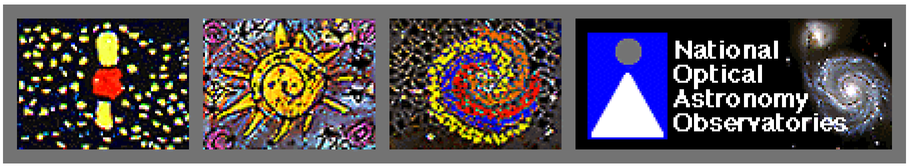

THE THOUSAND-STEP MODEL
or, The Earth as a Peppercorn

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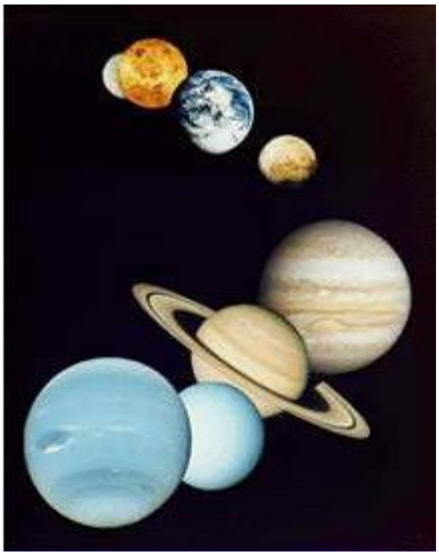
[Converted into metric units by Malcolm Coe]



This is a classic exercise for visualizing just how BIG our Solar System really is. Both the relative size and spacing of the planets are demonstrated in this outdoor exercise, using a mere peppercorn to represent the size of the Earth. Guy Ottewell has kindly given permission for this electronic presentation of The Thousand-Yard Model; his exercise is presented in its original form, indexed with a few anchors to help you find you way around the large file. Image of the planets courtesy of NASA.

Introduction

Can you picture the dimensions of the solar system?

Probably not, for they are of an order so amazing that it is difficult either to realize or to show them.

You may have seen a diagram of the Sun and planets, in a book. Or you may have seen a revolving model of the kind called an orrery (because the first was built for an Earl of Orrery in 1715). But even the largest of such models--such as those that cover the ceilings of the Hayden Planetarium in New York and the Morehead Planetarium at Chapel Hill-are far too small. They omit the three outermost planets, yet still cannot show the remaining ones far enough apart.

The fact is that the planets are mighty small and the distances between them are almost ridiculously large. To make any representation whose scale is true for the planets sizes and distances, we must go outdoors.

The following exercise could be called a Model, a Walk or a Happening. I have done it more than twenty times with groups of varied ages (once we were televised) or with a single friend; and others, such as elementary-school teachers, have carried it out with these instructions. Since it is simple, it may seem suitable for children only. It can, indeed, be done with children down to the age of seven. Yet it can also be done with a class consisting of professors of astronomy. It will not waste their time. They will discover that what they thought they knew, they now apprehend. To take another extreme, the most uncontrollable high-school students or the most blase college students unfailingly switch on their full attention after the first few paces of the excursion.

There is one other party that may profitably take the planet-walk, and that is yourself, alone. Reading the following description is no substitute: you must go out and take the steps and look at the distances, if the awe is to set in.

First, collect the objects you need. They are:
Sun-any ball, diameter 20 cm
Mercury-a pinhead, diameter 0.08 cm
Venus-a peppercorn, diameter 0.2 cm
Earth-a second peppercorn
Mars-a second pinhead
Jupiter-a chestnut or a pecan, diameter 2.2 cm
Saturn-a hazelnut or an acorn, diameter 1.8cm
Uranus-a peanut or coffeebean, diameter 0.8cm
Neptune-a second peanut or coffeebean
Pluto- a third pinhead (or smaller, since Pluto is the smallest planet)

You may suspect it is easier to search out pebbles of the right sizes. But the advantage of distinct objects such as peanuts is that their rough sizes are remembered along with them. It does not matter if the peanut is not exactly 0.8cm long; nor that it is not spherical.

A standard bowling ball happens to be just 20 cm wide, and makes a nice massive Sun, so I couldn't resist putting it in the picture. But it may not be easy to find and certainly isn't easy to carry around. There are plenty of inflatable balls which are near enough in size.

The three pins must be stuck through pieces of card, otherwise their heads will be virtually invisible. If you like, you can fasten the other planets onto labeled cards too.

Begin by spilling the objects out on a table and setting them in a row. Here is the moment to remind everyone of the number of planets -9- and their order--

MVEMJSUNP. (This mvemonic could be made slightly more pronounceable by inserting the asteroids in their place between Mars and Jupiter: MVEMAJSUNP.)

The first astonishment is the contrast between the great round looming Sun and the tiny planets. (And note a proof of the difference between reading and seeing: if it were not for the picture, the figures such as "20 cm" and "0.2 cm" would create little impression.) Look at the second peppercorn--our "huge" Earth--up beside the truly huge curve of the Sun.

Having set out the objects with which the model is to be made, the next thing is to ask: **"How much space do we need to make it?"** Children may think that the table-top will suffice, or a fraction of it, or merely moving the objects apart a little. Adults think in terms of the room or a fraction of the room, or perhaps the corridor outside. To arrive at the answer, we have to introduce scale.

This peppercorn is the Earth we live on.

The Earth is 13,000 km wide! The peppercorn is 0.2 cm wide. What about the Sun? It is 1 million 400 thousand kilometres wide. The ball representing it is 20 cm wide. So, one cm in the model represents a 70 thousand kilometres in reality.

This means that one metre represents 7 million km. Take a pace: this distance across the floor is an enormous space-journey!

Now, what is the distance between the Earth and the Sun? It is 150 million km. In the model, this will be 26 steps.

This still may not mean much till you get one of the class to start at the side of the room and take 26 paces. She comes up against the opposite wall at about 15!

Clearly, it will be necessary to go outside.

Hand the Sun and the planets to members of the class, making sure that each knows the name of the object he or she is carrying, so as to be able to produce it when called upon.

You can make some play with the assigning of the objects to the "gods" who are to be their bearers. Selecting a blond Sun, a hyperactive Mercury, a comely Venus, a redhaired or pugnacious Mars, a ponderous or regal Jupiter, a ring- wearing Saturn a blue-eyed Uranus, a swimming-champion Neptune, a far-out Pluto can enliven the proceedings and teach a few scraps of mytholgy or planetology. It is unfortunate that only Venus and Earth (the Moon) are female (most of the goddesses have given their names to asteroids instead).

SETTING OUT THE SOLAR SYSTEM

You will have found in advance a spot from which you can walk **a 115 steps** (up to and including Jupiter, or 1000 steps if you want to do the whole solar system!) in something like a straight line. This may not be easy. Straightness of the course is not essential; nor do you have to be able to see one end of it from the other. You may have to "fold" it back on itself. It should be a unit that will make a good story afterwards like "All the way from the flagpole to the Japanese garden!"

Start Put the **Sun** ball down, and march away as follows. (After the first few planets, you will want to appoint someone else to do the actual pacing-call this person the "Spacecraft" or "Pacecraft"-so that you are free to talk.)

10 paces. Call out "**Mercury**, where are you?" and have the Mercury-bearer put down his card and pinhead, weighting them with a pebble if necessary.

Another 9 paces. **Venus** puts down her peppercorn.

Another 7 paces. **Earth**

Already the thing seems beyond belief. Mercury is supposed to be so close to the Sun that it is merely a scorched rock, and we never see it except in the Sun's glare at dawn or dusk-yet here it is, utterly lost in space! As for the Earth, who can believe that the Sun could warm us if we are that far from it?

The correctness of the scale can be proved to skeptics (of a certain maturity) on the spot. The apparent size of the Sun ball, 26 paces away, is now the same as that of the real Sun-half a degree or arc, or half the width of your little finger held at arm's length. (If both the size of an object and its distance have been scaled down by the same factor, then the angle it subtends must remain the same.)

Another 14 paces. **Mars**

Now come the gasps, at the first substantially larger leap:

Another 95 paces to **Jupiter**

Here is the "giant planet"-but it is a chestnut, more than a city block from its nearest neighbor in space! From now on, amazement itself cannot keep pace, as the intervals grow extravagantly:

Another 112 paces. **Saturn**
Another 249 paces. **Uranus**
Another 281 paces. **Neptune**
Another 242 paces. **Pluto**

You have marched more than half a mile! (The distance in the model adds up to 1,019 paces – approximately 1 km !)

To do this, to look back toward the Sun ball, which is no longer visible even with binoculars, and to look down at the pinhead Pluto, is to feel the terrifying wonder of space.

That is the outline of the Thousand-Yard Model. But be warned that if you do it once you may be asked to do it again. Children are fascinated by it enough to recount it to other children; they write "stories" which get printed in the school paper; teachers from other schools call you up and ask you to demonstrate it.

So the outline can bear variation and elaboration. There are different things you can remark on during the pacings from one planet to the next, and there are extra pieces of information that can easily be grafted on. These lead forward, in fact, to the wider reaches of the universe, and make the planet walk a convenient introduction to a course in astronomy. But omit them if you are dealing with children young enough to be confused, or if you yourself would prefer to avoid mental vertigo.

I recommend that you stop reading at this point, carry out the walk once, and then read the further notes.

Establishing the scale

While you are talking and introducing the idea of the model, it may be helpful (depending on the age of the audience) to build up on a blackboard something like this:

	REAL	**MODEL**
Earth's width	13,000 km	0.2 cm
Sun's width	1,300,000 km	20 cm
therefore scale is	70,000 km	1 cm
and Sun-Earth distance	150,000,000 km	26 steps

Follow-up

Having come to the end of the walk, you may turn your class around and retrace your steps. Re-counting the numbers gives a second chance to learn them, and looking for the little objects re-emphasizes how lost they are in space.

It works well, in this sense: everyone pays attention to the last few counts-"240...241...242"-wondering whether Neptune will come into view. But it does not work well if the peanut cannot be found, which is all too likely; so you should, if you plan to do this, place the objects on cards, or set markers beside them (large stones, or flags such as the pennants used on bicycles).

Also, the Sun ball perhaps cannot be left by itself at the beginning of the walk-it might be carried off by a covetous person if not by the wind-so send someone back for it when the walk has progressed as far as Mars.

(I once, having no eight-inch ball, made a colored paper icosahedron, and had to give chase for afar when I saw someone appropriating it. On the return from another walk, I met a man holding his mouth while his worried companion said "Did you bite it?"-incredibly, he had picked up one of the peppercorns! The other edible planets are, of course, prey for passers-by. Hazards like these may be regarded as our model's counterparts of such cosmic menaces as supernovae and black holes.)

On each card, the child who recovers it may write briefly the place where it was-"At 5th Street," "At John Cabonie's house"... Then, back in the classroom, the objects as kept in a row on a shelf, as a reminder of the walk. Or they may be hung on strings from a rafter.

Since pecans, pinheads, peanuts, and especially peppercorns cannot always be readily found when another demonstration is called for, I keep at least one hand, in one of the small canisters in which 35-millimeter film is sold.

Looking at the real things

Anyone you take on this planet-walk may finish it with a desire to set eyes on the planets themselves. So it is best to be able to do it at a date when you can say: "Look up there after dark and you will see [Jupiter, for instance]."

For specific times, consult the Astronomical Calendar, the magazines Sky & Telescope or Astronomy, or a local college science department, planetarium, or amateur astronomer.

Orbits

Point out that the nine planets do not stay in a straight line. They stay about the same distances from the Sun, but circle around it (counterclockwise as seen from the north).

They go around at various speeds. The inner planets not only have smaller circles to travel but move faster. Thus, Mercury goes around in about 3 months; the Earth, in a year; and Pluto in about 250 years.

The circling movements mean that the planets spend most of their time much farther apart even than they appear in out straight-line model. The distance between two planets can be up to the sum of their distances from the sun, instead of the difference.

Jupiter and Saturn, for instance, can be as close as 95 paces as in the model, or up to 382 paces apart at times when they are on opposite sides of the orbits. This is the case in the years around 1970,1990, and 2010. (Jupiter overtakes Saturn about every 20th year.) Think of the spacecraft Pioneer 11, which actually covered this immense distance. Launched from Earth in April of 1973, it looped around Jupiter in December 1974, and arched back all the way over the solar system, on its way to visit Saturn also. This journey is so long-the distance back from Jupiter plus the even greater distance out to Saturn-that the spacecraft did not reach Saturn till September 1979. During the Thousand-Yard walk is the dramatic time to tell people about this, and let them reflect on the refinement with which the spacecraft had to be aimed around the south pole of Jupiter in just such a way that it might five years later drop between Saturn (this acorn) and its rings.

The Spacing of the Planets

Schematic pictures often show the planets on parade at about equal distances- much as when you first arrayed them on the table. This, as we have seen is unrealistic: the intervals are very unequal. There are these features to point out:

1. In general, the intervals get strikingly larger as we go outward.
2. But they increase very irregularly. No need to dwell on this unless someone asks, but for instance the first three jumps actually get smaller; after that they increase, but neither in an arithmetical progression (like 1, 2, 3, 4...) nor in a geometrical progression (like 2, 3, 8, 16...). A more complicated regularity has been discerned; it is known as "Bode's law," but is only a rough rule rather than a law. If Mercury is 4 units of distance from the Sun, the Venus is 4+3, the Earth 4+6, Mars 4+12. Then Jupiter is 4+48 and Saturn more roughly 4+96.
3. The most obvious exception to this "law" is the gap between Mars and Jupiter. This was where your class swooned, on hearing that the next distance to be the suddenly larger leap of 95 paces (more than twice as as the total distance walked up till then). This gap marks the boundary between the inner and outer solar systems. The inner solar system contains the four small, hard, "terrestrial" (Earth-like) planet; the outer solar system contains the four large, fluid, "Jovian" (Jupiter-like) planets, with the exception of Pluto. If,instead, there were a planet in the gap, Bode's law would be more regular. Indeed, this is where most of the asteroids are, so they may be fragments of a planet which broke up or which was never able to forms.
4. Mercury is not on ninth but only one hundredth of the way out to Pluto.
5. The Earth is only a little more than one forteith of the way out to Pluto.

6. Where is the half-way point in the journey out to Pluto? Most people would guess Jupiter or Saturn. But the surprising answer is Uranus. (It is 496 steps in our model.)

So, if you need to fold the walk back on itself, because of not having space to walk a thousand yards, Uranus is the point at which to turn.

The Outer Planets

Throughout most of human history, only six planets have been known: Mercury, Venus, Earth, Mars, Jupiter, Saturn. (Most of the time nobody knew what planets are or that the Earth is a planet.) Then, in the last three centuries, three new planets were discovered. Uranus, though theoretically visible to the naked eyer on fine nights if you know just where to look, was not noticed till 1718; Neptune was discovered by careful calculation and search in 1846; and Pluto in a similar way, but not till 1930 after a quarter of a century of meticulous search, for even in large telescopes it is lost among countless thousands of equally faint stars.

And anyone who takes our planet-walk will say: "No wonder!"

Pluto's Oddity

Pluto not only is smaller than the other eight planets, but is smaller than the Moon and half a dozen other satellites of planets. It is, as we have seen, the exception to the rule that the inner planets are small (and rocky) and the outer planets large (and gaseous).

It is also exceptional in its orbit, which somewhat messes up our model.

It is true that Pluto's average distance from the Sun is about 3,666,000,000 miles (1,019 paces in our model). But its orbit, instead of being nearly circular like those of the other planets, is very eccentric or elliptical: part of it is much nearer in toward the Sun and part much farther out. At present Pluto is on the inward part. In fact, it is nearer in than Neptune! This is so from 1979 until 1999, when Pluto will again cross outward over Neptune's orbit.

Thus a true statement is that Pluto is usually the outermost known planet (but for just these ten years out of 250 Neptune is) and that the distance in our model from the Sun to the outermost planet is about a thousand yards on average (but it should really vary from only Neptune's 777 yards in these ten years, to as much as 1,275 yards when Pluto is at the outermost part of it orbit).

The other planets circulate in the same plane as the Earth, at least nearly enough that we can represent this by the plane of the ground. But Pluto's orbit is inclined to this general plane by the fairly large angle of 17 degrees. This means that part of the huge orbit lies far above (north of) ours and part far below. At present Pluto is still well to the north side. So if you want to mention this, you can tell the last planet-carrying child to walk 242 paces and then climb a tree-"just kidding..." (Actually the tree should be 200 yards high! And there are parts of the orbit where Pluto should be up an even higher tree or down a very deep hole in the ground.)

Angular Size

When Mars, moving rapidly along its relatively nearby orbit, passes in front of Jupiter or Saturn, and we look at these planets through a telescope, we are surprised to find that the disk of Mars looks much the smaller. Jupiter looks three times as wide as Mars, though it it eight times farther away!

The planet-walk will have impressed you with the great distance from Mars onward to Jupiter, and thus will give this observation its surprising quality. However, the planet-walk also gives you the means to visualize the reason. The farther away two objects are, the less the distance between them counts, and the more it is a matter of their own actual sizes. Or, put another way, angular size decreases slower and slower with distance.

The Sun Vs. the Planets, and Jupiter Vs. the Rest

When we first laid the row of objects out on the table, there was an extreme contrast between the Sun and the rest. The word "size" is vague, since it could mean width (diameter), volume, or mass (amount of matter). In volume, the Sun is 600 times greater than all the planets put together. As compared with the small but rather dense Earth, the Sun is 109 times greater in width; 1,300,00 times greater in volume; and 330,000 times greater in mass.

Within the planets themselves, there is quite a contrast between Jupiter and the rest. Jupiter contains almost three times as much matter as all the other planets together- even though Saturn comes a good second to it in width.

This is partly because Saturn is the least dense of all the planets (it would float on water, if there was an ocean big enough). But it is also an illust- ration of the difference between the kins of "size." If you multiply a planet's width by, say, 3, you mutltiply its cross-sectional area by 9, and its volume by 27. Thus a relatively small difference between the widths of Saturn and Jupiter means a much larger difference between their capacity. This, too, is easier to understand when you look at the solid objects representing them.

The Moon

The Moon is, on our scale, 6 cm from the Earth.

You can, on reaching the position for the Earth, pause and put down a Moon beside it. This Moon will have to be another pinhead (theoretically between the sizes of Mercury and Pluto).

Look down on this distance, the length of your thumb; the greatest distance that Man has yet leaped from him home planet. Reflect on the manned mission to Mars now being suggested (14 paces in our model) or the trips proposed in science fiction: to Jupiter as in the film 2001 Space Odyssey (109 paces); to the nearest star (approx 6 thousand km in our model); to the Andromeda Galaxy (half a million times farther again).

The Emptiness of Space

The planet walk is an antidote to the "scientific" school of astrologers, who suggest that the planets disturb particles in our bodies. When one can visual- ize how remote these planets are, it is easy to understand that the nearest of them, Venus, when nearest to us, has the same gravitational or tidal effect as a truck 14 miles away, or a high-rise building 300 miles away.

During the walk, the immense distances between the planets and the Sun may make people incredulous that the planets can truly feel the gravitational influence of the Sun at all, let alone be so much in its control that they orbit faith- fully around it forever. After all, if our model is to scale, then this peppercorn, representing the Earth, must experience a similar gravitational pull from that far-off ball, representing the Sun. Does it? It certainly shows no inclination to fall toward the ball, and has no need to stave off such a fall by orbiting around the ball!

The peppercorn does feel the gravitational pull of the ball. The difference is that there is so much other matter in the environment of the model, which is not present in the environment of the things being modelled: the sidewalk, the pillars of the arcade you are walking along, the grass and trees, your feet and above all the air pressing down and the total mass of the Earth underneath. These are all so huge that the attraction of the ball, without becoming any less, becomes by comparison a negligible influence in the distance. If there were, in interplanetary space, any object corresponding to even one of these things - say, a four-million-mile slab of rock, corresponding to the paving-stone on which the peppercorn is lying - then the Sun's influence on the Earth would become negligible. It is only because space is so empty that the Sun is the nearest important gravitational influence on the Earth.

Greater Distances

The solar system does not really end with Pluto. Besides the planets, there is a thin haze of dust (some of it bunched into comets). Any of this dust that is nearer to the Sun than to any other star may be in the gravitational hold of the Sun and so counts as part of the solar system. So the outermost of such dust may be half way to the nearest star.

On the scale of our model, Pluto is a thousand paces or about 1 km out. But this true limit of the solar system on this scale is three thousand kms out.

One and half thousand km in our scale, is the distance called a light-year (in reality, about 10 million million kms).
The distance to the nearest star, Proxima Centauri, is 4.2 such light-years.

The human mind can never conceive this thing called a **light-year**, which is the currency of our small-talk about the universe. (It is probable that we cannot directly conceive any distances above about 600m, which is where we sub-consciously place the horizon). But through the model we move as far toward conceiving it as we ever can.

I, at least, have seemed to have some respect for the term, light-year; and to have some sense of what I mean when I use it-since I made the sensory approach to it through this model.

The rest of the stars in our galaxy are probably on the order of four to ten light-years apart from each other, as we are from our nearest neighbour.

This is a stunning thought when (having done the Thousand-Step exercise) you go out at night and look at the Milky Way. It is a haze of light so delicate that it can no longer be seen from inside our light-ridden cities. It consists of the bulk of the stars in our galaxy, piled up in the distance, so numerous and so faint that we cannot see them separately. Yet they are all the same kind of distance from each other as we are from the nearest of them. That is to say, if we could hop to any one of them, cavernous black space would open out around us,and the Sun itself would become part of that same dense far-off wall of stars, the Milky Way!

Giant stars

Most of the stars that populate space are smaller than the Sun, and certain exotic kinds are smaller than Mercury or the Moon. But others are incredibly larger.

Thus a "giant" star such as Arcturus, about 25 times wider than the Sun, would have to be represented in our model by a ball 5m across. Rigel, a "super- giant" 50 times wider that the Sun, would be a ball 10m across-the size of a whole classroom. If we stood it in place of the Sun, it would reach most of the way out to the first planet, Mercury. Red supergiants are larger still: Antares, 700 times wider that the Sun, would be about 150m across, so that Mercury, Venus, Earth, and Mars would be orbiting deep inside it! Betelgeuse is thought to vary from about 550 to 1000 times the width of the Sun, so that if substituted for the Sun it would be a colossal ball of 200m with Jupiter barely clearing its surface. (One more, the dark companion of the star Epsilon Aurigae, used to be regarded as the largest star known, 2800 times wider than the Sun-large enough to swallow the solar system to well beyond Saturn. But it is more likely some kind of cloud.)

Yet these monsters, like all stars, are so far away that they appear to us as points with no width at all.

(The Sun itself, in its "red giant" phase, will swell up like this and put an end to us-about 4,000,000,000 years from now.)

If you mention these facts during the walk, you are likely to stir up curiosity as to where these humongous stars can be seen. The Astronomical Calendar will show where, and also whether they can be seen at all at the necessary season. Epsilon Aurigae is almost circupolar, so it is visible at all seasons. It is the top of the little triangle of stars just down-right from Capella. Here again is an example of how much better it is to have done the Thousand-Yard Walk before anything else. I have often, while showing people the sky, drawn their attention to Epsilon Aurigae and told them they might be looking at the largest star; it has a certain interest, of course, but it has no such impact as when they have previously seen, the Sun Ball and the 247 paces to Saturn.

Globular Clusters

Globular clusters are awesome balls of up to a million stars, in a space perhaps 150 light-years across. In photographs such a cluster looks like a swarm of luminous bees, ever thicker toward the core, which appears a solid unresolved white. It seems as if the stars must be almost touching and the space among them must be white hot, burning with light. And in fact these stars are 25,000 times more densely packed than normal. Yet this means that they still average about a tenth of a light-year apart-in our model a mere hundred miles from each other instead of four thousand.

Even these densest aggregates of stars are mostly empty space.

Planetary Model of the Atom

Since the discoveries of Rutherford and Bohr about 1911, we have thought of the atom by means of the "planetary model"; a "Sun" (the nucleus) orbited by smaller "planets" (electrons). But there are great differences.

Leaving aside the entirely distinct natures of the bodies and the orbits, there is a difference in relative sizes: the spaces within the atom are even larger a hundred times larger-than the spaces within the solar system!

The distance from the Sun out to Mercury is about 45 Sun-widths. But the distance from the nucleus out to the nearest electron-orbit it on the order of 5,000 nucleus-widths. (There are nuclei of various sizes.) So, if our model were to represent the atom instead of the solar system, the "Sun" (nucleus) would have to be a ball 100 times smaller (the size of a peppercorn) and the "planets" (electrons) far too small to be visible; either that, or we would have to spread the objects 100 times farther apart.

Truly, the universe is mostly empty space, with very rarely encountered stars and planets. Yet even the matter of which those stars and planets-and people- are made is far emptier space, with far more rarely encountered particles.

Lesson One - How to Begin an Astronomy Course

What do you begin an astronomy course with? A first taste of the constellations? Celestial co-ordinates? Physics? History? I have found that the point never fails to come, either in these lessons or in later ones, where I am glad I can say (or wish I could say): "You remember how in the planet-walk we saw that..."

I conclude that this should be the first lesson, the aperitif, or at most the second. Tell the students: "Astronomy is an outdoor subject, and even though it's now daytine" (or, "is cloudy") "we're going right outside for our first exercise!" It will wake them up, make them think you are a lively teacher, leave them with a sense of expecting future lessons to be fun too (so that- don't be alarmed!-they will actually classify the rest of the course as fun even if some of it isn't).

Other models

Since devising the thousand-yard model, I have learned of similar ones by other people. The idea, after all, is obvious; what is crucial to its workability is the choice of scale.

Sir John Herschel, a wonderful scientist and son of Sir Williiam Herchel who discovered Uranus, proposed in his book Outlines of Astronomy (1849) a model of the solar system using peas, oranges, plums and the like. The scale he chose was too large, so that from the Sun to Pluto would have been 3 miles.

In the World Book is depicted another model, with the Sun reduced to the size of a quarter, so that the solar system fits within a baseball stadium. Here the scale is too small: the lesser planets would be almost invisible, and could not be represented by objects more memorable than variously sized grains of sand.

At least one modern education film shows a teacher making a model, with a weather-balloon as the Sun and steel globes of various sizes as the planets. Here again the objects are not memorable and the scale is too large. The Sun and Earth have to be at opposite ends of a football-field; after that the making of the model ends, and we are told that Jupiter would be 4 more football-fields away, etc.

Any model whose scale is much larger than that of the Thousand-Step Model (such as Herschel's and the film's) results in distances of 2 km or more, which people cannot be asked to walk during a lesson. Any model whose scale is smaller (such as those of orreries, ceiling models, the World Book, and all pictures) results in planets too small to see (unless the scale is falsified).

In both cases, therefore, the model remains something to be contemplated only in the head. And it is the real doing and seeing that are indispensable to the effect.

Head and pupil

If, instead of taking people for a walk, you are merely talking to them, it can be useful to say that if the Sun is shrunk to the size of your head, then the Earth will be the size of the pupil of your eye. These have about the same width as the 20cm ball and the peppercorn.

Light-time

Light travels 300,000 kilometres per second. It could travel, for instance, 7 1/2 times around the Earth in one second. A "light-year" is the distance light travels in a year, and similarly we can call the distance light travels in a second a "light second," etc.

Moon to Earth	1.28 light-seconds
Sun to Earth	8.3 light-minutes
Sun to Jupiter	43.27 light-minutes
Sun to Pluto	5 1/2 light-hours
Sun to Proxima Centauri	4.22 light-years

Daniel Washburn, working with the NOAO Educational Outreach Office and supported by NASA through the Arizona Space Grant Consortium, contributed greatly to this World Wide Web presentation of the ***Thousand Yard Model***. It was converted to metric by Malcolm Coe.

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Artwork by students of the Satori School, Tucson, Arizona