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## Astronomy for the Blind and Visually Impaired: An Introductory Lesson

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### Abstract

This article describes an introductory astronomy lesson for blind and visually impaired people. The lesson was conducted successfully and included hands-on activities. Beginning with the Solar System and concluding with the cosmological perspective, the lesson gave the participants a feel for the scales of sizes and distances in the universe and for its number of galaxies and stars.

## 1. INTRODUCTION

One can't touch the stars! Overwhelmingly, astronomy gathers its data by the detection of electromagnetic waves. Only in the rare cases of space probes is it possible to carry out in-situ experiments; cosmic rays—and eventually, gravitational waves—can be used to explore the cosmos. Occasionally meteoric material is found, or a rock is brought back from the Moon. Astronomy is a science based on light and, more important, astronomy education is largely based on beautiful images. Teaching astronomy to visually impaired people is therefore a major challenge. How can one explain astronomical insights and concepts and describe the beauty of the universe without relying on pictures?

I welcomed the opportunity to meet this challenge when I was asked to give an introductory astronomy lesson to a group of 12 visually impaired people ranging in age from 16 to 70 years old. The degree of visual impairment ranged from serious to total. All participants had little or no exposure to astronomy concepts, and the class time was limited to two hours. The students were arranged in a U-shape, giving my two assistants the advantage of short distances between the students in the inner part of the U.

The lesson goal that I set for myself, apart from being generally interesting, was to convey an understanding for, or at least an impression of, the vastness of the universe. Standard astronomy courses often begin with the Solar System and end with cosmological concepts; my introductory lesson was

structured along these lines. Many of the concepts described next might be useful for teaching sighted students as well.

## 2. THE EARTH IN THE PALM OF MY HAND

As has often been commented on, the universe is mindbogglingly vast, and to bring the concept into the classroom in its entirety, one must scale it down a bit. To avoid confusing the students with sheer numbers, I had to allow them to grasp it—literally. Visually impaired people often use their sense of touch with a skill that most sighted people lack. I chose to shrink the Earth to the size of a grain of sand.

A scaled model of the Solar System is a typical classroom tool. In a course for visually impaired people, it is important to pick a scale for which representations of various objects can be used that allow a tactile experience. The objects should be common so as to help the students to remember what they have learned and to make it easier to supply them in appropriate quantities. The question of practicability is not to be taken lightly, especially regarding the actual distribution and handling of the objects during the lesson. Assistance is advisable, especially with large classes. The scale must also be chosen carefully in order to convey a surprising and awe-inspiring tactile experience.

Each participant was given a large grain of sand and asked to imagine that it is the Earth. (Such a grain can, with little difficulty, be kept for the entire lesson even if other objects have to be handled to constantly represent a size scale. In cases of difficulties, the assistants and I could assist the participants.) A large grain of sand has a diameter of roughly 2 mm; sand grains range in size from a 16th mm to 2 mm (World Book 2000). The scale for the Earth-as-a-sand-grain model was therefore approximately  $6.378 \cdot 10^{-9}$  or  $1 \text{ mm} = 6,378 \text{ km}$ . The concept of a globe, a circle, and an ellipse was familiar and was used to describe the shapes of the planets and their orbits in the Solar System in general.

Some information was given regarding the specifics of the inner planets, like the temperature on Venus and the duration of a day on Mars. The sizes of the inner planets can be roughly represented by a grain of sand like the Earth, or easily scaled; for example, the Moon could be half a grain of sand. This is not true for the gas giants in the outer system (Table 1). (The distances and sizes of the planets can be found in any standard astronomy textbook; I have referred to Karttunen et al. 1990.)

**Table 1.** Representations of solar objects in the Earth-as-a sand-grain model.

Object	Diameter (km)	Scaled Diameter (mm)	Representation
Earth (inner planets)	12,756	2	grain of sand
Jupiter (gas giants)	142,984	22	large marble
Sun (stars)	1,392,500	218	basketball

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Large marbles (approximately 22 mm in diameter) were then distributed among the participants. They were told only that they would get a model of Jupiter, and only after every student had touched it were they told that it was a marble. This revelation led to some surprise. Because the unexpected is nearly always remembered in a way that the expected is not, adding the element of surprise is useful both in clearly demonstrating the size differences between the outer and inner planets and in helping the students to remember the experience. The students indeed expressed astonishment, particularly when the next object—the Sun, in the form of a basketball—was passed. Some details about the outer planets and the Sun were then discussed. The regular basketball (circumference 787 mm; see <http://www.fiba.com/>) overestimates the size of the Sun by about 10%, but this seems acceptable with regard to the error introduced by irregularities in the diameter of the sand grains. Plus, basketballs can be found in abundance in the local school gym. I generally found relative errors of about 20% acceptable, and most often unavoidable, in the process of producing the models in practice.

The Earth-as-a-grain-of-sand model has the following advantages: (1) sand, marbles, and basketballs can be handled easily; (2) these objects are usually easy to obtain; (3) they are familiar objects, and the exercise can be repeated at home or whenever participants encounter these objects; and (4) it can be rescaled to represent the universe outside the Solar System (discussed next). Although it is a good first approximation to represent the inner planets as sand grains and the outer planets as marbles, one might wish to represent the relative sizes of the planets a bit more accurately—for example, if only the Solar System is the lesson topic. In this case, the relative sizes of the planets could be represented by paper circles. Jupiter can be assigned the size of the largest circle that fits into a standard size piece of paper (A4 or letter size), and the relative sizes of the remaining planets determined accordingly. The Sun would then span the whole of the table, which should be pretty surprising for the students. Because the aim of this lesson was also to discuss the outer universe and time was scarce, this paper model wasn't used.

To give the participants an impression of the appearance of some planets, we referred to the remarkable braille book on astronomy by Noreen Grice (2002; see <http://darwin.nap.edu/books/030908332X/html/>), who has published a number of braille astronomy books. Unfortunately, we had only one copy available, which slowed things down considerably but was worth the time.

### **3. THE SOLAR SYSTEM ON A STRING**

The next step was to experience the size of the Solar System—how basically empty it is—and the increasing distances between the planetary orbits. For this activity, the model had to be rescaled to be practicable. The students were told that their grain of sand, formerly the Earth, would now be equated with the Sun, formerly a basketball; that is, everything to follow would be true if, in their imagination, they could shrink the basketball to the size of a grain of sand. This would in turn shrink the diameter of the Earth to the diameter of a typical droplet in a veil of fog or of a human hair. I felt that it would have been best to avoid a rescaling to prevent confusion, but it turned out not to be a problem. The new Sun scale was  $1.4 \cdot 10^{-12}$ , or  $1 \text{ mm} = 692,250 \text{ km}$  (Table 2).

**Table 2.** Scales of the two models used.

Model	Scale	1 mm=
Earth as a grain of sand	$6.378 \cdot 10^{-9}$	6,378 km
Sun as a grain of sand	$1.4 \cdot 10^{-12}$	696,250 km

The model for the Solar System was a knotted string, with the knots representing the average distances from the Sun (but not the sizes!) of the different planets. The string had a diameter of about 0.5 cm—more a cord than twine—so the knots were comfortably large and there was no danger of the cord snapping. The model was explained to the students, but they were not told how long the cord would be. The order of the planets was explained, as was the phenomenon of the asteroid belt between Mars and Jupiter. The string was then passed along, beginning with the first student in the U. Each student would run his or her fingers along the string, detecting the knots and then passing that section of string along to the next student. For this activity, the U-shaped seating configuration was ideal. I and my assistants told each student the name of the planet that he or she had reached or was "traveling to."

Almost all participants described their experience similarly: Upon detecting Mercury after only just 8 cm, they expected the overall length of the string to be rather short. This expectation was reinforced by Venus, Earth, and Mars, by which time the planets seemed to be roughly equidistant. Jupiter then came as a surprise, and all the planets thereafter seemed unbelievable. The meaning of inner and outer planets became clear (Table 3). (Orbit radii [semimajor axis, to be precise] taken from Karttunen et al. 1990.)

**Table 3.** The string model of the Solar System.

<b>Object</b>	<b>Radius of orbit (<math>10^6</math> km)</b>	<b>Distance of knot (m)</b>
Sun	0	0
Mercury	57.9	0.08
Venus	108.2	0.16
Earth	149.6	0.21
Mars	227.9	0.33
Jupiter	778.4	1.12
Saturn	1425.6	2.05
Uranus	2870	4.12
Neptune	4501	6.46
Pluto	5885	8.45

The overall length of the string seemed long enough to bring about a surprising experience, but was short enough to be handled; for example, in the model with the Earth represented by a grain of sand, the string would have been almost 1 km long. Aside from the first student in the U, the others were limited in the speed with which they could feel along the string by the students before them. This seemed unfortunate; alternatively, the students could have felt the string sequentially by themselves. I decided against that, because it would not have been so much a shared experience. Another alternative is to produce a string for each student, which is a lot of work. The way we did it turned out to work very well; most students stopped for a while when reaching the knots, which seemed to heighten the anticipation of the subsequent participants as they waited for more string. This way, an exact assessment of the planet distances might have been lost, but the general message—that the distances between the planets become larger and that the Solar System is largely empty—was clear.

An alternative for the string model would have been a literal walk in the park. Many walk-through models of the Solar System exist around the world, some many kilometers long. These models have the advantage that one scale can be used for planet distances and sizes. But unless in a city with such a model, they are often impracticable for classroom purposes because of time constraints, weather, or disabilities. In this case, I decided against an outdoor model not only because it would have been a lot of work to build one, but also because the experience of walking through it would have been more time oriented, and thus not experienced directly by the senses but via memory. The string model exercise, even in a group, takes only a few minutes and is a much more direct experience.

## 4. THE UNIVERSE IN A BUCKET

For the next step out into the universe, I explained our concept of the stars as basically being suns like ours, possibly with planets of their own, but much more distant and arranged in the form of galaxies. Noreen Grice's book (2002) was extremely valuable in explaining the shape of a spiral galaxy and some other constituents of galaxies like nebulae and clusters. We discussed the distances of stars and galaxies in the string model and compared them with local distances and the size of the real Earth (Table 4). (Distances were taken from Karttunen et al. 1990 and <http://www.voyager.jpl.nasa.gov>.)

**Table 4.** Distances of objects outside the Solar System on the string model.

Object	Distance from Sun (pc)	Distance on string (km)
Nearest star (Proxima Centauri)	1.31	58
Nearest galaxy (Andromeda)	650,000	28,807
Farthest Space Probe (Voyager 1 - March 2006)	0.00048	0.021

How many stars are there? In the sky? In a galaxy? Overall? To answer these questions, I used very fine sand (grain diameter 16th mm). In practice, one would most likely not be able to measure the grains, but as long as it's not coarse sand, the following examples at least roughly mirror the correct order of dimensions.

A typical galaxy contains about  $10^{11}$  (100 milliard, or 100 billion in the short-scale system used in the United States) stars (ranging from  $10^7$  to  $10^{12}$ ; Karttunen et al. 1990). This is roughly the same number as the number of very fine grains of sand in one bucket. A 20-liter container, which held about 18.79 liters (see appendix) of fine sand representing the stars in a typical galaxy, was passed among the participants. The extra volume allowed participants to delve their hands into the sand without spilling it.

Each grain represents one star in our galaxy, but each one can also be regarded as a representation of one galaxy in the observable universe, the number of which is estimated to be in the order of  $10^{11}$  (Karttunen et al. 1990). The students were asked to imagine, for each grain in the bucket, another bucket completely full of sand. The number of grains of sand in all these buckets combined, about  $10^{21}$  (10 trilliard or 10 sextillion in American nomenclature), would be very roughly 100 times the number of grains of sand on all the beaches on Earth (see <http://www.hawaii.edu/suremath/jsand.html>). This large number represents the number of stars in the visible universe! Students might remember this comparison the next time they have the opportunity to walk barefoot on a beach. The experience was then complemented with a braille image of the Hubble Deep Field from the Grice (2002) book, which emphasized that galaxies come in different forms and sizes.

As an afterthought, I think it would have been better to approach this number slowly. My suggestion is to first hand each student a pinch (a couple dozen grains) of fine sand. The number of grains is roughly the number of stars that the unaided eye can see on a clear city night. Then, give each student a rounded teaspoon of fine sand, which represents the number of stars visible on a clear night in a dark location (about 6,000). This should give an impression of how much of the richness of the night sky is lost in modern cities and, when finally proceeding to the bucket, how much more of the universe can only be observed with the aid of telescopes. In that sense, sighted astronomers don't use their eyes but scientific instruments to observe the universe; without them, everyone is blind to the wonders of the universe.

## 5. CONCLUSIONS

The feedback from the participants was uniformly positive. The comments during and after the lesson indicated that a general sense for the proportions in the universe had been successfully conveyed, and a sense of awe brought about. The lesson concluded with questions from the students, which showed that they understood the concepts and that their imagination had been inspired.

## Acknowledgments

I especially thank the course participants and my assistants. I also thank an anonymous referee for suggesting the paper circle model for the planet sizes. I would like to stress that my expertise lies with astronomy, and my experience with visually impaired people is limited; I therefore welcome corrections to any aspects of this work that may have resulted from my inexperience.

## References

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## APPENDIX

For the calculation of the different volumes of sand, I have assumed the sand grains to be roughly spheroidal in shape and packed in a body-centered cubic lattice that is neither the densest nor the loosest possible packing, and therefore likely a good zeroth approximation for reality. In this arrangement, the sand grains have a volume filling factor of  $(\sqrt{3})/8$ , which is about 68%. Fine grains were assumed to have a diameter of 0.00625 mm and normal grains 1 mm. The volume of 6000 normal sand grains is therefore

$$6000 \cdot (\pi \cdot \sqrt{3})/8 * [4/3 \cdot \pi \cdot (0.001\text{m}/2)^3] = 0.00461 \text{ l} = 4.61 \text{ ml},$$

a normal teaspoon having a volume of 3–5 ml. The volume of 100 milliard grains of fine sand is accordingly

$$10^{11} \cdot (\pi \cdot \sqrt{3})/8 * [4/3 \cdot \pi \cdot (0.0000625\text{m}/2)^3] = 18.791 \approx 1 \text{ bucket.}$$

In the U.S. system, one bucket equals 5 liquid gallons, or about 18.93 liters. In the U.K. imperial system, one bucket is 4 gallons, or about 18.19 liters.

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