reviews, enhancing students' understanding and memory and correcting misconceptions. Teachers are also encouraged to break away from curriculum constraints and introduce core concepts like "solar altitude angle at noon," "orbital characteristics," and "solar declination" in the first year of high school to reduce students' discomfort in handling multiple abstract concepts at once, aiming for a complete scientific understanding at the top cognitive level.

5.1.2. Designing Exam Questions to Reflect Broader Knowledge Domains

The value of distractors in traditional multiple-choice questions is often underestimated, particularly in routine training. This can lead students to rely on everyday experiences when making judgments. This study suggests that distractors should be designed to effectively convey diagnostic information and explore potential valid insights. It is essential to establish a connection across "options—concept maps—cognitive levels—broader knowledge domains" to accurately assess higher-order cognitive processes. If necessary, designing "graded scoring" essay questions on the same topic can help refine answer choices and better reflect students' thoughts as expressed in the concept maps, thereby diagnosing students' geographical thinking more effectively.

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5.1.3. Developing Spatial Thinking by Integrating Observable and Actual Movements

Transforming short-term and working memory into long-term memory for abstract and specialized knowledge remains a challenge. For topics like "Earth's Movement," which involve complex spatial geometry and astronomy, using AI to integrate text with observable movements can enhance students' creative and spatial thinking abilities. While students may grasp concepts like "Earth's orbit around the Sun" and "Earth's rotation around its axis," they often struggle with varying question contexts and more complex distractors. Integrating visual and interactive tools can aid in bridging this gap.

5.2. Future Outlook

The seamless progression of key concepts like "Earth's Movement" between middle and high school is an inevitable trend in geography education. Designing learning progression models and concept maps reflects the "progressive" nature of students' cognitive development. Therefore, teachers at both levels should not only be familiar with their own curriculum standards but also systematically study the standards of the other educational stage to solidify the foundation of geographical concepts and tailor future instruction accordingly.

Due to limitations such as insufficient research time and small sample size, the design of concept maps and the development of Ordered Multiple-Choice questions require further refinement. Future studies should include empirical validation to create more rigorous concept maps and corresponding test items. Additionally, the diagnostic interpretation of test results from Ordered Multiple-Choice questions can be analyzed qualitatively (e.g., through classroom observations and interviews) and quantitatively (e.g., by correlating with other course tests and scores) to determine their usefulness and appropriateness.

References

[1] Ministry of Education of the People's Republic of China. General High School Geography Curriculum Standards (2017 Edition, Revised 2020) [M]. Beijing: People's Education Press, 2020.
[2] Briggs, D.C., & Alonzo, A.C.. The psychometric modeling of ordered multiple-choice item responses for diagnostic assessment with a learning progression. Paper presented at the Learning Progressions in Science (Lea PS) Conference, Iowa City, IA. 2009, June
[3] Liu Yanjun, Duan Yushan, Zhou Weiguo. Cognitive Construction and Learning Progression of Secondary School Geography Concepts Based on SOLO Classification Theory: A Case Study of "Earth's Revolution" [J]. Geography Teaching, 2020, (05): 16-20.
[4] Feng Shiji, Zhao Guangping, Luo Xingkai. Diagnostic Function of "Graded Scoring" Question and Its Implications for Students' Thinking [J]. Geography Teaching, 2013, (24): 14-17.
[5] Zhang Yunke, Tan Lihua, Feng Shiji. Strategies for Students to Handle "Counterexamples": Using Hierarchical Assessment Tools to Test Students' Understanding of Electric Current Concepts [J]. Physics Bulletin, 2022, (05): 106-111.
[6] Liu Sheng, Liu Enshan. Learning Progression: Focusing on Students' Cognitive Development and Life Experiences [J]. Journal of Education, 2012, 8 (02): 81-87.