A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION

Astronomy Education Review

Volume 5
Issue 2

The Human Orrery: A New Educational Tool for Astronomy

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Received: 10/03/06, Revised: 01/07/07, Posted: 03/15/07

The Astronomy Education Review, Issue 2, Volume 5, 2006-2007

Abstract

The Human Orrery is an innovative outdoor exhibit in the grounds of the Armagh Observatory in Northern Ireland. Stainless steel disks mark the orbits of the classical planets, two comets, and the dwarf planet Ceres with a high level of precision. The idea is to provide a large-scale interactive educational facility to promote greater public understanding of astronomy, mathematics, and space science. In the Human Orrery, people play the part of planets moving in their orbits. Thus, visitors can learn, through active involvement, about the motions of the planets and the position of the Earth and the Solar System in space.

1. ASTROPARKS AND ORRERIES

1.1 The Armagh Astropark

A few years ago, the first two authors were attending a conference at the Dynic Astronomical Observatory in Japan. Walking through the Dynic Astropark each day, we were greeted by a large grinning dinosaur and passed a model (Figure 1) designed to explain the planetary orbits to the interested public. The scale was such that the orbits were a convenient size for visitors to walk around, and colored markers along the orbit of each planet gave a rough idea of Kepler's third law, showing that planets closer to the Sun have faster orbital speeds and much shorter orbital periods.

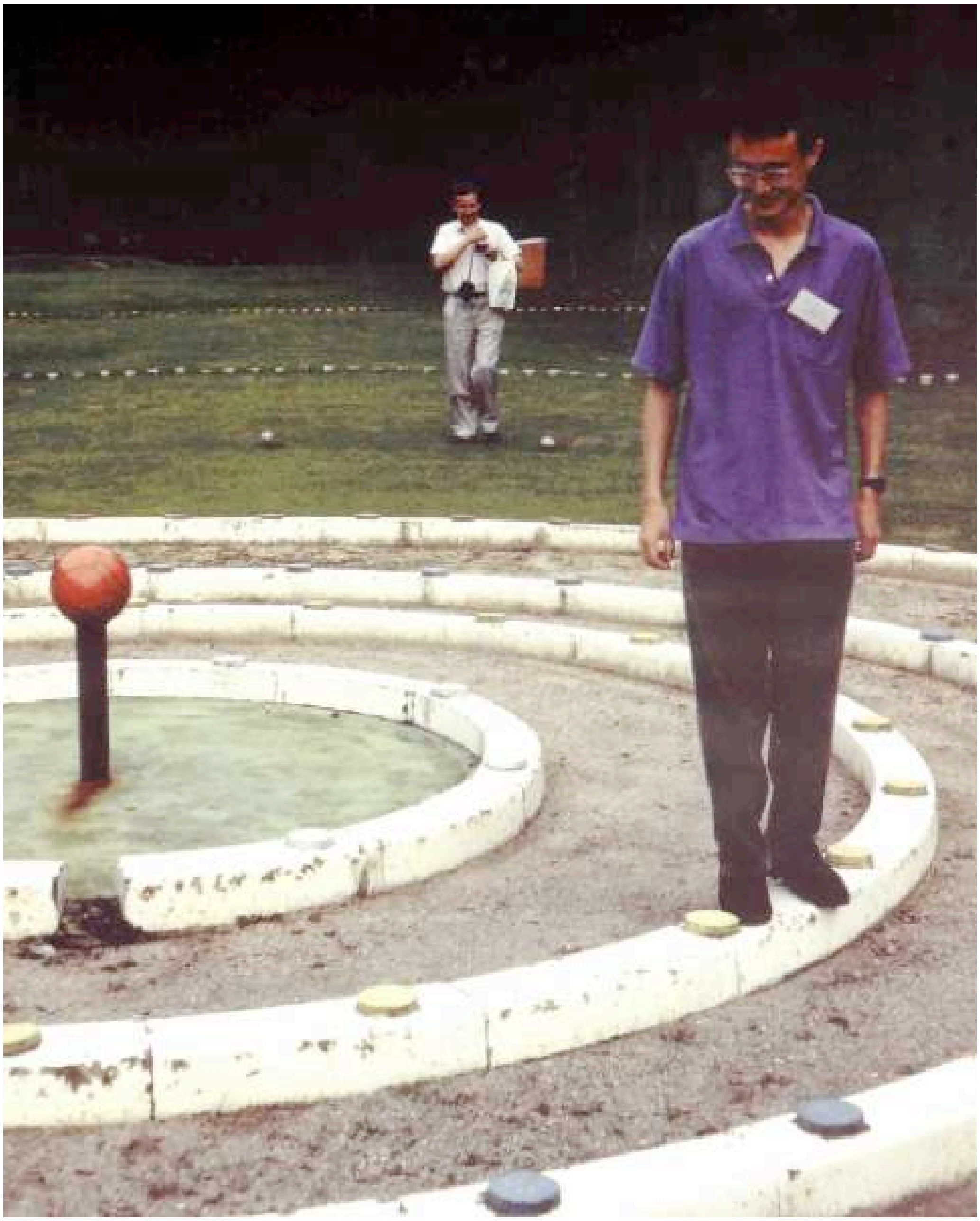

Figure 1. Armagh Observatory astronomers Bill Napier and David Asher try out the model of the planetary orbits in the Dynic Astropark, Japan.

Our own institute, the Armagh Observatory, is similarly located in the midst of attractive landscaped grounds known as the Armagh Astropark. The Astropark was created by astronomers John Butler and Mart de Groot in the 1990s, and a gentle stroll around the park takes the visitor past the Sun and inner planets, through the outer Solar System and beyond, and eventually to the edge of the observable universe and the Big Bang.

The Armagh Astropark has many interesting features. For example, when standing near the Sun or Earth, you see a string of stainless steel spheres with sizes proportional to those of the real planets. These represent the "classical" planets out to the distance of Saturn (i.e., the "naked-eye" planets known since antiquity; see Figure 2). However, to see beyond this region—for example, to view Uranus and Neptune—you have to cross a ridge known as the "telescope horizon." This separates the outer Solar System from the inner part recognized before the invention of the telescope.

Figure 2. The start of the Astropark (see http://star.arm.ac.uk/astropark), showing the Sun and six classical planets. The steel spheres representing Jupiter and Saturn are large enough to be seen in this picture. This exhibit was designed a decade before the Human Orrery.

The scale of the Astropark is such that every three paces on the ground corresponds to approximately 100 million kilometers. On this scale, the planets would be too small to see, so the stainless steel planet models and the large arch representing the Sun have been made 200 times larger than their scale sizes to be easily seen. Beyond Neptune and Pluto, the scale of the Astropark model changes from simply linear to exponential, so that every successive 10 paces corresponds to a factor of 10 farther in distance, rather than just another 10 units. This allows the Armagh Astropark to encompass the whole visible universe.

1.2 The Human Orrery

Some years later, in 2002, work began on the restoring three of the observatory's 19th-century telescopes. Demolition of an obsolete telescope dome and installation of a new one created an empty space well over 20 meters across, close to the historic main observatory building. Inspired by the examples of the Dynic and Armagh Astroparks, we considered the idea of constructing a "human orrery": an outdoor exhibit that would accurately illustrate the motions and positions of the planets in space and how the position of the Earth relates to other visible objects in the sky.

Many people's learning, even our own, is significantly enhanced by doing—that is, by active participation rather than by being a passive recipient of information from a teacher or lecturer—and there are many novel ways to encourage such participation in the learning process (e.g., Francis 2006). How, we asked, might we use this to help explain celestial mechanics and the geometry of the planetary system?

Taking a leaf from the observatory's archives, we considered the mechanical device known as an orrery. This was first introduced around the beginning of the 18th century to explain in a simple and entertaining way what then was a relatively new idea: namely, the heliocentric theory of the Solar System. More about the invention of the first orrery by the English instrument maker George Graham and how it subsequently became a hugely successful educational tool, acquiring the name "orrery" after Charles Boyle, the fourth Earl of Orrery, can be found in the articles by Bailey, Asher, and Christou (2005), Bailey (2006), and Beech (2007). Briefly, orreries are designed to be *dynamic* models of the Solar System, showing the correct relative periods of revolution of the planets (and some moons as well) and sometimes their relative sizes and relative distances from one another. The Armagh Observatory has a fine example of an early orrery, one made by Gilkerson (Figure 3).

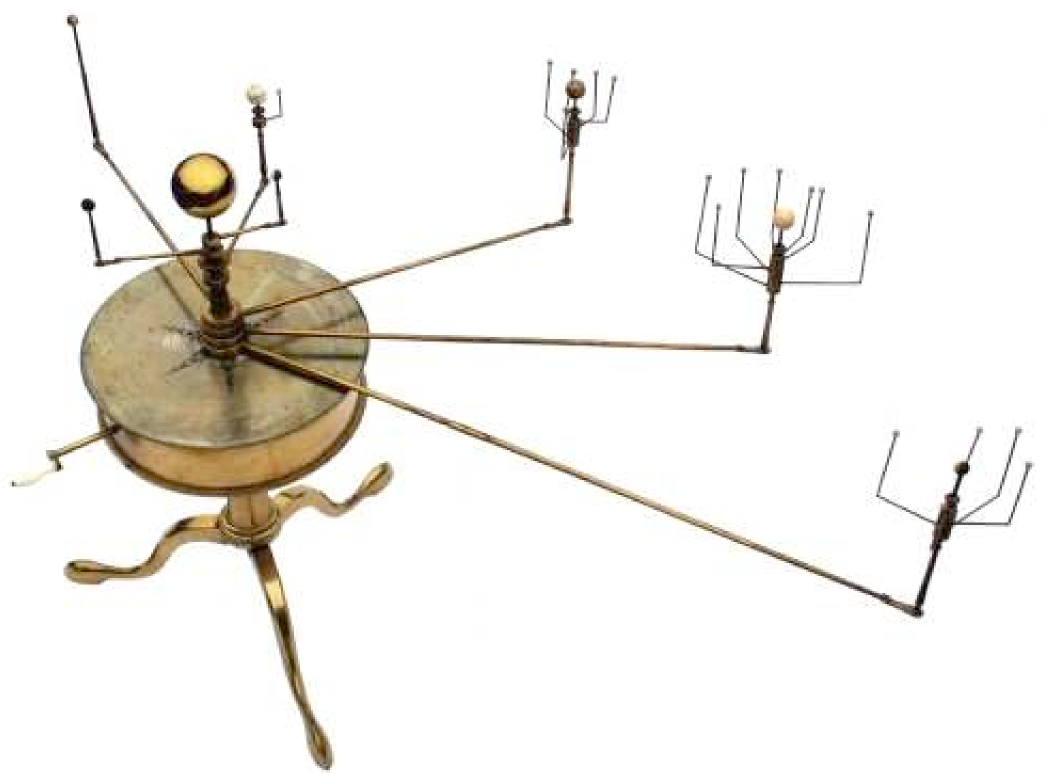

Figure 3. A brass orrery constructed around 1810 by Gilkerson and Co., Tower Hill, London, now in the archives of the Armagh Observatory.

Seeing an orrery in operation can help immensely in the visualization of the Solar System, perhaps even more so than the computer graphics that have been introduced in recent years. Orreries help people to understand how the planets move, and reinforce that the Earth, as well as other planets, orbits the Sun. The Human Orrery has the same advantages but increases users' involvement to a level where they actually become part of the model.

Indeed, various Solar System models have been devised around the world that are excellent for illustrating to the public the vast distances of interplanetary space. These range in scale from the 1 to 10 billion of the Voyage model on the National Mall in Washington, D.C. (Goldstein 2002; see also http://www.voyagesolarsystem.org/) to the 1-to-15-million scale of the SpacedOut project (http://www.spacedout-uk.com/) centered at Jodrell Bank. Demonstrating the motions of planets presents a further substantial challenge but is achievable, and such ideas, including activities to involve teams of students, are described by Gould (2005). Kinesthetic astronomy, in which participants move in ways that enable them to appreciate concepts including time, seasons, and motions of astronomical objects, has also been proved a highly effective learning method (Morrow 2006; see also http://www.spacescience.org/education/extra/kinesthetic_astronomy/).

In the Armagh Human Orrery, perhaps because of our background in Solar System dynamics, we wondered what level of accuracy could be achieved. Would it be possible to go further than the model that had originally inspired the idea and illustrate the clearly elliptical, not circular, planetary orbits? And after displaying the orbits on the ground, how accurately could planetary motion be demonstrated? Would it be good enough to explain all three of Kepler's laws with precision? Would it be possible to include dates in the exhibit, such that at any given time, the model would accurately show the relative positions of the planets and whether they were visible from Earth? Could the Armagh Human Orrery, like the Astropark, also show features beyond the planetary system—for example, the 13 ecliptic constellations and the directions to various astronomical objects: a selection of stars, galaxies, and other bodies that happen to lie close to the ecliptic?

In the remainder of this article, we describe some of the considerations that arose when we had to design the Human Orrery in detail. We also describe our use of the exhibit to explain astronomy at different levels, and our experience of how the model has successfully encouraged visiting groups to learn more about the position of the Earth in space. The final section briefly summarizes some ideas for adapting the concept of the human orrery if it is built in a different environment. More information on the Armagh Observatory Human Orrery is available from http://star.arm.ac.uk/orrery/.

2. DESIGN

The scale of the Human Orrery is 1 meter to 1 astronomical unit, or approximately 1 to 150 billion. This allows just enough space for people to move around the orbits of the inner planets—Mercury, Venus, and Earth—without bumping into each other, and the available space allowed all the planetary orbits out to Saturn to be included. The model thus shows all the classical planets—that is, those bright enough to be visible with the naked eye and that have been known since antiquity.

2.1 Timestep

One of the strengths of the Human Orrery is its ability to demonstrate the motion of the planets about the Sun at their correct relative speeds. This is achieved by marking each orbit with tiles—we used stainless steel disks—spaced at suitable intervals. If the distance between successive tiles on the ground corresponds to the same fixed timestep for all the planets, then the relative speeds are correct when people (one playing the part of each planet) move from one tile to the next in lockstep. This is known as "walking the orrery." Choosing the length of the fixed timestep in proportion to the scale of the model (for example, one should be able to move comfortably from one tile to the next for even the fastest moving objects) is at the heart of the Human Orrery design.

Mercury takes almost exactly 88 days to orbit the Sun. The timestep should evidently be a whole number of days, because an interval of, say, 8.8 days, providing Mercury with exactly 10 tiles, would be impossibly confusing when trying to explain the orrery or to find the planetary positions at any given calendar date. Similarly, an interval as long as 22 days can be ruled out, because Mercury would then have only four tiles, too few to indicate the shape of an ellipse. An eight-day timestep would be better from this point of view, but the tiles would then be too close together for the other terrestrial planets, which need a shorter spacing on the ground because they move more slowly in space. Of course, one could then reduce the size of the tiles, but their information content would be similarly reduced.

The choice of an 11-day timestep, as used in the Dynic Astropark, leads to a different problem. Whereas the position of Mercury is well modeled, the motion of some other planets is rather poorly defined. For example, the orbital period of Venus is about 224.7 days, but would it have 20 tiles (220 days) or 21 (231 days)? Either way, an error of five or six days would accumulate after only one revolution. This is unacceptably large if we are seeking to explain planetary alignments and the visibility of these fast-moving planets, or the occasional transits of Mercury and Venus in front of the Sun.

Planets do not obligingly choose their orbital periods to aid the design of orreries, and it turns out that there is no single timestep that is simultaneously ideal for all planets. Our solution, which best illustrates the shape of Mercury's orbit and avoids any planet having a rapid build-up of errors, is to adopt a 16-day timestep. Mercury then has 11 tiles, and individuals representing this planet return to their starting point after two complete orbits (the tiles for the second revolution being interleaved with those of the first). With every other planet, you return to your start tile after one revolution and continue from there. With this optimal solution—at least for timesteps that are a whole number of days—Venus, Earth, and Mars have, respectively, 14, 23, and 43 tiles.

Jupiter and Saturn would need hundreds of such tiles at 16-day intervals, and so only every 10th tile is included for these slow-moving planets. Jupiter thus has 27 tiles on the ground at 160-day intervals, labeled 0, 10, 20, and so on, up to 260, while Saturn has 67 tiles labeled 0 to 660. The main asteroid belt is represented by its first and largest member, the "dwarf planet" (1) Ceres, with every fifth tile appearing (21 tiles at 80-day timesteps labeled 0 to 100). History's most famous comet, 1P/Halley, and the comet with the shortest known orbital period, 2P/Encke, also appear on the orrery; both have every fifth tile included. It is convenient that the more distant parts of Halley's orbit lie outside the available area, and so only the part within Saturn's orbit needs to be shown. Halley is also unique in being the only retrograde object shown, orbiting clockwise as seen on the ground.

Even with the optimum 16-day time interval, errors eventually build up. This happens soonest with the Earth. If you repeatedly go around its orbit, always stepping back to tile 0 whenever you have reached the final tile (numbered 22), you are a whole step behind where you should be (based on the Earth's real motion) after about six revolutions. If at this time you take an extra step (a "leap step," by analogy with leap days in the calendar) while those marching around the other planetary orbits do nothing, you will be back at the correct tile number for the date. Some objects eventually require a "leap stop," requiring the planet to stand still for one timestep while everyone else continues to move forward. Double leap steps or double leap stops can also be introduced for the purist, in exact analogy with the Gregorian reform of the Julian calendar, but the reality is that few people have the patience to count planetary timesteps forward (or backward) for the requisite number of years. The relative positions for the planets at times far removed from the present are simply accomplished by calculation or by using a lookup table to give the planetary tile numbers for a range of convenient or interesting dates.

2.2 Constellations

An important objective for many astronomy educators is to convey a clear distinction between the modern ecliptic constellations (those through which the Sun passes in the course of a year) and the astrological signs of the zodiac (e.g., LoPresto 2003). Many members of the public are much more familiar with astrology than astronomy, and so a discussion of the former is often a useful entry to the latter. To facilitate this activity, the area beyond Saturn's elliptical orbit is surrounded by a circular ring showing the directions to each of the 13 ecliptic constellations and their corresponding ranges of ecliptic longitude.

In astronomy, the constellations are two-dimensional regions on the celestial sphere, so to decide which points should be considered as the boundaries of the ecliptic constellations, we defined the plane of the Human Orrery to be the ecliptic for the epoch J2000 (i.e., January 1, 2000). We then calculated the sequence of points for which the ecliptic crosses each of the constellation boundaries, giving a range of longitudes for each of the 13 ecliptic constellations.

According to this definition, the largest constellation (i.e., the one with the largest range of ecliptic longitude) is Virgo, at 44 degrees, whereas Scorpius (not Scorpio!) is the smallest, at only 7 degrees. Ophiuchus, the one that is not a traditional member of the zodiac, has a length of 19 degrees. With this information, users can work out how long the Sun spends in each of the modern constellations, and perhaps puzzle over why the Sun is in a different constellation on their birthdate compared with their familiar astrological sign. In the Armagh Human Orrery, the 13 ecliptic constellations are marked near their midpoints by a set of vertical posts that can be seen from anywhere on the Orrery's flat surface (Figure 4).

Figure 4. View of the Human Orrery showing some of the posts marking the positions of the 13 ecliptic constellations.

2.3 Construction

The Human Orrery covers a circular area approximately 25 meters across. The base is compacted hardcore covered with bit-mac (a form of asphalt). Holes were drilled at the required tile locations to a precision better than 1 cm. The tiles consist of two circular stainless steel plates, each 3 mm thick, welded together. The backplate holds a fixing that allows the tile to be installed in the appropriate drilled hole. The upper plate provides information cut with a high-pressure water jet—for example, the coordinates of the tile and the name of the planet, comet, or asteroid whose location it represents (Figure 5). In addition to the orbital tiles, this Figure 5 also shows the Sun tile at the very center of the orrery. The diameters of the tiles are 32 cm for the Sun and the gas giants Jupiter and Saturn, and 16 cm for the other objects (Figure 6).

Figure 5. The center of the Human Orrery, showing the Sun tile and the three inner planets. Each planetary tile shows the planet's astronomical symbol and name; the tile number, indicating the number of 16-day timesteps from 2005 January 1; the planet's ecliptic longitude, ***L***; its heliocentric distance, ***r*** (in astronomical units); and the true anomaly, ***f***. The Sun tile shows the direction of the First Point of Aries and, in relation to a schematic elliptical orbit, the quantities ***L***, ***r***, and ***f*** from the orbital tiles. The small yellow disk is 0.93 cm across, the Sun's true size on the scale of the orrery.

Figure 6. A pile of planets: planetary tiles awaiting inclusion in the Human Orrery, July 2004.

In addition to identifying the constellation names, the constellation ring provides a "clock" scale of ecliptic longitude (though the numbers increase counterclockwise). A short distance beyond this, in a second, slightly larger annulus, are the names and directions of various astronomical objects in each of the 13 ecliptic constellations. The selection of objects is deliberately diverse, providing an opportunity to introduce many different aspects of astronomy: extrasolar planetary systems, X-ray binaries, star clusters, galaxies, and quasars, to name just a few.

The two outer rings, both made of stainless steel, are constructed in the same way as the orbital tiles. They comprise two nearly identical segments welded together, the upper one inscribed with information using a high-pressure water jet. The segments are each several meters long and 20 cm wide, with boundaries chosen to match the ecliptic constellations. The gaps between each ring segment were chosen for aesthetic reasons, and to satisfy the practical requirements of allowing space for expansion in hot weather and the need for the all the steel to be cut from standard-sized stainless steel sheets.

The space not occupied by steel is filled with resin-bonded gravel. The gravel comes in two colors, a fairly neutral beige for the main part of the orrery just over 20 meters across, and a reddish color for the path between the constellation ring and the outer ring that contains pointers to distant objects. This all provides a firm, slightly permeable nonslip surface suitable for "walking" the orrery. The orrery is completed by the 13 suitably placed stainless steel posts depicting each constellation.

2.4 Calendar Dates

Although some activities, such as walking the orrery, require no knowledge of the precise positions of the planets at a given instant, others, such as working out planetary alignments or whether a given planet is visible tonight or at any other time, require information about time. This is one of the key educational strengths of the Human Orrery: it was designed to show where the planets are at any given date. We chose January 1, 2005, as the Human Orrery start date because it is very close to 300 years after the invention of the first orrery by George Graham.

The start date is chosen as the date of the zero tile for each planet and for the dwarf planet Ceres. Subsequent tiles are labeled at 16-day timesteps to show the date when the object in question is at the corresponding position. The cometary zero tiles were chosen for the most recent perihelion passage of each comet: February 9, 1986, for 1P/Halley, and December 30, 2003, for 2P/Encke. In the case of Halley's comet, the tiles are spaced symmetrically about perihelion. Dates increase from 1986 along the outward leg of the orbit and leading up to the next perihelion passage, July 29, 2061, at the end of the inward leg. The outer annulus indicates the directions of the planets Uranus and Neptune at January 1, 2005, and those of Pluto and a representative distant trans-Neptunian object, namely (90377) Sedna. However, Sedna, like the dwarf planet Pluto, often strays significantly above and below the ecliptic.

For dates within the range shown on the tiles (i.e., roughly within the orbital period of Saturn), finding the planets is easy. But the Human Orrery must work for more dates than this. Are there simple ways that users might be able to locate the positions of the planets on any given date—for example, the day when they were born or some interesting date in history? This was one of the main points requiring thought, not so much to construct the orrery, but, after it was built, to make use of it as an astronomy education tool. A lookup table covering several decades at 16-day intervals would, of course, provide the answer, but it would need a prohibitively large number of pages.

It turns out that the Earth is the key. This is because, to a very good approximation, it returns to the same position at the same calendar day in any year. We assume here that the desired date is close enough to the present day that precession of the equinoxes can be neglected.

Consider a lookup table whose only entries are for January 1 of each year—that is, providing the tile number for each planet on that date. Because the Earth is always at tile 0 on January 1 and because each tile is labeled with the tile number and date, it is obvious how many steps the Earth moves between January 1 and the desired date. But all planets have the same timestep. So, whichever planet you are, you move to the January 1 tile (given by the lookup table) for the year in question and then progress through the year to the date in question by counting forward the correct number of steps. Basically, anyone who can "walk the orrery" in step with the Earth will finish on the right tile.

An information panel has been designed that provides a lookup table of planetary tile numbers. Moreover, because the tile numbers have been derived from an accurate planetary ephemeris, the error accumulation eventually necessitating leap steps or leap stops is avoided. It is worth noting that the artistically designed background to the panel (Figure 7) shows real images of the Sun, the Solar System's eight planets, asteroids, and the orrery's two comets. This too helps the general public to visualize the objects on the Human Orrery, because any object other than the Sun would be too small to be seen on the scale of the Human Orrery. A companion panel provides further general information about the orrery.

Figure 7. Artistically designed background to the Human Orrery information panels, showing up-to-date images of many of the objects referred to in the exhibit.

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3. LEARNING

The Human Orrery was originally conceived as an exhibit that would introduce some mathematical concepts and explain astronomy and space science to users at a range of different levels. However, it can also be used in many other ways; for example, young users can even "run" the orrery rather than merely walk it, or use the available space to perform a choreographed "dance of the planets" (Figure 8).

Figure 8. Children from the Armstrong Primary School, Armagh, at the launch of the Human Orrery on November 26, 2004. The innovative "Dance of the Planets"' was choreographed by dance teacher Jennifer Rooney.

For members of the public who begin by knowing very little about astronomy and space, the Human Orrery clarifies the distinction between the heliocentric model of the Solar System and our more familiar geocentric view of the sky. It shows, for example, why you sometimes see a given planet to the left and sometimes to the right of the Sun, making it respectively an evening or morning "star" (as viewed in the northern hemisphere). You can also stand on the "Earth" and look toward the Sun tile, or you can have the "Sun" behind you, to your left, or to your right to represent different times of day or night. And asking people to work things out for themselves (for example, "Can you see Jupiter this evening?") is an excellent way to avoid the problem that people's attention can wander if they are spoken to for too long.

Although the Human Orrery can be effectively explained to individuals (for example, "You stand where the Earth is; I'll be Saturn; what time of night can you see Saturn?"), one of its attractions is its ability to involve groups of several people—for example, one person playing the role of each planet (and perhaps Ceres and the comets too). Such a group can either walk the orrery or stand still to illustrate, for example, what is visible at night.

Planetary alignments are also an interesting phenomenon perfectly suited to a demonstration on the Human Orrery. One of our most successful activities is to get people to step through the planetary positions from 7 BC April to December, to explain the famous triple-conjunction theory of the Star of Bethlehem. Another activity for small groups is to measure the distance on the ground between two planets at a given time and calculate how many million miles it is in reality, one person at each end of a tape measure. Others can compute, also by measurements on the ground, the speeds of the different planets at various points in their orbits.

Users who are academically more advanced, such as those studying mathematics up to school-leaving age, can use the Human Orrery as a tool for quantitative investigation of Kepler's laws, particularly because the layout is accurate enough to illustrate various mathematical properties of ellipses. Students at such a level can involve themselves in calculations of leap steps and leap stops. They can discover the analogy with the calendar and how double leap steps (needed after a large number of revolutions when even the inclusion of leap steps eventually fails to keep in time with the real motion) provide an analogy with the conversion from the Julian calendar to the modern Gregorian one. These activities provide important links with mathematics (for example, modular or "clock" arithmetic and calculus) and also with history and the social sciences.

The comets are an especially interesting case. The eccentric orbit of Encke's comet is ideally suited for investigations of Kepler's second law of equal areas (even for the more advanced exercise of determining the area of a sector of an ellipse), and the position where its path crosses that of the Earth can be used to introduce the subject of meteor showers: when they occur and why some occur at night and others during the day. A "crocodile" of people marching round Encke's orbit readily shows the periodic bunching and dispersal of the co-orbiting dust particles near aphelion and perihelion, respectively.

Many of the groups visiting the orrery have been able to try a human orrery quiz. There is indeed an almost endless variety of quizzes; for example, questions such as "Where are the planets tonight?" can be specific to the date of the visit. Some of the quizzes have been compiled as work experience projects by high school students spending a week at the observatory under our supervision. It is notable that developing a quiz in this way can teach the author of the quiz just as much as the people who will attempt it later. The resources associated with the Human Orrery teach people not just about the Solar System and the motions of planets, asteroids, and comets, but also about the various distant objects identified in the orrery's outer ring, and about the history of orreries (of the traditional as opposed to human variety) and some of the personalities involved in their invention and development 300 years ago.

A simple question in some of the quizzes is the instruction to count the tiles on the ground. This apparently straightforward exercise has led to a surprisingly wide range of different answers and to the correct answer in only a small fraction of cases. It seems that many people have lost the facility to count! At any rate, it provides another useful learning exercise and encourages people to explore the whole area. Assessing the range of answers, even for a single group, gives an additional route into statistics.

In addition to visits by members of the public (Figure 9), we have had many larger groups make organized visits to the Human Orrery, ranging from schoolchildren (Figure 10) to lifelong-learning evening classes and amateur astronomy clubs. More than 20,000 visitors enjoy the Armagh Observatory Grounds and Astropark each year. To date, the Human Orrery has fulfilled our hope that engaging people in interactive demonstrations—indeed, making them part of the explanations—inspires them to think about astronomy and the Earth's place in space.

Figure 9. Child absorbed by the Human Orrery, August 2006.

Figure 10. Seven children take the parts of the Sun and classical planets, July 2006.

4. VARIATIONS

The Human Orrery is an immensely adaptable tool for teaching astronomy, mathematics, and space science, lending itself to many variations as to how it might be designed and built. The general idea is as versatile as a sundial. The available space will determine the scale of the model, and the available resources will constrain the materials to be used (at Armagh, the stainless steel and associated ground works were a major component of the overall cost). Although we found that the basic timestep of 16 days is a good choice, leading to enough tiles to make the model interesting but not so many as to be unmanageable, the start date does not need to be January 1, 2005, as in the Armagh version. Given a suitable start date, the planetary coordinates for all orbital tiles can be obtained from an appropriate data source, and this can become a project in its own right.

Laying out the tiles—they need not be physical tiles; for example, the correct coordinates could simply be painted on the ground—requires only a measuring tape and a way to measure angles. How complex the installation is depends on the materials being used. The Armagh Observatory version is a high-quality, long-lasting exhibit that reflects its location close to the architecturally significant Georgian Observatory building, so its fabrication was a major part of the project. However, the same educational value can be obtained with much less elaborate versions. Something less elaborate could even be temporary, with tile positions marked by inserting pegs in the ground. The idea here is that the process of building the model (i.e., finding the correct points to locate such pegs) could be a major part of the learning exercise. Alternatively, one could use the property of ellipses—that the sum of the distances from the two foci is constant—and thus trace out an orbit by looping a string or rope around the two pegs located at the Sun and the empty focus of a given ellipse. This concept is sometimes demonstrated with string, pencil, and paper in the context of ellipses, though not generally in the context of orbital motion. A portable human orrery kit could be built that would contain pegs and strings of suitable lengths, and a predrilled template for the respective foci and orientation of each elliptical planetary orbit.

Figure 11. Laying out the Armagh Human Orrery.

The simplest way to construct a human orrery is to use string, a protractor, and paint, and locate the planetary positions on a firm, level surface in a heliocentric polar coordinate system (Figure 11). We could help by providing lists of planetary, asteroidal, and cometary coordinates versus time; similarly, if you are attempting a version similar to that in Armagh, as far as physical materials are concerned, we can tell you more about the difficulties that we encountered and the solutions that were found. The range of educational activities involving human orreries is almost limitless, and we hope that readers will explore this new field.

Acknowledgments

The Human Orrery was built with funding from the Northern Ireland Department of Culture, Arts and Leisure, with additional funding for leaflets from the Particle Physics and Astronomy Research Council. The leaflets can be found on the Human Orrery Web site (http://star.arm.ac.uk/orrery). We thank the many people who have been involved in the exhibit's design and construction, and in the development of associated educational materials (information panels, leaflets, Web site, and quizzes). We would be pleased if others who are developing human orrery activities would send us their ideas and experiences,

which we can add to our Web site in due course. Finally, we appreciate the helpful comments on this article by the referee, Dr. Cherilynn Morrow.

References

Bailey, M. E. 2006, "The Armagh Observatory Human Orrery," *The Observatory*, 126, 236.

Bailey, M. E., Asher, D. J., & Christou, A. A. 2005, "The Human Orrery: Ground-based Astronomy for All," *Astronomy and Geophysics*, 46(3), 31.

Beech, M. 2007, "The Living Orrery," *The Observatory*, 127, 60.

Francis, P. 2006, "Using Role-Playing Games to Teach Astronomy: An Evaluation," *Astronomy Education Review*, 4(2), 1. http://aer.noao.edu/cgi-bin/article.pl?id=158.

Goldstein, J. 2002, "Voyage: A Journey through our Solar System," *Voyages in Education and Public Outreach* [NASA newsletter], 4, 1.

Gould, A. 2005, "A Human Orrery," (University of California publication, trial edition), http://kepler.nasa.gov/ed/pdf/HumanOrrery.pdf.

LoPresto, M. C. 2003, "Tolerance for Astrology?" *Astronomy Education Review*, 1(2), 125. http://aer.noao.edu/cgi-bin/article.pl?id=41.

Morrow, C. A. 2006, "Kinesthetic Astronomy: Experiencing the Movement of the Spheres," *ASTC Dimensions*, Sept/Oct, 7.