Development and validation of the moon phases concept inventory for middle school

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We present the development and validation of a new assessment tool, the Moon Phases Concept Inventory for Middle School (MPCI-MS), a concept inventory about the phases of the moon targeting students aged 10 to 14 years old. Items in the questionnaire are based on a careful examination of the concept domain of phases of the moon, ideas and concepts necessary to understand the mechanism of lunar phases, as chosen by a panel of seven professional astronomers. Questions and multiple-choice answers were tested for readability with 5th grade students, tested for reading level, and submitted to a second panel of professional astronomers to check for face and construct validity of the items. The MPCI-MS was tested with $N = 296$ students from grade 5 in elementary school to secondary 2 ($M_{\text{age}} = 10.2$ to 14.1). One item about global perspective on lunar phases had to be removed because of poor psychometric properties. The revised MPCI-MS has a post-test Cronbach alpha score of 0.786 and good overall psychometric properties: the mean difficulty index for the MPCI-MS pretest is 0.47, and 0.61 for the post-test; mean point-biserial correlation (post-test) is 0.376. Test-retest without instruction at one-week interval showed high test-retest reliability [$M_{\text{pre}} = 13.696$, $M_{\text{post}} = 14.523$; $t(45) = 1.315$, $p = 0.192$]. We conclude that the MPCI-MS is a reliable and valid instrument that can discriminate between novices and experts, and can be used to assess 10 to 14 year-old students' learning gains on the topic of lunar phases. The final version of MPCI-MS is a 19-item instrument, including two new questions about eclipses, that takes between 15 and 25 min for students to complete.

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I. INTRODUCTION

Assessment is an integral part of teaching at any level, whether to reveal misconceptions present among students, to measure students' performance before and after a teaching intervention or to compare the effectiveness of different teaching strategies. Most assessment tools used in teaching and research are a type of tests known as concept inventories, designed to determine the "amount" of knowledge a student possesses at one point in time about a specific set of concepts. Concept inventories usually are criterion referenced, composed of multiple-choice questions with only one correct answer per question, and a series of distractors which are incorrect or irrelevant

answers often based on students' commonly held misconceptions [1]. Ideally, a student's score on a concept inventory will reflect the amount of content knowledge this individual has learned. Contrary to a norm-referenced test (i.e., a personality questionnaire), the goal of a concept inventory is to ascertain whether a respondent has mastered a predetermined amount of content knowledge about a specific topic.

This paper presents the development and validation of a concept inventory instrument about the phases of the moon intended for students aged 10 to 14 years old. The rationale behind this choice of topic and age group is the fact that the concept of lunar phases is present in the curriculum, at the end of elementary (middle school) and the beginning of high school, in most jurisdictions in Canada [2], in the United States [3,4], and in many member countries of the Organization for Economic Co-operation and Development (OECD) [5]. This means there is a real need for an assessment tool that can be used to measure knowledge possessed by students of that age group about lunar phases.

Unfortunately, assessment tools tailored to the topic to be taught, and which are appropriate for specific age groups,

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TABLE I. Currently available assessment tools about earth science, astronomy, and/or lunar phases. Instruments targeting students 10 to 14 years old are set to bold.

Instrument	Author(s)	School level
LPCI: Lunar Phases Concept Inventory	Lindell & Olsen [11]; Lindell & Sommer [12]	Middle school and College
ADT2: Astronomy Diagnostic Test 2	Zeilik [9]; Hufnagel [10]	College
LSCI: Light and Spectra Concept Inventory	Bardar <i>et al.</i> [13]	College
GECI: Greenhouse Effect Concept Inventory	Keller [14]	College
ASSCI: Astronomy and Space Science Concept Inventory	Sadler <i>et al.</i> [15]	K-12
CMPA: Comprehensive Moon Phases Assessment	Sherrod [16]	Middle school
CMPA-R: Comprehensive Moon Phases Assessment-Revised	Yetter <i>et al.</i> [17]	Middle school
ACI: Astronomy Concept Inventory	Bilici <i>et al.</i> [18]	College
SPCI: Star Properties Concept Inventory	Bailey <i>et al.</i> [19]	College
NGCI: Newtonian Gravity Concept Inventory	Williamson [20]	College
TOAST: Test Of Astronomy STANDards	Slater [21]	College
ABI: Astronomy Beliefs Inventory	Favia <i>et al.</i> [22]	College
ACT: Astronomy Concept Test	Kanli [23]	High school and College
PFCI: Planet Formation Concept Inventory	Simon <i>et al.</i> [24]	College

are not always readily available. There are concept inventories in many fields, like the Force Concept Inventory in physics [6], the Chemical Concept Inventory in chemistry [7], the Biological Concept Instrument in life sciences [8], as well as the Astronomy Diagnostic Test in astronomy [9,10], but most of these use a rather complex vocabulary, and test for concepts targeted at older adolescents (end of high school) and/or adults (college students, pre-service and in-service teachers, nonscience majors, etc.). A review of assessment tools developed specifically to measure knowledge in astronomy and/or about the phases of the moon found very few instruments adapted to younger students (see Table I).

Therefore, the present paper describes the development and validation of a new concept inventory about the phases of the moon (the Moon Phases Concept Inventory for Middle School, or MPCMS) targeting students 10 to 14 years old. The MPCMS addresses the many concepts and ideas that students should master when learning about lunar phases (i.e., the lunar phases concept domain). Prior research has shown that students have a variety of misconceptions about lunar phases, and that these ideas can interfere with their ability to develop a complete understanding of the topic [25–28]. It is hoped that this new tool can be used in middle school classrooms to assess the teaching of lunar phases, as well as in science education research to test new ways to teach this difficult astronomical concept. In the following sections, the existing assessment tools and concept inventories in astronomy that deal with lunar phases will be reviewed, and the reasons we chose not to use an already existing instrument, but to create a new one, will be exposed. Then, the development of the MPCMS, its validation process, and its psychometric properties will be described. Finally, we will conclude by proposing ways to improve the instrument.

II. REVIEW OF INSTRUMENTS TO ASSESS KNOWLEDGE ABOUT LUNAR PHASES

As mentioned above, several assessment tools are already available to evaluate knowledge possessed by students of different age groups about astronomical concepts (see Table I). Unfortunately, most of these are aimed at adults (college and university), are too complex to use with younger students, and/or do not target concepts related to lunar phases; they will not be reviewed here. There are five assessment tools listed in Table I that address the phases of the moon and target, or are close to targeting students aged 10 to 14 years old. One of the most popular and widely used concept inventories about lunar phases is Lindell and Olsen’s Lunar Phases Concept Inventory (LPCI) [11,12]. Even though this instrument was designed for college-level students, there are examples of its use with middle school students (see Refs. [29,30]). Next is Sadler *et al.*’s Astronomy and Space Science Concept Inventory (ASSCI) [15], an instrument targeted at K–12 students. Unfortunately, this vast and comprehensive concept inventory contains only five questions about the phases of the moon, a number we consider insufficient to measure the whole breadth of knowledge necessary to understand the mechanism of lunar phases. Other instruments to consider are Sherrod’s Comprehensive Moon Phases Assessment (CMPA) [16], Yetter *et al.*’s revised version of the CMPA (the CMPA-R) [17], and Kanli’s Astronomy Concept Test (ACT) [23]. The latter, a 16-item instrument, was tested with 12th grade students, pre-service science teachers, and physics teachers, and contains very few questions about the phases of the moon. We consider that it targets too few lunar phases concepts, and that the language is too complex for the age group we are focused on. We review the CMPA, CMPA-R, and LPCI here.

The CMPA is a 47-item instrument (including six items for demographic purposes and one open-ended question) targeting upper elementary and middle school students, while the CMPA-R is a 31-item tool targeting the same grades and using questions similar to those found in the CMPA, although the CMPA-R contains several new questions about the global perspective on lunar phases (i.e., the aspect of the moon as seen from both hemispheres of the earth). Both instruments are based on a careful examination of the United States's state standards for middle school about the phases of the moon [16].

We have identified several issues with these two instruments. First, we found that the items in the CMPA and the CMPA-R were quite difficult for middle school children to understand, especially with regard to questions about the global perspective on lunar phases. This finding is confirmed by one of the authors of the CMPA-R, who wrote that “the reading level [of the CMPA-R] is about 5th grade; but it is still a rather difficult instrument for children” [31]. Another important issue with the CMPA and CMPA-R is the presence of items that contain hints or clues that could help respondents find answers to other items in the test, as this has the potential to skew the distribution of answers. For instance, items 12 and 15 in the CMPA-R (items 35 and 36 in the CMPA) show a polar view on the sun-earth-moon system. These items, and others, like item 21 of the CMPA-R, state that the moon orbits the earth; however, in item 16 of the CMPA-R, one proposed answer is “The moon does not move around the earth,” which is clearly contradicted by statements in previous items, and is likely to be artificially less popular among respondents for this reason. Item 21 of the CMPA-R also mentions a duration of “one month” in relation to the moon’s revolution around the earth, which is a clue to item 1 of the same instrument. In item 15 of the CMPA-R, one reads “If you were in a spaceship looking down on the earth’s North or South Pole, in which position will the moon be located (a, b, c, or d) when we see a full moon on earth?”; the 2D polar view illustration accompanying the item can be confusing for younger students, since the sun, earth and moon appear to lie on the same plane (that of the page), and a respondent could be led to believe that the earth will cast a shadow on the moon at its full moon location (position c in the illustration), preventing him or her from choosing that particular answer to the question. Also, the earth casting a shadow on the moon is a common misconception to explain lunar phases (see Table S2 in the Supplemental Material [32] for a list of the most common misconceptions about the phases of the moon found in the literature). Item 22 of the CMPA-R states “If the moon is seen to change over several days in the Northern Hemisphere from a new moon to waxing crescent to first quarter to waxing gibbous to full moon, how will the moon be seen to change during the same time period in the Southern Hemisphere?” This clear description of the evolution of lunar phases from new

moon to full moon (“waxing moon”) is a direct clue to item 2 “When we see more of the illuminated portion of the moon today than we did yesterday, the moon is called a _____” (one choice answer is “waxing moon”).

Finally, we found at least two incorrect or confusing statements in the CMPA: item 12 reads “When the sun reaches its highest point above the horizon from where you are standing, that point in the sky is known as the sun’s:...” with the target answer being “zenith”; later on, item 44 asks “When does a First Quarter moon reach its zenith?”. In everyday language, the word “zenith” is sometimes used as a synonym for culminating point, but in astronomy, and all the more so in a teaching context, the zenith should be strictly defined as the point in the sky located directly overhead of an observer. It is quite possible for the sun and moon to reach the zenith in tropical zones, but for most respondents living at higher latitudes north or south of the tropics, item 12 is misleading, and risks strengthening the idea that the sun reaches the zenith every day at noon, which is a common misconception about the sun’s apparent motion across the sky [33]. Item 44 would have made more sense if it asked instead “When does the first quarter moon reach its highest point in the sky?”.

The LPCI is a 20-item multiple choice instrument (plus one confidence question and eight demographic questions) which assesses eight science and four spatial domains, all specifically related to lunar phases. It was originally designed to be used with college-level students, but several authors used it to measure learning gains about the phases of the moon with younger students, including middle school [29,30]. Despite this, we think that many of the same issues we identified in the CMPA and CMPA-R are also present in the LPCI when it comes to its use with students aged 10 to 14 years old. For instance, items 11, 16, and 19 of the LPCI show the same polar view on the moon’s orbit, with the sun, earth and moon lying on the same plane, that can be confusing for younger children. Items 2 and 3 clearly state that the moon revolves around the earth; even though the knowledge that the moon revolves around the earth can probably be taken for granted with college students, it is not clear that middle school students know this for a fact, a crucial information the LPCI will miss in its inventory. Indeed, many misconceptions about lunar phases found in Table S2 (Supplemental Material [32]) can be linked to a misunderstanding (or ignorance) of the motion of the moon around earth, for instance, the idea that phases of the moon are due to the revolution of the sun around the earth and moon in 24 h, found in children 11 to 12 years old [25]. Also, contrary to best practice for this type of instrument (See Sec. III B), the LPCI makes ample use of the “none of the above” or “all of the above” answers. There are also answers for the same items that diverge considerably in their length, as well as answers that combine previous propositions (i.e., “Both a and d,” “Both b and d,” etc.). The reading level of the LPCI

is also a concern for younger students; a rough examination of the reading level of some of the statements contained in the instrument put it at the secondary (high school) level, probably too high for children in middle school. Finally, for several questions in the LPCI, different phases of the moon are represented by white silhouettes in a black square, instead of using real photographs of the moon. This abstract representation can be problematic for younger students to associate with lunar phases, adding an unnecessary level of difficulty to the instrument. It is for these reasons that we decided to develop a new instrument to evaluate knowledge held by students 10 to 14 years old about the phases of the moon, which we present in the following sections.

III. DEVELOPING THE MOON PHASES CONCEPT INVENTORY FOR MIDDLE SCHOOL

A. Concept domain of the MPCI-MS

The concept domain of the MPCI-MS is based on a detailed examination of the different notions, ideas, and concepts necessary to explain the mechanism of lunar phases. According to Brewer [34], the scientific model for lunar phases states that “the moon revolves around the earth and that the half of the moon facing the sun is always illuminated by the sun. On earth we see portions of the illuminated half and the portions [percentage] we see are determined by the relative positions of the earth, moon and sun” (p. 194). To understand the mechanism of lunar phases, one has to coordinate and combine several basic concepts, like the fact that the moon is a sphere, that it revolves around the earth, that it shines by reflecting light coming from the sun, that it’s always half-illuminated and half-dark, etc. These ideas, which form the concept domain for lunar phases, are like bits of knowledge, or “atoms of understanding” about the moon, its physical and orbital characteristics, and the characteristics of the sun-earth-moon system, which one has to know and integrate into a working mental model in order to be able to understand the mechanism of lunar phases [35,36]. Using these basic ideas to form the lunar phases concept domain is the key to building an assessment tool that will measure the level of knowledge of every student with respect to the mechanism of lunar phases.

To determine the content of the concept domain of the MPCI-MS, the authors, both professional astronomers with research experience in the field, came up with a comprehensive list of statements about the moon, its physical and orbital characteristics, phases and eclipses, and the sun-earth-moon system. A total of 67 statements related to the moon were created; statements directly related to the phenomenon of lunar phases were included, like “The moon doesn’t produce its own light, but shines by reflecting light coming from the sun,” as well as statements that have no link with the mechanism of lunar phases, like “Craters on the moon were created by asteroids and comets that hit

the moon’s surface,” or “Unlike earth, the moon has no atmosphere or magnetic field.” The complete list of 67 statements is in Table S1 (Supplemental Material [32]).

Next, the list of statements was submitted to seven professional astronomers in three Ph.D.-granting universities in Montréal and Québec City, Canada. These astronomers are all teaching Astronomy 101 (including the phases of the moon) in their respective institutions and are also active in research. They were asked to (i) check for any statement missing in the list and add any new statement that they felt was needed to describe the full mechanism of lunar phases; and (ii) indicate for each statement (original and new statements that they might have added) on a three-point Likert scale how important they thought it was for the understanding of lunar phases. A three-point scale was chosen (“essential,” “more or less necessary,” and “unnecessary”) in order to avoid excessive “spreading” in the decisions made by professional astronomers when judging each statement, thus forcing them to make a clear decision between statements that were essential and others that were less important. The scoring proceeded as follows: for each statement, the number of astronomers who checked essential, more or less necessary, and unnecessary were counted. All statements that received a clear majority of essential marks were retained. Ties were resolved by consensus. No new statement was added to the list, and 18 statements were considered essential by the majority of judges. They are listed in Table II. Statements that are similar to items found in the other instruments highlighted in Table I are also indicated.

B. Item development

One item for each of the 18 statements in the list shown in Table II was written. According to Mattheis and Nakayama [37], several criteria are important to consider when crafting items in a test: the items must represent a wide range of difficulty levels; the items must require an appropriate amount of reading and be at the appropriate reading level for the targeted age group; the items must be devoid of technical terms and scientific jargon that are not understood by children; and the length of the test must allow students to complete it in about 25 min or less. Towns [38] adds that multiple-choice answers should all be about the same length, be similar to each other, be clear of hints or clues that might lead to one of the proposed answers, and be arranged logically or alphabetically, so none of the possible answers stands out. The responses “all of the above” or “none of the above” should also be avoided. Krosnick and Presser [39] encourage the use of simple syntax, and warn against words and expressions with ambiguous meaning. They recommend that a questionnaire should “strive for wording that is specific and concrete (as opposed to general and abstract); make response options exhaustive and mutually exclusive; ask about one thing at a time (avoid double-barreled questions); and avoid questions with single

TABLE II. List of 18 statements considered “Essential” by seven professional astronomers to understand the mechanism of lunar phases and forming the MPCl-MS concept domain. Items targeting similar lunar phases concepts in the CMPA, CMPA-R, LPCl, ASSCI, and ACT are indicated.

Statement	CMPA	CMPA-R	LPCI	ASSCI	ACT
1. The names of the major phases of the moon that can be seen from earth during one cycle are (in chronological order): new moon, waxing crescent moon, first quarter moon, waxing gibbous moon, full moon, waning gibbous moon, last quarter moon, waning crescent moon.	✓	✓	✓		
2. From earth, the moon can sometimes be visible during daytime, sometimes during night-time, sometimes both.	✓	✓	✓		
3. As seen from earth, the moon rises and sets about 50 minutes later each day.	✓	✓	✓		
4. As seen from earth, the visual aspect of the moon (i.e., its phase) changes from day to day in a systematic and predictable manner. One can thus predict the future visual aspect of the moon, i.e., its phase as seen from earth, based on its actual aspect or phase.	✓	✓	✓		
5. As seen from earth, the same phases of the moon repeat about every 29.5 days.	✓	✓	✓	✓	
6. The moon is (very close to) a sphere.					✓
7. Lunar phases are caused by the changing fraction of the sunlit hemisphere of the moon that is visible from earth due to the moon’s orbital motion around our planet.	✓	✓	✓		
8. There is always half the moon illuminated by the sun and half in the moon’s self-shadow.	✓				
9. The moon doesn’t produce its own light, but shines by reflecting light coming from the sun.	✓	✓			✓
10. The moon revolves around the earth.		✓	✓	✓	
11. The moon takes about 29.5 days to complete one revolution around the earth.	✓	✓	✓		
12. The moon’s diameter is about 4 times smaller than the earth’s. The sun’s diameter is about 110 times larger than the earth’s.	✓	✓			
13. The distance between the earth and the moon is about 400 times smaller than the distance between the earth and the sun.	✓	✓		✓	
14. From earth, the new moon is invisible in the sky.	✓	✓	✓		
15. At any given time, the phase (i.e., visual aspect) of the moon is the same for all observers located at the same latitude around the earth.			✓		
16. At any given time, the phase of the earth as seen from the moon is always the reverse (or complement) of the phase of the moon as seen from earth (i.e., new moon is full earth, full moon is new earth, first quarter moon is last quarter earth, etc.).					
17. As seen from earth, the moon moves eastward by about 12 degrees each day with respect to the sun and background stars.		✓			
18. As seen from earth, during waxing phases (i.e., from new moon to full moon), the moon’s elongation (i.e., the angle with the sun) increases from about 0 degree to about 180 degrees; during waning phases (i.e., from full moon to new moon), the moon’s elongation decreases from about 180 degrees to about 0 degree.		✓			

or double negations” (p. 264). As for question order, the authors add that “early questions should be easy and pleasant to answer” (p. 264).

Similarly to most of the instruments listed in Table I, the distractors used as multiple-choice answers for most items in the MPCl-MS were based on a careful examination of past research on students’ misconceptions about the lunar phases (see Table S2 in the Supplemental Material [32]). For each item, following recommendations of exhaustivity made by Krosnick and Presser [39], we attempted to propose as many answers as necessary to cover the most common misconceptions found in the literature, or to exhaust all possible answers a child could think of for any given situation described in the items. Hence, on occasion, we divert from best-practice advice to keep the

number of choice answer to four or five, with the number of multiple-choice answers ranging from two to seven, numbers that are warranted for the sake of completion. Note that the LPCl has up to ten possible answers for several of its items.

Since the MPCl-MS is intended for middle school children, for which reading can still be difficult, the items were written in a style reminiscent of story books, with which children are already familiar, and accompanied with children’s book-style illustrations (see Keely and Sneider [40] for several examples). Sixteen out of 18 items used a multiple-choice design, while one item used an association game, and another a true-or-false design. Figures 1–3 present examples of questions included in the MPCl-MS.

1. The images on the left show the different phases of the Moon. The names of these phases are on the right, in random order. Using a line, connect each image to the name of the corresponding phase.

- First quarter

- Waning gibbous

- New moon

- Waning crescent

- Waxing gibbous

- Waxing crescent

- Third quarter

- Full moon

FIG. 1. Item 1 of the MPCl-MS: Association game between photos of lunar phases and their names.

The first version of the MPCl-MS was subjected to intensive scrutiny by the same professional astronomers that rated the list of statements in Table II, this time making sure that each question was representative of the statement it was associated with, that questions and answers were unambiguous, and that there was one, and only one, right answer for each item. The MPCl-MS was then tested for readability in three 5th grade classrooms, assuming that if children in these classrooms could easily read and understand the items, older and more mature students targeted by the instrument would have no difficulty either. Students were asked to read each question first, and then one of the authors (P.C.) would have a group discussion with the whole class about what they understood the question to mean, if there was any word or

2. Read each statement below and indicate whether you think it is true or false. Circle the answer of your choice after each sentence.

	Your answer...	
You can see the Moon in the sky in the morning.	True	False
You can see the Moon in the sky at noon.	True	False
You can see the Moon in the sky in the afternoon.	True	False
You can see the Moon in the sky in the evening.	True	False
You can see the Moon in the sky at night.	True	False

FIG. 2. Item 2 of the MPCl-MS: True-or-false question about the visibility of the moon by day and by night.

expression that they didn’t understand, and what they thought the right answer was, and why. Special care was taken to ask less talkative children to give their opinion as well. One school with a large number of non-native French learners (children of first-generation immigrants) was purposely visited to make sure that even children facing greater difficulties reading French would be able to cope with the wording of the items. Teachers were also consulted to obtain their opinion on the reading level of the items. Major and minor adjustments were made to several items after each visit, until there were no more adjustments necessary, and it was clear that children aged 10 to 11 years old (5th grade) and older would not find the MPCl-MS too difficult to read.

An evaluation of the readability index of each item was also performed using the online tool *Scolarius*¹ [41], a free readability analysis tool in French that combines several well-known readability indexes: The Flesh Formula, The Gunning Formula or Fog Index, The Fry Formula, and The Easy Listening Formula (ELF). *Scolarius* analyzes the level of difficulty of a text according to the length of words, sentences, and paragraphs, allowing users to determine if the level of difficulty of a text corresponds to the level of understanding of the target audience, that is, middle school students in the case of the MPCl-MS. The result of this evaluation is presented in Table III.

All questions and answers listed in Table III have a reading level well below 80 (the cutoff for elementary reading level is 89), except for item 11, which has a reading level of 83, still below the cutoff. In the case of item 11, the use of the conditional (“If the moon revolves around another celestial body, ...”) lengthens and complexifies the sentence, which then raises the reading level by several points. However, the overall text for this question is very short, and students who took the test did not have any difficulty understanding it. Finally, after some more fine-tuning, the final version of the MPCl-MS was again submitted to the same seven professional astronomers as before, to make sure that no scientific error had been introduced during the revision process. No more changes

¹*Scolarius* was developed by Influence Communication. For the time being, *Scolarius* is only available for texts in French.

14. Nora is looking at the calendar, which shows the phases of the Moon each month. She sees that the Moon will not be visible in the sky today. What do we call the phase of the Moon that we cannot see from the Earth? Circle the answer that best reflects what you believe.

- A. New moon.
- B. First quarter.
- C. Full moon.
- D. Third quarter.
- E. It is impossible to know.

FIG. 3. Item 14 of the MPC-I-MS: An example of a question written like a short story, with illustration.

were made to this version, which was then field tested with students aged 10 to 14 years old (see next section).

IV. VALIDATING THE MPC-I-MS

A. Psychometric properties of the MPC-I-MS

Data were gathered with the MPC-I-MS among the target group, i.e., students from 5th and 6th grade in elementary (middle) classrooms (aged 10 to 12 years old) and 1st and 2nd grades in secondary (high) schools (aged 12 to 14 years old). All students received the same paper version of the MPC-I-MS, and recorded their answers directly onto the test by circling them. Students' scores were then recorded manually and double checked by at least two researchers and graduate students in education science. Classical test theory (CTT) was used to evaluate the psychometric

TABLE III. Reading level of 18 items and multiple-choice answers contained in the MPC-I-MS as measured with the online tool Scolarius. Elementary reading level: 50–89; High school: 90–119.

Item	Reading level of the item	Reading level of multiple-choice answers
1	68	24
2	73	46
3	61	32
4	70	48
5	75	38
6	69	43
7	53	73
8	79	56
9	61	39
10	60	55
11	83	31
12	69	26
13	78	38
14	74	21
15	69	33
16	65	65
17	75	52
18	69	58

properties of the MPC-I-MS [42]: Cronbach's alpha coefficient [43,44], a measure of reliability or internal consistency of a psychometric test; the level of difficulty P (the percentage of correct answers per item, in other words a measure of how "easy" an item is) for each item in the pretest and post-test; and the point-biserial correlation r_{pb} for each item, i.e., the correlation between the answer given to a single item by one student and the total of correct answers obtained by this student to all items in the instrument. The point-biserial correlation coefficient, which is a special case of Pearson's correlation coefficient [45], quantifies the relationship between a continuous variable (the test score) and a variable that is a discrete dichotomy (the answer to a particular item of the test, which can be either 0 or 1, see Field [46]). For practical and cost-related reasons, a convenience sample composed of students from the metropolitan area of Montréal, Canada was selected after their teachers and parents agreed that they could participate in the research and signed the appropriate ethics approval form. The MPC-I-MS was administered in 13 classrooms from grade 5 in primary schools to secondary 2 (2nd year) in high schools, to a total of 289 students [$M_{age}(SD) = 10.2(0.3)$ to $14.1(0.2)$]. Table IV presents the demographics of our sample.

Most students in our sample answered the MPC-I-MS twice in a test-retest setup, with or without teaching intervention about the lunar phases between administrations; a subset of two classes (5 and 8) answered the MPC-I-MS a third time as a delayed post-test two months after instruction. Three classes (7, 12 and 13) answered the MPC-I-MS only once when we were testing administration procedures. For students who answered the MPC-I-MS at least once as a pretest ($N = 289$), the average score on the MPC-I-MS is 46.2% (standard deviation is 10.2%), with the lowest score being 20.0% and the highest 80.0%. As a post-test ($N = 223$), the average score on the MPC-I-MS is 60.4% ($SD = 15.8\%$) with the lowest score equal to 23.3% and the highest score equal to 100% (only one student reached maximum score on the post-test). As a delayed post-test ($N = 34$), average score is 65.7% ($SD = 15.0\%$), lowest score is 26.7%, and highest is 90.0%. Figure 4

TABLE IV. Demographic data for the 289 students who answered the MPCl-MS at least once (pretest). Post-test, delayed post-test, and teaching intervention (if any) for each class are also identified. “None” in the teaching intervention column indicates that students received no instruction whatsoever on lunar phases between the test’s administration.

Class number	Teacher	School level	Mean age (SD)	<i>N</i>	Post-test	Delayed post-test	Teaching intervention
1	Ms. M. G. and I. D. G.	5th	10.2 (0.3)	23	✓		None
2	Ms. C. L.	5th	10.5 (0.3)	22	✓		Textbook, exercise book and videos
3	Ms. J.-A. M.	5th	10.5 (0.5)	24	✓		Observation and modeling
4	Ms. C. O.	5th	10.5 (0.3)	21	✓		Observation and modeling
5	Ms. É. C.	5th–6th	11.4 (0.5)	21	✓	✓	Observation and modeling
6	Ms. M. F.	6th	11.1 (0.2)	23	✓		None
7	Ms. S. P.	6th	11.3 (0.3)	23			None
8	Ms. J. R.	6th	11.8 (0.4)	13	✓	✓	Observation and modeling
9	Ms. I. P.	Sec. I	13.1 (0.3)	26	✓		Observation and modeling
10	Ms. I. P.	Sec. I	13.1 (0.3)	26	✓		Observation and modeling
11	Ms. I. P.	Sec. I	13.2 (0.3)	24	✓		Observation and modeling
12	Ms. G. P.	Sec. I	13.1 (0.3)	22			None
13	Ms. É. B.	Sec. II	14.1 (0.2)	21			None

presents a histogram of students’ pretest and post-test scores on the MPCl-MS (delayed post-test score distribution is similar to post-test, but not shown). The distribution of all students’ responses to individual questions on the MPCl-MS (pretest only) is presented in Table S3 (Supplemental Material [32]). A chi-square test for each item allowed the rejection of the null hypothesis that students’ responses were randomly distributed: $\chi^2(1, N = 289) = 10$, $p = 0.002$.

The Cronbach alpha score is a measure of interitem correlations, and can be interpreted as a measure of how well a set of items measures a single construct. According to Kline [47], the generally accepted value of 0.8 for Cronbach’s alpha is appropriate for cognitive tests, such as intelligence tests, whereas for ability tests and concept inventories, such as the MPCl-MS, a cutoff point of 0.7 is more suitable. The post-test Cronbach alpha score of the MPCl-MS ($N = 223$) is 0.780, indicating a satisfactory

interitem correlation; the MPCl-MS is thus a reliable instrument to measure 10 to 14 year-old students’ knowledge about the lunar phases.

Item difficulty P is related to the percentage of good answers for each item; it represents the proportion (or percentage) of students in a sample who answered an item correctly. Bardar *et al.* [13] and Simon *et al.* [24] suggest that the ideal interval for P should be between 0.20 and 0.80, whereas Haladyna, Downing, and Rodriguez [48] propose the interval 0.30–0.90; in this paper, we will be more conservative by using the 0.30–0.80 interval. Finally, the point-biserial correlation, r_{pb} , is the correlation between the answer to a single item given by one student and the total score obtained by the same student to all questions in the instrument. This discrimination index is used to quantify how an item differentiates between students who do well on a test and those who do poorly. Ideally, r_{pb} should be positive and larger than 0.20 [49], with an ideal range between 0.30 and 0.70 [50]. Table V presents the results of the psychometric analysis of the MPCl-MS.

In Table V, the P index for the pretest ranges from 0.17 to 0.92, with a mean $P = 0.45$, and from 0.18 to 0.95 for the post-test, with a mean $P = 0.58$; mean point-biserial correlation r_{pb} (post-test) is 0.359, with a minimum of 0.066 and a maximum of 0.811. Note that for item 1, the association game between images of lunar phases and their names (see Fig. 1), individual answers are not independent, because the way a student answers part of the question narrows down the options left, increasing the probability of getting other parts of the question right or wrong. As a result, the probability of getting the next association correct or incorrect changes with every new association made. Association games are not usually found in a concept inventory, but we think it’s an efficient way—and a fun way

FIG. 4. Histogram of students’ scores on the MPCl-MS, pretest ($N = 289$) and post-test ($N = 223$).

TABLE V. Item difficulty (P , pretest and post-test) and point-biserial correlation (r_{pb} , post-test) for each item in the MPC-I-MS. For item 1, 2 and 12, the item difficulty is calculated on all subquestions combined, and the biserial correlation is reported.

Item	P pretest ($N = 289$)	P post-test ($N = 223$)	r_{pb} ($N = 223$)
1	0.35	0.55	0.811
2	0.70	0.81	0.357
3	0.25	0.61	0.481
4	0.27	0.40	0.315
5	0.68	0.74	0.459
6	0.92	0.95	0.236
7	0.47	0.65	0.361
8	0.30	0.34	0.292
9	0.59	0.86	0.352
10	0.62	0.79	0.221
11	0.17	0.45	0.449
12	0.51	0.54	0.343
13	0.28	0.36	0.313
14	0.85	0.91	0.354
15	0.20	0.18	0.066
16*	0.32	0.56	0.569
17*	0.30	0.35	0.273
18*	0.40	0.42	0.206

*After item 15 is removed (see Sec. IV B), these items are renumbered 15, 16, and 17, respectively, in the final version of the MPC-I-MS, available in the Supplemental Material [32].

for children—to demonstrate their mastery of an important aspect of the lunar phases concept domain, i.e., the nomenclature of phases. Thus, for item 1, our analysis is as follows: instead of reporting a difficulty level and point-biserial correlation for each of the eight subquestions, we calculated the percentage of correct answers for each student (pre- and post-test), and based our calculations of P and of the biserial correlation on these numbers. We did the same with item 2 (see Fig. 2): even though each of the five true or false choices is independent, we again combined all subquestions in a single percentage of correct answers (pre- and post-test) and used these numbers to calculate P and the biserial correlation reported in Table V. Item 12, with two subquestions, was treated the same way.

Ideally, students should achieve better results on the MPC-I-MS after having received instruction on the topic of lunar phases. Accordingly, the difficulty index P should be higher for all of the MPC-I-MS post-test items compared to pretest scores (i.e., a larger proportion of students should have answered these items correctly after teaching). This is true for all items in the MPC-I-MS, except for item 15, where P is lower in the post-test (see Fig. 5). In terms of point biserial correlation r_{pb} , only item 15 falls below the 0.20 cutoff (see Fig. 6). Even if we follow Simon *et al.* [24] and lower the point biserial correlation threshold to 2 standard deviations of r_{pb} [$2/(N-1)^{-1/2} = 0.134$ with

FIG. 5. Pretest item difficulty (P) versus post-test, as reported in Table V. Item difficulty values are higher in the post-test for all items in the MPC-I-MS (i.e., a larger number of students answered the items correctly), except for item 15, which lie below the diagonal line representing equal pre- and post-test difficulty.

$N = 223$], this item remains problematic; it will be discussed below.

B. Reviewing the items

As is apparent by looking at Table V and Figs. 5 and 6, most items in the MPC-I-MS have good psychometric properties overall: difficulty index P is higher in the post-test and most point-biserial correlation coefficients fall in the 0.30 to 0.70 range; only one item has a r_{pb} value below 0.20. The one exception is item 15 (aspect of a lunar phase as seen from different countries in the same hemisphere simultaneously) which is more problematic: it is very difficult (P goes from 0.20 to 0.18 from pretest to post-test) and its point-biserial correlation $r_{pb} = 0.066$ is well below the 0.134 cutoff. It seems that figuring out what the phase of the moon looks like as seen from two countries simultaneously is extremely difficult for most 10 to 14 year-old students, and that this question does not discriminate well between students. It is thus better to remove this item from the final version of the MPC-I-MS. With item 15 removed (and items 16 to 18 renumbered 15 to 17; see Supplemental Material [32] for the final version of the instrument), the final Cronbach alpha score of the MPC-I-MS becomes 0.786, the pretest mean difficulty index becomes 0.47, and 0.61 for the post-test; mean point-biserial correlation becomes 0.376.

FIG. 6. Post-test item discrimination (r_{pb} , $N = 223$). Ideal range for r_{pb} is between 0.30 and 0.70, but values greater than 0.134 are still acceptable. The horizontal blue line is at $r_{pb} = 0.20$, while the dashed line is at $r_{pb} = 0.134$. Only item 15 falls below that line.

C. Item validity

Another aspect of the psychometric evaluation of a concept inventory is its validity, i.e., the characteristics of measured constructs and the way results can be interpreted [51]. In the case of a concept inventory, validity refers to how well the items in the instrument measure the scientific concepts targeted by the test [52]. With the MPCMS, students' understanding of the mechanism that causes the moon to show phases as seen from earth is the construct that could explain their performance on the test.

Content validity refers to the extent to which the test items are scientifically accurate, while face validity verifies how well the items represent the whole concept domain the instrument seeks to evaluate [24]. In other words, content validity checks that there are no scientific errors in the items, while face validity (completeness) promises that all relevant ideas related to the concept domain are covered by the test. Face validity of the MPCMS regarding the concept domain of lunar phases was already confirmed by the fact that the seven professional astronomers who ranked the 67 statements about the moon (Table S1 in Supplemental Material [32]) did not add any new statements, and agreed on the 18 statements necessary to represent basic ideas about lunar phases (i.e., the lunar phases concept domain). Content validity was also evaluated by experts: if the instrument has good content validity, experts should reach a perfect score on the test. To verify

the MPCMS content validity, the final version of the instrument was submitted to four more professional astronomers (unrelated to the seven who scored the list of statements in Table S1 [32]), and they indeed obtained a perfect score, except for one who, after review, realized that he misread one question and checked his answer too fast. After correction, he too reached a score of 100%.

Following Simon *et al.* [24] and Trochim's [53] recommendations, we also checked the concurrent validity of the MPCMS, i.e., the instrument's ability to distinguish between different populations of respondents. We ran an independent samples t test comparing post-test scores of 5th graders ($N = 45$, $M_{\text{score}} = 16.8$, $SD_{\text{score}} = 4.7$) and older students in the first year of high school ($N = 76$, $M_{\text{score}} = 20.3$, $SD_{\text{score}} = 3.8$), both samples having participated in the observation and modeling experiment. Results confirmed that the MPCMS was able to distinguish between the two groups (different by age and maturation): $t(119) = -4.379$, $p < 0.001$. We also asked late elementary and early high school in-service teachers ($N = 18$, $M_{\text{score}} = 27.6$, $SD_{\text{score}} = 2.1$), who participated in a two-day training seminar on lunar phases conducted by one of the authors (P.C.), to answer the MPCMS as a post-test, after observing the moon for a month and modeling the lunar phases (same treatment as 5th grade and secondary 1 students above). We compared their MPCMS post-test scores to those of high school students, using an independent samples t test, and found a statistically significant

difference between the two groups: $t(92) = -11.202$, $p < 0.001$. Finally, we compared post-test results of all the students in the experimental group ($N = 155$, $M_{\text{score}} = 19.6$, $SD_{\text{score}} = 4.5$) with post-test scores of in-service teachers and again found a statistically significant difference: $t(171) = -13.157$, $p < 0.001$. Interestingly, it appears that the MPC-I-MS can also be used with adult in-service teachers with a minimum ceiling effect (only 4 out of 18 respondents had a perfect score on the post-test, none on the pretest). For the teachers who reached a perfect score after instruction, one could say that the training seminar turned them into experts on the mechanism of lunar phases, much like the professional astronomers who helped create the instrument and review its psychometric properties.

Finally, we checked the test-retest reliability of the instrument [49]: if a reliable test is administered twice at different times (not too far apart), to the same sample of students and in the same environmental conditions, then there should not be any significant difference between the test scores. Test-retest without instruction at one-week intervals with classes 1 and 6 shows no significant difference between the pretest and the post-test mean scores [$M_{\text{pre}} = 13.696$, $M_{\text{post}} = 14.523$; $t(45) = 1.315$, $p = 0.192$], indicative of the high test-retest reliability of the MPC-I-MS.

We thus conclude that the MPC-I-MS is a valid and reliable instrument to measure knowledge about the concept domain of lunar phases with students aged 10 to 14 years old. The final version of the MPC-I-MS (translated into English by the authors), without item 15, with items 16 to 18 renumbered 15 to 17, and two new questions about eclipses added (items 18 and 19, see Sec. V) is available in the Supplemental Material [32]. This new numbering system will be used henceforth.

V. DISCUSSION AND CONCLUSION

Without assessment, learning cannot be measured and teaching cannot be improved. As the saying goes, we measure what we value and we value what we measure. Unfortunately, valid assessment tools about a particular topic, and tailored for a particular student age-group, are not always readily available, as was certainly the case with an assessment tool about the phases of the moon for younger children aged 10 to 14 years old. Because of several issues identified with other instruments about lunar phases targeting the same age group, like the LPCI, the ASSCI, the CMPA, the CMPA-R and the ACT (see Table I, Sec. II), this paper reported on the development and validation of a new concept inventory about lunar phases, the Moon Phases Concept Inventory for Middle School (MPC-I-MS), a valid and reliable instrument to measure knowledge about the construct of lunar phases with students aged 10 to 14 years old. This new instrument can be used in realistic teaching situations, thus making it not only a practical research instrument to evaluate and compare teaching strategies, but also an easy-to-use

assessment tool that can be readily utilized by teachers in their classrooms. Nonetheless, the MPC-I-MS can definitely be improved and avenues to explore are presented below.

A. Items about eclipses

The items in the MPC-I-MS are all based on a careful examination of the lunar phases concept domain, encompassing all the elements of the mechanism of lunar phases and the “bits of knowledge” that professional astronomers think students must possess in order to be able to understand the origin of the phenomena. In retrospect, though, it is possible that the criteria used to make the final decision about what statements to keep from the list in Table S1 (Supplemental Material [32]) may have been too tight, and one can wonder if it was wise to leave out from such a concept inventory items about eclipses of the sun and the moon, as these two phenomena are so closely linked with lunar phases. Eclipses occur because, in the moon’s monthly journey around the earth which causes lunar phases, our satellite sometimes casts its shadow on part of our planet (solar eclipse), or travels through earth’s shadow (lunar eclipse). Items about eclipses are indeed included in the LPCI, the ASSCI, the CMPA, the CMPA-R, and the ACT. When discussing with professional astronomers to draw up the final list of statements upon which items were based (see Table II, Sec. III), there were strong arguments in favor of asking questions about eclipses, but not enough in the end to retain them, especially since it was feared that the MPC-I-MS would be too long to complete by students aged 10 to 14 years old. But now that the instrument has been trialed in several classrooms, and that the time it takes to fill it out was measured to be between 15 and 25 min, which is quite acceptable, according to Mattheis and Nakayama [37], two new questions, one on lunar eclipses and one on solar eclipses, have been added to the MPC-I-MS (see items 18 and 19 in the MPC-I-MS in Supplemental Material [32]).

B. Items 2 and 15

Item 2 about the visibility of the moon during the day and at night is a series of statements that are either true or false; this item has very good psychometric properties. Item 15 in the final version of the MPC-I-MS (was item 16 previously) about the possibility of seeing phases of the earth from the moon, has excellent psychometric properties as well, but only a two choice answer (Ann or Bob). For item statistics (discrimination and difficulty), it is best practice to have a minimum of three answer choices. Indeed, it is hard to assert the validity of a test item’s discrimination if there are only two choices.

To improve these items, we suggest modifying item 2, asking students to choose among a series of four statements, only one being true: “The moon can only be seen at night”; “The moon can only be seen during the day”;

“The moon can sometimes be seen at night, and sometimes during the day”; and “The moon can only be seen around sunrise and sunset”. For item 15, we could add a third answer choice, which could read: “Candice: I don’t think you can see the earth from the moon”, and modify the illustration to include a third student. It is unlikely these modifications will profoundly change the psychometric properties of these two items, or that of the whole test, but it will make the MPC-MS a better instrument overall.

C. Limitations and future studies

There are several limitations in the present study that need to be acknowledged, the first of which is the relatively small sample size of our study, which limits its generalizability. Second, although the MPC-MS has good psychometric properties overall, there remain a few items (items 6, 8, 10, 12, 16, and 17, these last two being items 17 and 18 in Table V) that either have a low point-biserial correlation index (below 0.30, typically), or show a very small increase in difficulty index between pre- and post-test. It could be that the wording of these questions is still difficult to understand, that the multiple-choice answers are confusing, or that the concepts targeted (i.e., the daily eastward motion of the moon among the stars for items 16 and 17) are too difficult for children 10 to 14 years old. In the case of item 12, it seems that determining the size of the sun to scale with the earth represented by a basketball remains difficult, but it could also be because children do not have direct experience with the size of an actual hot-air balloon, or that such an object appears to be out of place in relation to the other objects in the list of possible answers. These items will need to be reevaluated to improve their psychometric properties, hence, new testing of the MPC-MS to overcome these limitations is planned. This revision process will offer the possibility to measure the psychometric properties of the two new items about eclipses that have been included in the final version (items 18 and 19), as well as the revised items 2 and 15.

Third, the instrument was developed in French, which makes it less useful outside French-speaking countries, and even though the MPC-MS has already been translated into English (see Supplemental Material [32]), the English version will also need to be validated, and the instrument translated into other languages (Chinese, Spanish, etc.). Any offer to collaborate to that end will be welcome by the authors. Having the same concept inventory available in different languages would allow comparative studies to be conducted using the same instrument in different circumstances to test students’ knowledge about the phases of the moon, a ubiquitous astronomical phenomenon that is easy to observe and which is present in most curriculums across the world, but remains difficult to teach and to learn.

Finally, even though the MPC-MS can be used as a summative test at the end of a lesson on lunar phases, or as a pre- and post-test research instrument, it is also recommended that teachers and instructors use this instrument as a formative assessment tool, and analyze the pattern of answers given to each question individually, with the purpose of designing teaching interventions more directly targeting students’ nonscientific ideas about the mechanism of lunar phases and the different aspects of the lunar phases concept domain.

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