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The Size, Scale, and Structure Concept Inventory (S3CI) for Astronomy

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Abstract. We present a concept inventory to evaluate student understanding of size, scale, and structure concepts in the astronomical context. Students harbor misconceptions regarding these concepts, and these misconceptions often persist even after instruction. Evaluation of these concepts prior to as well as after instruction can ensure misconceptions are addressed. Currently, no concept inventories focus exclusively on these geometrical ideas, so we have developed the Size, Scale and Structure Concept Inventory (S3CI). In fall 2013, we piloted a 24-item version of the S3CI in an introductory astronomy course at a small private university. We performed an item analysis and estimated the internal consistency reliability for the instrument. Based on these analyses, problematic questions were revised for a second version. We discuss the results from the pilot phase and preview our updated test in this work.

A valid and reliable concept inventory has the potential to accurately evaluate undergraduates' understanding of size, scale, and structure concepts in the astronomical context, as well as assess conceptual change after targeted instruction. Lessons learned in the evaluation of the initial version of the S3CI can guide future development of this and other astronomical concept inventories. Instructors interested in participating in the ongoing development of the S3CI should contact the authors.

1. Introduction

Many undergraduate students harbor strong and persistent misconceptions regarding the size, scale, and structure of the universe (Miller & Brewer 2001). These misconceptions can affect not only student understanding of the geometry of the universe, but also their understanding of how objects in the universe interact and evolve.

These misconceptions can be grouped into three general and related categories:

- **Distance underestimation:** Students can often order celestial objects in terms of distance from Earth (e.g., the Sun is farther away than the Moon), but often grossly underestimate the actual distances.

- **Distance compression:** Students often place very distant objects nearly equally far away. That is, they grossly underestimate the factors by which the distances are different.

- **Crowding:** Largely because they underestimate the broad range in distances to different objects, students place celestial objects closer to each other than they really are.

A valid and reliable concept inventory has the potential to accurately evaluate undergraduates' understanding of size, scale, and structure concepts in the astronomical context, as well as assess conceptual change after targeted instruction. Currently, no concept inventories focus exclusively on these geometrical ideas, so we have started to develop the Size, Scale and Structure Concept Inventory (S3CI) to address this need. We present the results of the early development and initial testing of the S3CI here.

The current version of the S3CI contains 24 multiple choice questions designed to probe student understanding of size, scale, and structure in a variety of ways. When possible, we paired numerical and non-numerical, analogical questions in an effort to separate the effects of rote memorization from a deeper understanding of these concepts. The concept inventory also contains a demographic survey, with questions regarding gender, race, and previous academic preparation.

2. Analysis of Student Performance

We administered the S3CI to a group of 40 undergraduates taking a general education astronomy class at Bucknell University in the fall semester of 2013. We administered the concept inventory twice—once in the first week of class, and again during the last week of class. Coincident with the first administration, we also administered the Astronomy/Space Science Test (ASST) developed by Sadler et al. (2010) to compare students performance on the S3CI with their performance on the validated ASST.

Below is a scatterplot of student performance on both tests. The data show a general correlation between student performance on the two measures, with broad scatter. While this correlation is comforting, it is not surprising to see variations, since the ASST is a broad based astronomy assessment while the S3CI focuses on size, scale and structure.

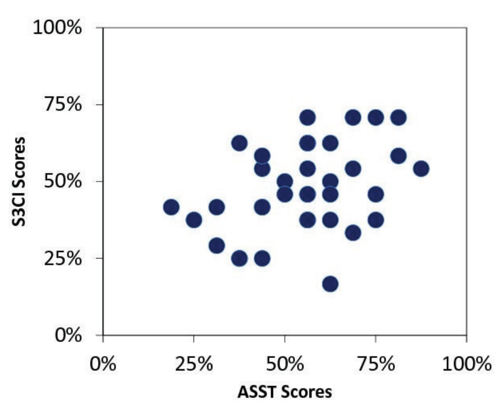

Figure 1. Student performance on the S3CI vs the ASST.

For each question on the S3CI, we calculated two quantities: 1) the item difficulty and 2) the item discrimination. Below are plots of the difficulty and discrimination for each of the 24 questions on the S3CI.

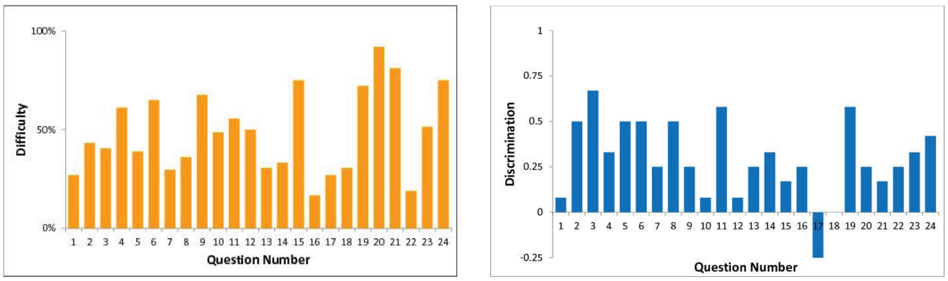

Figure 2. Question difficulty and discrimination.

Difficulty was defined simply as the fraction of the students who answered the question correctly on the pre-test. The data show a large range in difficulty, with some questions answered correctly by nearly all of the students, and a few questions that only a few students answered correctly.

Item discrimination is defined as the difference between the fraction of correct answers among the high-performing students (those whose total scores placed them in the top third of the group) minus the fraction of correct answers among the low-performing students (those whose total scores place them in the bottom third). The data show a broad range in discrimination, including one question (#17) which shows negative discrimination. Questions with discrimination > 0.20 are generally considered to be good discriminators (Brown 1983).

3. Evaluating Questions

Using these data, we evaluated each question for its continued inclusion in the concept inventory. We identified some questions that performed well, with moderate difficulty and good discrimination, such as Question #11:

> *All of the stars in the Milky Way galaxy are*
> *a. distributed evenly in a roughly spherical volume of space.*
> *b. concentrated together in a flattened, pizza-shaped disk.*
> *c. concentrated together in a circular band at the edge of our Solar System.*
> *d. distributed evenly in a shell just beyond the edge of our Solar System.*

The distractors for this question were equally attractive to those who answered incorrectly. A discrimination rating of 0.58 makes this question particularly strong.

Another question (# 22) performed rather poorly, with a low difficulty value (i.e., it was very difficult for students) and weak discrimination.

How would the night sky look to you if you observed it from the surface of Pluto?
a. The stars and constellations would look the same as they do from Earth.
b. The constellations would look different, but the brightnesses of the stars would be the same.
c. The constellations would look different, and the stars would be brighter.
d. The constellations would look different, and the stars would be fainter.

We determined that this question was difficult for students in part because of the wording. In particular, students had difficulty with the ambiguity of the phrase "constellations would look different." Based on the results we have revised the question and answers to stress the relative orientation of the stars.

Question 22, Revised version: How would the constellation Orion look to you if you observed it without a telescope from the surface of Pluto?
a. The constellation would look the same as it does from Earth.
b. The constellation would look distorted, but the brightnesses of the stars would appear the same.
c. The constellation would look distorted, and the stars would appear brighter.
d. The constellation would look the same as it does from Earth, but the stars would appear brighter.

We deleted one question entirely (# 20), primarily because nearly every student answered it correctly and it therefore provided no discrimination. We replaced this question with a new question designed to probe students' ability to visualize the arrangement of balls viewed from two different perspectives. It tests some of the basic concepts underlining astronomical parallax. The new question is shown below.

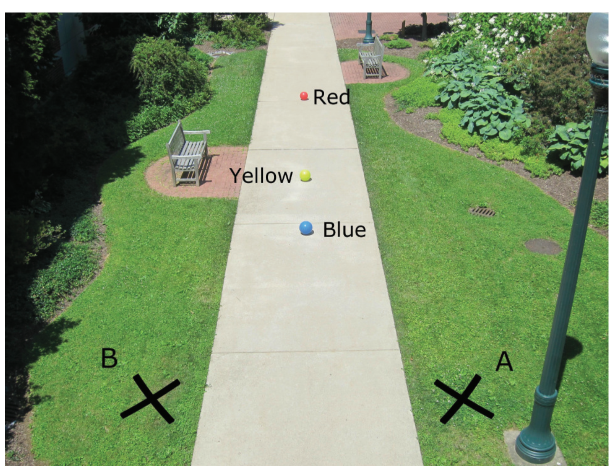

Figure 3. Photo showing the layout of balls used in the parallax question.

A blue ball, yellow ball, and red ball are located in a sidewalk as shown in the overhead photograph above (Fig. 3). As you walk from position A to position B in the grass,
a. the blue ball appears to move from the right side of the yellow ball to the left side of the yellow ball, but remains to the right of the red ball.
b. the blue ball appears to move from the left side of the other balls, to the right side of the other balls.
c. the blue ball appears to move from the left side of the yellow ball to the right side of the yellow ball, but remains to the left of the red ball.
d. the relative order of the balls from left to right remains the same.

A second version of the S3CI which includes the changes detailed above, as well as changes to the wording of other questions, is being tested on another group of undergraduate students taking general education astronomy classes at two colleges this fall.

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