Contemporary Mathematics and Science Education
2025, 6(1), ep25004
ISSN 2634-4076 (Online)
https://www.conmaths.com/
Research Article
OPEN ACCESS

Assessing misconceptions in astronomy: The use of ordered multiple-choice items

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Citation: Taasoobshirazi, G., & Sneha, S. (2025). Assessing misconceptions in astronomy: The use of ordered multiple-choice items. *Contemporary Mathematics and Science Education*, 6(1), ep25004. https://doi.org/10.30935/conmaths/15885

ABSTRACT

This study pilots a unique test item known as the ordered multiple-choice (OMC) item. These OMC items were administered to two high school astronomy classrooms participating in a NASA *classroom of the future: Astronomy village* program. The OMC items were included on a pre- and post-test to assess common misconceptions in astronomy, as part of study employing a quasi-experimental design. Each answer choice in an OMC item is linked to varying levels of student understanding, allowing for diagnostic interpretation of student responses. Results from the items indicated that although students did improve in their levels of understanding at the end of the program, there were still gaps in the students' knowledge. We anticipate these items will allow for a unique and comprehensive assessment of student understanding of science.

Keywords: misconceptions, science education, assessment, astronomy, ordered multiple-choice

Received: 26 Nov. 2024 ◆ Accepted: 17 Jan. 2025

INTRODUCTION

Students in science courses often have strongly held, but incorrect scientific beliefs (Özmen, 2024). Students enter their science courses with incorrect understandings, and even after instruction, leave their courses with the same or even new misconceptions (Herman et al., 2024). Science instructors are sometimes unaware that students hold these misconceptions and how to effectively address them (Jones, 2024). One subject area in which students hold many misconceptions is astronomy (Salimpour et al., 2024). There are several explanations for why students hold so many misconceptions about astronomical phenomena, one of which is that the teaching of events such as the rising of the sun and the rotation of the moon with abstract and two-dimensional representations leads to incorrect understandings (Gali, 2021). Cartoons and films are also presumed to be a source of astronomical misconceptions (Serttaş & Türkoğlu, 2020). As an example, science fiction films tend to portray asteroids as being clustered closely together. However, unlike in movies such as *The empire strikes back* where the spacecrafts flying through an asteroid belt cannot avoid crashing into them, real asteroids are at least tens of thousands of kilometers apart from one another. Another explanation is that colloquial terms are used to describe astronomical objects or events, which lead to incorrect perceptions (Suprapto, 2020). Examples include Saturn's 'rings', a comet's 'tail', or a 'shooting star'. Further, many misconceptions originate in the classroom because teachers sometimes hold these misconceptions themselves (Karademir & Yıldırım, 2021). Perhaps most significantly, students' misconceptions are anticipated to be the result of instruction focused on transmitting factual knowledge with less attention paid to the development of deeper conceptual understanding (Russell & Martin, 2023).

ASSESSING STUDENT MISCONCEPTIONS

To understand student misconceptions, researchers have sought and designed methods for assessing these misconceptions. One way of assessing misconceptions has been with focus interviews (Karakaya et al., 2021). However, interviews with classes of students are often not practical due to time constraints. More common methods of assessing student misconceptions by instructors is with traditional assessments. In particular, the use of the multiple-choice format is a common way of assessing misconceptions in STEAM, particularly with large numbers of sections and students (Yonemoto, 2023). Multiple-choice items have been found to be an easy and objective way to measure student understanding. Typically, multiple-choice items include a single correct answer choice, and several incorrect 'distractor' answer choices. However, by treating multiple-choice item responses as correct or incorrect, useful information about student understanding is lost. While open-ended items may be used to obtain more detailed information about students' understanding and to assess higher order cognitive processes, these items have limitations. For instance, student scores based on such items are often unreliable because fewer items must be administered to be completed in a set amount of time (Clifton, 2020), and the scoring of these items introduces the issues of correct reading and interpretation of responses and scoring bias.

This paper describes the use of a unique item format, the ordered multiple-choice (OMC) item (Briggs & Alonzo, 2012), designed to provide instructors and researchers with objective yet detailed information about students' understanding, allowing for a better grasp of where support is needed than the traditional multiple-choice item. A special feature of the OMC item is that each answer choice is linked to a different level of student understanding, allowing for comprehensive diagnostic interpretation of student responses. Briggs et al. (2006) developed the OMC item. Since their development, only a handful of peer-reviewed studies have developed and administered the items to K-12 students. These studies have been in chemistry (Hadenfeldt et al., 2013) and primarily mathematics (Chin & Chew, 2023; Chin et al., 2021). Ours is the first study to be used in astronomy. The OMC items in this study were designed and administered following Briggs et al.'s (2006) methods and guidelines. This was done while implementing a *NASA classroom of the future: Astronomy village* software program, described further below.

An important feature of OMC items is that they provide greater information about student understanding than traditional multiple-choice items, while retaining their advantage of being objective and easy to implement and score. In addition to the OMC items, there are other types of multiple-choice items that are used to obtain diagnostic information about student understanding in science. Some of these include two- and three-tier diagnostic items (Lengkong et al., 2021) and science concept inventory items (Coletta & Steinert, 2020). Although these assessment items are well-designed, widely used, and have influenced the development of the OMC items (Briggs et al., 2006), the OMC items were selected for design and administration because of the connection they provide between students' response options and progression of student understanding. No other item provides this type of distinctive information in the response options.

What makes OMC items unique is the process by which the distractors for each item are developed and categorized. To develop the distractors for our OMC items, various books, research articles, and internet resources were thoroughly reviewed to obtain information about student understanding of astronomy and common misconceptions at the high school level (e.g., Barbieri & Bertini, 2021). Once potential distractors were obtained, a *construct map* was developed for the OMC items, linking various answer choices for the items to levels of student understanding. A construct map plays a key role in the development and interpretation of OMC items. On a construct map, each response option represents a different level of student understanding.

For the six levels of their construct map, Briggs et al. (2006) used the knowledge that students should have about a topic at a particular grade level, as indicated by the national science education standards, to define the top two levels of their construct map. To define the last four levels, they reviewed the research on student misconceptions and placed the alternative choices into levels based on complexity of understanding (with the lowest level response indicating a lack of knowledge of the concept). The use of four levels of our construct map was because there were only four levels of useful and relevant responses appropriate for the topics and assessed by our items. This was determined by reviewing the research on student misconceptions in astronomy. Briggs et al. (2006) have six levels for their construct map for the astronomy topics they assessed; it is possible that their OMC items may provide a clearer continuum for the progression of student understanding, providing more valid diagnostic information. Other studies, like ours, have also used only four levels for their construct map (Chew & Chin, 2024; Hadenfeldt et al., 2013).

For the present study, when developing distractors for our items, it was expected that as students move up on levels of the construct map that they should become progressively more sophisticated in their understanding. The research on astronomical misconceptions and the state and national standards in astronomy that were examined provided valuable evidence for determining the transition from less complex to more complex understanding for the astronomical topics we were assessing and resulted in four levels for our own construct map. Level one on our construct map suggests that the student lacks knowledge of the concept, and this lack of knowledge has not even allowed for a misconception to develop. At level two, the student appears to have some knowledge (more than that at level one) about the concept, but not enough to have developed a misconception. Level three suggests that the student holds a common misconception that competes with their understanding of the concept. At level four, the student appears to have an accurate understanding of the topic without misconceptions. Thus, the methods we used to develop our construct map are analogous to those used by Briggs et al. (2006) and Briggs and Alonzo (2012); the various answer choices for each of our items were placed into levels based on complexity of understanding with the highest level illustrating an understanding of the topic.

The development of the items and construct map was based on the expectation that responses are hierarchically ordered, illustrating how students' progress towards a complete understanding. Further, it is expected that errors in understanding represented in one level of the construct map should be resolved as students move to the next level. To help ensure that we met these expectations and that the levels of the map for each item were logical, two astronomy professors and four educational psychologists reviewed the items and constructed the map.

METHOD

Curricular Context

Astronomy village®: Investigating the universe™ (AV) is an inquiry-based software program designed by NASA that places students in a virtual observatory on the Kit Peak Observatory in Arizona where they learn about and conduct inquiry into celestial science. The investigations that students complete are based on issues of current importance to astronomers, and the activities in those investigations are designed to give students insight into the type of problems astronomers solve.

The AV program was implemented in suburban schools in Georgia and the OMC items were administered as part of a classroom test assessing the AV content, including the material and misconceptions evaluated by the OMC items. Reflecting the current emphasis in the United States on student achievement on tests aligned to state-mandated content standards, 13 of Georgia's state science standards were identified that were relevant to the various investigations in the AV software. A four-week/20-hour curriculum was then designed by selecting activities that targeted these 13 standards, resulting in a curriculum that consisted of four (of the 10) AV investigations. Each of

1. Radio waves are a type of
- ◻ Light waves
- ◻ Sound waves
- ◻ Heat waves
- ◻ None of the above
- ◻ Cannot be determined from this information

2. Below is a picture from the night sky. Which of the two stars is closer to earth?

- ◻ The star on the right
- ◻ The star on the left
- ◻ None of the above
- ◻ Cannot be determined from this information

3. Some stars can change in brightness in a short time period (such as a few minutes).
- ◻ True-some stars change their brightness in a short time
- ◻ False-it must take millions of years for a star to change in brightness
- ◻ Partly true-some stars change brightness in a short time, BUT these types of stars have never been studied or observed
- ◻ False-stars stay constant and do not change in brightness

4. Our sun will eventually explode into a supernova
- ◻ True-our sun will explode into a supernova
- ◻ False-our sun is too small in mass to explode into a supernova
- ◻ True-all-stars eventually explode into a supernova
- ◻ False-stars do not explode

Figure 1. OMC items assessing the four misconceptions [created by the authors based on the text: Mathews & Tang (2025)]

ITEM 1
Level 1: Cannot be determined from this information
Level 1: None of the above
Level 2: Heat waves
Level 3: Sound waves
Level 4: Light waves
ITEM 2
Level 1: None of the above
Level 2: Star on the right
Level 3: Star on the left
Level 4: Cannot be determined from this information
ITEM 3
Level 1: False-stars stay constant and do not change in brightness
Level 2: True-but these types of stars have never been observed
Level 3: False-it takes millions of years for a star to change in brightness
Level 4: True-some stars change their brightness very quickly
ITEM 4
Level 1: False-stars do not explode
Level 2: True-all-stars eventually explode into a supernova
Level 3: True-our sun will explode into a supernova
Level 4: False-our sun is too small in mass to explode into a supernova

Figure 2. Answer options/construct map for OMC items [the answer choices are based on the text: Mathews & Tang (2025)]

the four investigations initially included 11-23 possible activities; these activities were examined, and a subset were selected based on

(1) their relevance to the core investigation topic,

(2) ability to be completed in four 50-minute class periods, and

(3) their alignment to the standards.

However, it is important to point out that all the activities in an investigation were centered on informing students about the main topic of the investigation.

The incorporation of OMC items in the present study was spurred by the fact that each of the four AV investigations included activities that addressed a common misconception about the core concepts in that investigation. The first AV investigation helped students understand various light waves and that radio waves are *not* sound waves (e.g., Barbieri & Bertini, 2021). Students examined the division of the electromagnetic (EM) spectrum into seven components according to our uses, and the notion that the EM spectrum is a single-long *light* wave that gradually decreases in wavelength as it moves from one end to the other end of the spectrum. Students were informed that many individuals associate the term *radio* with sound, but radio waves are a form of light, and that radio stations encode sounds (voices and music) as electrical signals which they broadcast as radio waves.

The second investigation involved the measurement of astronomical distance and addressed the misconception that stars that appear brighter in the night sky are closer to us (Bitzenbauer et al., 2023). Students were taught about parallax, and it was shown that one cannot use apparent brightness (how bright a star appears) to determine how distant a star is from earth because many stars that appear very bright may be very far away.

The third investigation concerned the life cycle of stars and addressed the misconception that it takes millions of years for a star to change in brightness (Barbieri & Bertini, 2021). It was explained that although, when looking out into the night sky, most of the stars don't change their brightness noticeably, there are stars that brighten or dim over a few years, months, days, or even seconds.

The fourth investigation concerned the sun and the misconception that our sun will explode into a supernova (e.g., Salimpour et al., 2024). Students were informed that because our sun is a medium sized star, no supernova occurs. Rather the sun slowly loses its outer envelope of gas, and all that will one day be left is a white dwarf at the center.

Assessment Design and Administration

The OMC items were administered as part of a classroom test assessing the state standards targeted by the curriculum. The OMC items and answer options are presented in **Figure 1** and **Figure 2**.

For item 1, which assesses the misconception that radio waves are sound waves, the responses to *none of the above*, or *cannot be determined from this information* are categorized as level one. The level two distractor *heat waves* suggests a lack of understanding of the EM spectrum but is more advanced than the level one distractor because it suggests the student recognizes that radio waves are labeled as some type of wave. However, at level two, students do not appear to have the common misconception. Further, there is no classification of waves as a heat wave in physics or astronomy, even outside of the EM spectrum. The level three distractor, *sound waves,* indicates that students hold the common misconception. In addition, a sound wave is a type of wave that exists outside of the EM spectrum, so this response is considered more sensible than the response at level two. Finally, the level four selection, *light waves,* suggests that the student is knowledgeable about this aspect of the EM spectrum wave.

Item 2 concerns the misconception that stars that appear brighter in the night sky are closer to the earth. The selection of *neither star* suggests the absence of relative knowledge and is categorized as level one. Selecting *the star on the right* suggests a level two on the construct map because students recognize that there is some difference between

Table 1. Number of students answering OMC items at level 4

	Pre-test				Post-test			
	Item 1	Item 2	Item 3	Item 4	Item 1	Item 2	Item 3	Item 4
Implementation classroom 1 (n = 21)	6	17	7	4	7	21	18	21
Implementation classroom 2 (n = 9)	0	4	1	1	6	8	8	9

the two stars. However, the response is inconsistent with that of a common misconception. Also, there is no clear logic behind this response. The level three response, *the star on the left*, illustrates the common misconception that stars that are brighter are closer. Finally, at level four, the response *cannot be determined from this information* suggests that the student recognizes that one cannot determine distance from apparent brightness.

Item 3 concerns the misconception that it takes stars millions of years to change in brightness. The selection *stars stay constant and do not change in brightness* is categorized as level one. Categorized at level two is the response *some stars do change in brightness in a short time, but these types of stars have never been studied or observed*. At this level, it appears that students are assuming or even guessing that these types of stars exist, without using existing evidence that, in fact, these stars do exist. The level three response, *it must take millions of years for a star to change in brightness*, illustrates a common misconception. At this point students appear to expect that stars do change in brightness but seem to hold the common misconception that it takes millions of years for them to do so. Finally, a level four response, *some stars change their brightness in a short time,* suggests that students recognize that there are, in fact, stars that change their brightness quickly. The responses for levels two and three for this item could be switched, but it was expected that the level two response was less advanced than the level three response because the level two response appears to be based on more of an assumption or guess rather than knowledge of astronomy. A level three response is at least consistent with existing research because there are stars that do take millions of years to change in brightness.

Item 4 concerns the misconception that our sun will explode into a supernova. Categorized at level one is the response *stars do not explode*. At level two, the response includes *all stars eventually explode into a supernova*. This is similar to the response at level one in that there appears to be a failure to understand the life cycle of stars, but in this case, students seem to have developed some recognition that stars do explode. However, there is still no differentiation between various stars. At level three, the response *our sun will explode into a supernova* suggests that students can differentiate between stars: Some stars do explode, yet not all stars will explode. However, in this case a misconception about our sun has developed. Finally, the level four response, *our sun is too small in mass to explode into a supernova,* suggests that the student is knowledgeable about this aspect of the sun.

Participants

The curriculum and assessment were implemented in two high school astronomy classes in Georgia. One implementation classroom was made up of 22 11th and 12th grade students from a relatively affluent suburban community. The second implementation classroom was comprised of 11 11th and 12th grade students from a different suburban community. 60% of the students were male and 40% were female; 54% were White, 30% were Black, 10% were Asian, and 5% were Hispanic.

RESULTS AND DISCUSSION

The number of students answering the OMC items at level 4 for both implementation classrooms and at both pre and post testing is reported in **Table 1**. There is a clear improvement from pre to post testing in both classrooms, suggesting that, for most students, misunderstandings and misconceptions were cleared up by the end of the implementation of AV. Data for this pilot study can be obtained by contacting the first author.

We developed and implemented OMC items within a program to implement AV. As an initial exploration, we conclude that OMC items have substantial potential within innovative assessment practices. The OMC items allowed the opportunity to observe the levels in which students were initially responding, how students' understanding improved after the implementation of AV, and provided detailed feedback as to where students were still having problems.

Although our items provided useful diagnostic information, having only one item per misconception was a limitation. Further, the lowest level response on the construct map was rarely chosen by students as an answer choice on any of the four OMC items; this was also the case for the level 2 response for items three and four. Although a review of the research helped us develop the distractors for these levels, interviews with students and administering open-ended exam items to students can provide suggestions for more effective distractors. However, our study provides the possibility of establishing a link between a framework (i.e., a construct map) and students' performance on test items, which is important for test development (Hadenfeldt et al., 2013).

Instructors, students, and researchers can use the information provided by the OMC items to improve studying and instruction. For instance, although we summarized the results of the OMC responses for entire groups of students, results of the OMC items can also be computed for individual students. This can provide information (with whole numbers indicating levels) for instructors and researchers as to where gaps in knowledge may exist for individual students, allowing for an instructor or researcher to intervene accordingly. Student responses on the OMC items could be presented to individual students to allow them to reflect on their scores and give them an idea where they are in their understanding and how they need to further improve. The number of students scoring at each level of the OMC distractors could also be obtained, resulting in percentages of students at each level on the construct map.

When scoring the items for groups of students, the information obtained by scoring student responses on the OMC items based on the levels of their responses was juxtaposed to scores obtained by dichotomously scoring the OMC items. For instance, by scoring the items as right or wrong, we learn that 22 out of 30 students in the two implementation classrooms missed item three on the pretest. By scoring the items based on levels, we learn that approximately 88% students are responding at a level 3, indicating that students hold the misconception assessed by this item.

This study was an exploratory study attempting to pilot these items within a larger research project on technology and assessment. More OMC items need to be developed and implemented in astronomy and other STEAM subjects such as physics and engineering, where significant misconceptions exist (e.g., Kulgemeyer & Wittwer, 2023). Research in these areas may provide a clearer continuum of the progression of student understanding. This would increase the efficacy of the OMC items by providing a stronger link between the response options and the OMC construct map. Interviews with students used alongside the development and pilot of the items can help ensure that the misconceptions and alternative responses cited in the research are consistent with those held by the students. We encourage research that involves developing OMC items and examining how the items can be used to assess and improve instruction to minimize the prevalent misconceptions that exist in science.

Author contributions: Both authors were involved in concept, design, collection of data, interpretation, writing, and critically revising the article. Both authors approved the final version of the article.

Funding: The authors received no financial support for the research and/or authorship of this article.

Ethics declaration: The study was approved by the University of Cincinnati Institutional Review Board IRB4038. All participants provided written informed consent and all data were stored in a private and secure office and computer device.

Declaration of interest: Authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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