Krieger Science

Science project ideas for homeschools

How to Make a Digital Home Planetarium

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An Artificial Sky

One of the main difficulties in familiarizing students with the nighttime sky is that you don't have convenient access to it, and to your students, at the same time. You are normally teaching indoors during the daytime, and to show students The Big Dipper, you need to be outdoors at night. Homeschoolers and small groups could probably make a pretty good go of things by arranging special night-time observing sessions, but this isn't normally feasible for larger schools.

One daytime option is a field trip to a planetarium, but very seldom do planetaria take full advantage of the educational possibilities of a star projector. In my experience, you basically get an IMAX movie, and a minute or two devoted to the star projector, completely neglecting the potential of having an artificial sky. It would be much better for you, the teacher, to have complete control over the star projector, and be able to point out all the constellations one by one, to show their gradual drift through the sky by speeding it up, and show the locations and motions of the sun, moon, and planets as well. It would be very helpful to have a planetarium of your own.

In December of 2009, my students and I built a planetarium dome out of cardboard, and I projected the nighttime sky onto it with a personal computer, a digital projector, and a mirror. This enabled me to effectively play god with the sky, controlling the stars, the sun, the planets, and even the blue daytime glow. You can do this, too. The rest of this post is a description of how we did it.

We already owned a digital projector, and the expense for the rest of the supplies was well under $400. We bought nearly all of our supplies new–you may be able to build a planetarium for less, depending on how resourceful you are.

The Dome

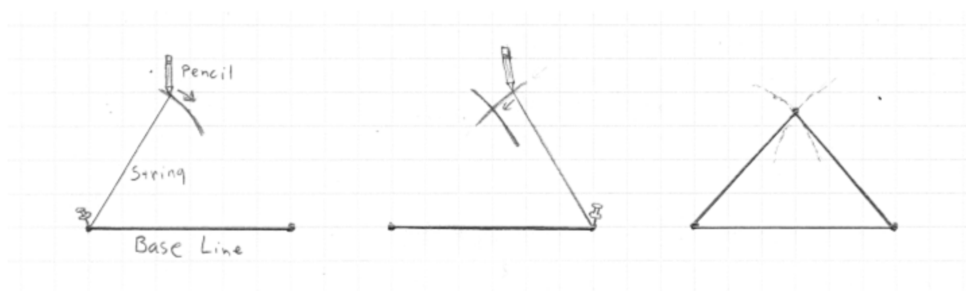
To make the dome on which to project the sky, the students and I constructed a geodesic dome from cardboard triangles, painted white on the inside, held together by large binder clips pinching flaps along the edge of each triangle, and lifted off the ground a little bit by a wall of cardboard rectangles. It looked something like this:

(Thanks to Mr. Jeff Adkins for giving me this idea. His description of his dome is here.)

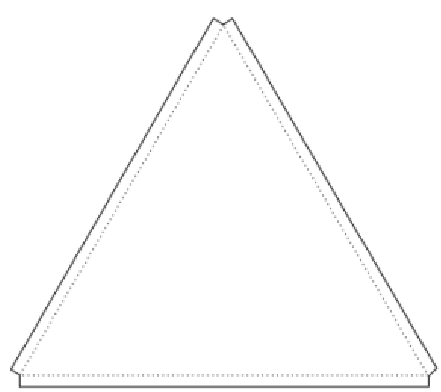
For the dome itself, you need to cut 40 triangles and 10 rectangles out of cardboard. For a dome roughly 12 feet across, all 50 pieces need to be roughly 3-4 feet on a side. Where do you get that much cardboard? I tried finding scrap cardboard from retail stores, thinking that they receive shipments in cardboard boxes, but few places receive goods in boxes with large enough sides. Eventually I gave up and ordered 4'x8′ sheets of corrugated packing cardboard from a packing supply store. The bundle cost a little under $200, but the convenience of having clean blank sheets of a regular size was worth a lot. Jeff Adkins' site gives some other ideas for where to obtain cardboard. Packing cardboard comes in a few different thicknesses–mine was 1/8″. Thicker cardboard would presumably make a sturdier dome, but would also be harder to cut and fold. You'll have to make your own judgement about thickness.

Now, all those triangles and rectangle–exactly what size and shape do they need to be? The following measurements will produce a dome about 12 feet across, which will comfortably hold a class of 15 elementary students, and uncomfortably hold a class of 15 Junior High students. You can make the dome any size you want–simply multiply or divide every measurement by the same scale factor. Of the 40 triangles, you need 10 equilateral triangles and 30 isosceles triangles, with dimensions shown below. All blue sides are 44.5 inches, and all red sides are virtually 39 3/8 inches. This will enable you to cut three triangles from one 4×8 sheet of stock cardboard, if you are careful.

To manufacture the cardboard triangles, I suggest drawing and cutting out one of each shape, then using those as templates to trace the outlines for the rest of them. To manufacture a template triangle, you can use the "compass and straightedge" technique used by the ancient Greeks: Start by drawing the line representing the base (the longest side in the case of the isosceles triangles). One simple way is to lay a yardstick alongside the edge of a blank piece of cardboard, then trace along the yardstick, making a line parallel to the edge and inset about 1 inch. (You can't use the edge itself, because you need to leave space for the flaps that will fold up and bind the triangles together.) Next, pin or hold one end of a string or stick at one end of the base, measure out the appropriate length of string, fasten a pencil at that point, and draw a circular arc through the point where you think the peak of the triangle should be. You are using the string or stick as a giant compass. Re-pin the string to the opposite side of the base and repeat the procedure, drawing a second arc that intersects the first one. The point where the two arcs intersect is the third vertex of the triangle–use a straight edge to connect it to the two ends of the base, and form the triangle.



You have just traced the face of the triangle, the portion that will fill the proper place in the geodesic dome. Around this face there must be flaps that will fold up and will be used to bind each triangle to its neighbor. For this, you just need parallel lines along each edge, an inch or so to the outside. Again, a simple way to draw these is to lay a yardstick along the outside of the triangle, then trace along the outer edge of the yardstick. How you terminate the flap at each end doesn't make a great deal of difference, as long as you don't damage the vertex of the triangle.

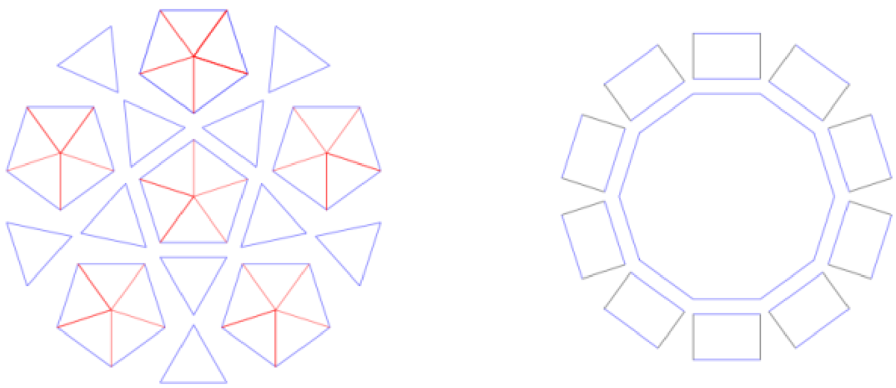


A Single Triangular Panel, With Flaps

Once the templates are made, you simply trace them to make all the other triangles in as efficient an arrangement as you can on the blank cardboard, then cut them out, fold the flaps up, and paint the inside white. To fold the flaps, I recommend laying a yardstick or something similar along the inside of the fold line, sliding your hand underneath the flap on the outside of the line, and gradually creasing the cardboard from one end to the other. Using a straightedge to guide the fold produces a much neater fold than doing it free-hand. To paint, use a cheap water-based, roller-applied flat white paint. The flaps will fold *out* to be pinched by the binder clips, so paint the side opposite to the direction of the flap-folds. You don't have to be too finicky with the paint job, but the more careful you are, the neater and more professional the dome will look on the inside.

By the way, we had serious curling problems with our triangles. The wet paint caused the cardboard triangles to warp as they dried, even if they were lying flat. The curl can be more-or-less removed by pressing them after they are dry: Stack them neatly, and place a wide flat weight, like an overturned table, on top of them for a while.

Now comes the hard part: assembling the pieces. The figure below shows how they are to be assembled. All equilateral triangles have three blue sides, and all isosceles triangles have one blue side and two red (slightly shorter) sides. All of the isosceles triangles will be grouped together into pentagons, and the equilateral triangles will fill the gaps between the pentagons.



We started our assembly by arranging all of the isosceles triangles into pentagons. When they are clipped together, they will not form flat pentagons, but will form a shape that resembles a pointed beanie, with the perimeter being a pentagon. Once all of the pentagons are assembled, we made a ring of pentagons with the gaps filled in with equilateral triangles, and finally we placed the crowning pentagon on top. The binder-clipped cardboard dome was pretty sturdy once complete, but the pieces were extremely floppy until then. It may be better not to assemble all of the pentagons first, and just work upwards from the base of the dome in rings of triangles. Either way, it definitely works best to work up from the sides, sort of like assembling a Roman arch, with the final pentagon being the keystone. In any case, I suggest having several adults around to hold things where they are supposed to be until the final piece is bound in place, and having boxloads of binder clips to reinforce weak spots. We ended up with five binder clips along most seams, for a grand total, including the binder clips used in the base wall, of nearly 400 clips. (If you use one-inch flaps and jumbo binder clips, this raises the expense of the project by another $100 or so. Narrower flaps and smaller binder clips would lower the expense considerably, but the smaller the clips, the easier the panels will pull apart. Also, [Jeff Adkins' site] gives the suggestion of using PVC pipes instead of binder clips. Sounds like a great idea, but I've never tried it.)

The base wall is relatively simple. The rectangular panels need to have one side equal to the bases of the triangles (44.5″ in my case), and a height of whatever you want. Ideally, it should be about eye-height of a student sitting cross-legged on the floor, but it doesn't make a great deal of difference. The dimensions of our rectangles are given in the figure above. (Remember, those are the dimensions *without flaps*.)

The bottom side of the rectangles will be resting on the ground and the flap on that side is actually superfluous. We just folded the flap sideways into a kind of "foot" for the wall. Once the dome is assembled with plenty of binder clips, it is quite sturdy, and can be lifted fairly easily, so you can simply join the wall pieces together into a ring, then lift the dome onto the wall and fasten it with more clips.

Do you need to paint the inside of the cardboard wall? In general, you want the interior of the planetarium to be as dark as possible, so you could paint the inside of the walls black. I didn't, mostly for time considerations, and I didn't find incomplete darkness to be too harmful. I actually found it helpful to have a little ambient light to work by, and to see the students by.

How do you get in and out? You could cut a door into one of the sides, but I found it much simpler just to remove one of the wall panels and enter through the gap. We had our dome in a fairly dark room, so once inside we could just slide the panel crudely back into position without fastening it or having to worry too much about sealing out light. Furthermore, if the opening had been any smaller, adults and even Junior High students might have had some difficulty crawling in and out.

If you have only one or two small groups using the planetarium, that will be all you need to do. However, after extended use, an unventilated cardboard box containing sixteen people and a hot projector will get unbearably stuffy. We tried setting an electric fan on the floor near the door, and that helped a little, especially when we opened up an additional gap on the opposite side to allow flow-through. If you intend extended use for your planetarium, I suggest trying to implement some of Jeff Adkins' ideas on how to ventilate the dome.

The Projector

Once you have a dome, how do you show stars and planets on the inside? A small toy projector like this one is cheap and quite effective at projecting stars onto the interior of a dome, but I found something much, much better: With a digital projector and a dome-shaped security mirror, you can display on the interior of the planetarium anything that you can display on your computer screen. With the free planetarium software Stellarium, you can display any and all components of the sky in any configuration. In a nutshell, you can play god with the sky. (One exception: while Stellarium can show just about anything under the sun, so to speak, one thing it does not do is to show the phase of the moon. The moon always appears as a full white disk, regardless of the phase. Perhaps in future editions….)

Actually, there's a complication, but for the end user, it is very minor. The image shone by the projector is going to reflect off of the curved mirror onto the curved dome, so in order for the image to come out right on the dome, you have to "pre-warp" it properly in your computer. Fortunately, a man by the name of Paul Bourke figured out how to do this for a spherically shaped mirror, such as a typical hallway "security mirror", and the people who make Stellarium incorporated his idea into their software. This means that all you have to do is to check a selection box, and Stellarium warps the image for you, making the image projected onto your dome look and move exactly the way the sky does.

Here's how to make it work:

1. Obtain Stellarium

Download Stellarium onto your computer and practice using it. Make sure to set your current viewing location to your town. Also make sure that your computer is capable of driving a digital projector, with a bare minimum resolution of 1024×768 (XGA).

2. Obtain a Mirror

   Buy a half-dome security mirror, like this one. This is an uncommon item, so you may have to mail-order it. Ours cost about $60.

3. Obtain a Digital Projector

   There are certain requirements of the projector, so make sure you can obtain a suitable one. (I suspect that any projector made in the last few years will be fine, but I can't say for certain.)

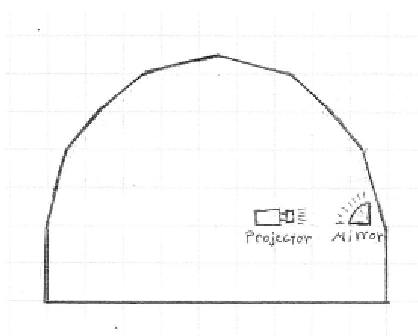
   - Resolution:
     I used an XGA projector, which was ok for basic classroom purposes, but the image, which is greatly expanded when it is projected onto the dome, looked a bit coarse and grainy. An SXGA or HD projector would be better. Also remember that even if your projector is HD, it won't display HD unless your computer tells it to, so your computer needs to be able to output as high a resolution as your projector.

   - Focal Length:
     I'll admit the focus issue confuses me a little bit. The projector needs to be close enough to the mirror so that the image doesn't get too large, and all of the image (except for the upper corners) lands on the mirror. Apparently the image also needs to be focused by the time it strikes the mirror, and this is an unusually close focal distance for a projector. If your projector can produce focused images a foot across on a screen six feet away, as ours did, it should be ok.

   - For a more official discussion of the projector requirements, see Paul Bourke's discussion of the issue.

4. Arrange the Optics

   Place the mirror at the edge of the dome, and place the projector several feet from the mirror. In other words, arrange the pieces of your planetarium like this:



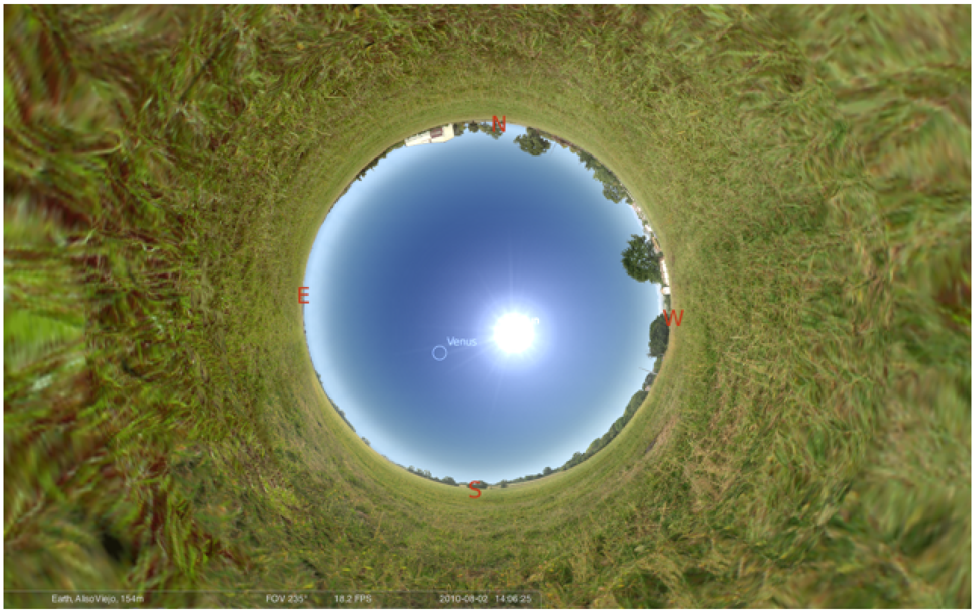
   I placed my projector and mirror on a cart so that I could roll the whole projector assembly in and out of the dome. However you support your projector and mirror, allow some flexibility in the positioning, because you will undoubtedly find that you need to make fine adjustments to improve the alignment and focus of the image on the inside of your dome. Here is what my projector assembly looked like:

You may think that the projector looks as if it were projecting directly into the cart, but most projectors are intended to stand level and illuminate a screen considerably higher than they are, so they shine their beam upwards at an angle. Therefore, to shine the beam horizontally, you need to tilt the projector well forwards.

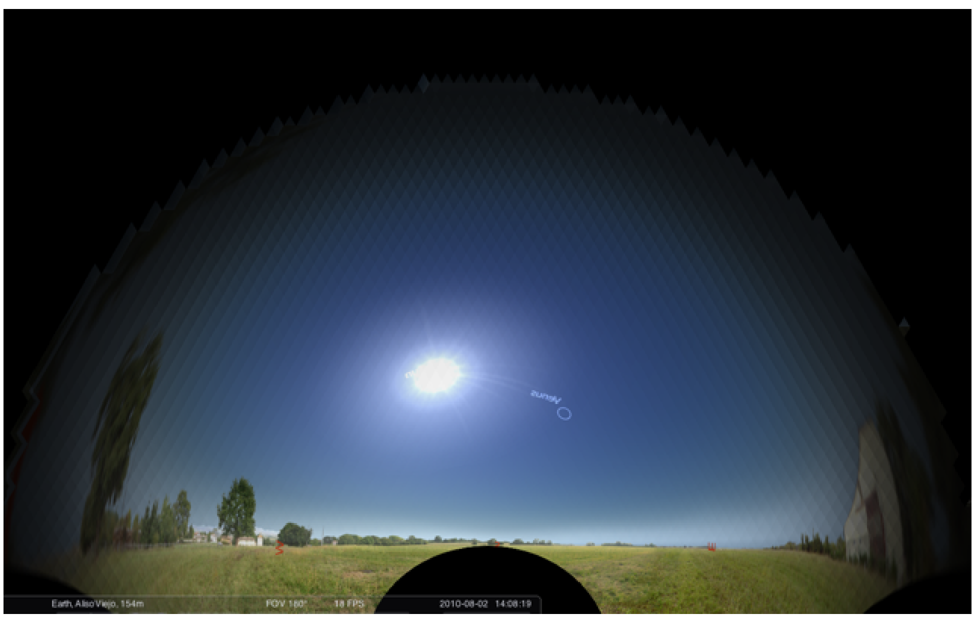
5. Configure Stellarium

If you have never set the viewing location before, you will have to change it from the default (Paris, France), to your location. Do this in the “Location” window, either by selecting a nearby city, or entering your latitude and longitude coordinates. From now on, when you start the Stellarium program, it will begin with an un-warped South-facing view of the sky at the present time in your location.

In order to project the entire sky onto the dome, you will have to display the entire sky, and turn on the "spheric mirror distortion". Display the entire sky by zooming out (on a MacBook, two-finger drag on the touchpad) and shifting the image (arrow keys) until you see a circle centered in your screen representing the entire sky.



Turn on the "spheric mirror distortion", by opening the "Configuration" window, clicking on the "Tools" tab, and checking the "spheric mirror distortion" box. The image should now look more or less like a hemicircle, with the horizon lying along the bottom.



(For long-term use, you can save yourself the trouble of repeating these steps, as well as customize and fine-tune various settings for your particular planetarium, by editing Stellarium's configuration file *config.ini*. For more details and recommendations on using Stellarium to drive a home planetarium, see [Paul Bourke's discussion of the issue](#)).

6. Enjoy the view

If you now shine this image onto the mirror, it will reflect onto the interior of your dome, filling it with an image of the sky. You may have to adjust the height, distance, and orientation of the projector to get the sky-dome picture to align as well as possible with the cardboard dome. Mine was always a little bit skewed, probably because the mirror was too low.

With the sky projected properly onto the dome, the left and right arrow keys will rotate the sky (and the terrain on the horizon) around the zenith, just as if you the observer were twirling in a circle. This is helpful because the quality of the projected image is worst above the projector and best opposite to the projector (a drawback of the spherical-mirror-projection technique). With the arrow keys you can rotate the interesting part of the sky to the opposite side of the planetarium, where the image quality is best.

For added realism, I suggest "hazing" the sky a little bit. If you show kids a full, clear starry sky in all of its glory, and then they go home and look up at the hazy, glow-filled sky of a typical urban area, they may be able to find only a few stars, if any, and get discouraged with astronomy. It is a good idea to focus attention only on the brightest stars, and to this end it is helpful to fiddle with the "relative scale" and "light pollution" settings of Stellarium. (They are in the "Sky and Viewing Options" window.) You can always undo these things later to impress them with the beauty of a clear, dark, desert sky.

Planetarium Activities

Once you have your planetarium active and running, what do you do with it? Here are my ideas. In what follows, I am assuming that you are in mid-northern latitudes, like the United States, Europe, Korea, and Japan. All keyboard commands given below work on my MacBook. Check the help menu in Stellarium for commands on your computer.

For a first activity, I suggest just showing tonight's sky, identifying the constellations, finding north, etc.

For a second activity, try familiarizing students with the motion of the stars. Use the "J" and "L" keys to speed up and slow down the rotation of the sky, and the "K" key to revert to normal speed (once around every 24 hours). The students should notice that one point in the sky stands still, and that it is always in the same place, and everything else spins around it. This point is very nearly (though not exactly) occupied by Polaris, the North Star. There is also a "waist" or "belt" around the middle of the sky, an exact half circle with one end touching due East and the other touching due West. This is the celestial equator, and you can mark it with a line by pressing the "." (period) key.

For another activity, you can show students the annual motion of the sun in the sky. Start by reviewing the daily motion of the sun through the sky–an arc from East to West peaking in the South. Then stop the sky and set the time to noon, with the sun at its peak in the Southern sky. Now use the "add one solar week" or "subtract one solar week" buttons ("[" and "]" on a MacBook) to advance or retreat in time, a week at a time, quickly through the year. You will see the sun oscillate around the equator, high in the summer (with the peak at the summer solstice, roughly June 21), low in the winter (with a low point at the winter solstice, roughly December 21), and cross the equator at the two equinoxes (roughly March 21 and September 21). Astute observers will notice that the sun doesn't go straight up and down, but traces out a figure-8 over the course of a year. This is an "analemma", and the width of it is due to the fact that the sun's motion through the sky actually speeds up and slows down very slightly over the course of a year. In some months, it is slightly ahead of where it is supposed to be at 12 O'Clock, and in some months, it is slightly behind.

You can also observe the motion of sun, moon, and planets with respect to the "fixed" stars by "freezing" the stars in the same place every day. To jump forwards to the time tomorrow when the stars are in exactly the same position in the sky, you need to jump ahead one "sidereal day", which is four minutes less than 24 hours. To jump backwards, you need to subtract a "sidereal day". (The corresponding keys are Alt – and Alt = on a MacBook). You may notice, if you haven't already, that the sun, moon, and planets always lie along the same path through the stars. The stripe of constellations through which they pass is the zodiac, and the precise line through the middle of the zodiac along which the sun moves is the "ecliptic". You can draw the ecliptic on the sky by pressing the "," (comma) key. If you are not worn out yet, try spinning the sky with the ecliptic drawn in, and notice that it is like a tilted equator, with a high point in Gemini and Taurus (the sun is here in the summer), and a low point in Sagittarius and Scorpius (the sun is here in the winter).

> *Important Note: I do need to point out that, if you set up the planetarium as I have described, it will project everything* backwards. *This means that any text labels will be printed in reverse, and all the constellations will appear backwards. If you use the animation feature to demonstrate any motions–the daily motion of the sun, the motions of the moon and planets through the zodiac, etc.– these too will be reversed. For example, if I wanted to show the sun rising in the east and setting in the west, it would erroneously show the sun rising in the west, and setting in the east. In my demonstrations to students, I could compensate to some degree for this by telling Stellarium to animate* backwards, *i.e. to run from sunset to noon to sunrise, and it would then show the sun "rising" (setting backwards) in the east and "setting" (rising backwards) in the west.*
>
> *The fundamental problem is that the image projected by the projector is reversed when it reflects off of the mirror, and the people who wrote Stellarium didn't take this into account, and give you a way to flip the image in the projector so that it comes out right on the dome. Maybe they were imagining a different more compact projector arrangement, with a second flat mirror and a double reflection, which wouldn't reverse the image. In any case, I would think that it would be a very simple fix, for some programmer who knew what he was doing, to dig into Stellarium and insert a minus sign at the appropriate place in the code, but I don't have the ability to do that yet. I would also be possible to design a double-mirror projector which doesn't reverse the image, but I don't have the time or ability to do that either.*
>
> *Given the context–that we are designing a budget planetarium for schoolchildren–I don't think this is a major flaw. My students still thought the planetarium was very cool, and I still found it to be an enormously useful and fun teaching tool. But the backwards-display glitch is a bit annoying.*
>
> *Followup: A commenter below has made the very valuable point that you can just reverse the image by adjusting the settings of your projector. You tell it to use "rear projection mode" or "floor-rear configuration" or whatever your projector's term is for horizontal flipping. Many thanks to michaelaldridge857303542.*

Miscellaneous

If you want to explore the subject of small planetariums further, here are some links that you might find interesting:

- Domes:
  - For homemade domes, you could also try the Small Planetarium Group at Yahoo.
  - For inflatable domes, and expensive but really cool "immersion" systems, see Elumenati.
- Projectors:
  - Cheap toy star projectors are very effective for the price, although they are a little underpowered for large domes, unless you have done a good job of making the dome really dark. Other flaws are that the constellations don't always look realistic, the difference between bright and dim stars is not accurate, and there are streaks of light and shadow from junctions and imperfections.

    It is fairly straightforward to make a cheap star projector from a lightbulb and a dark covering with holes poked in it, although it would take a lot of work to make, and it would be hard to get the relative brightnesses of the stars right. It is also rather difficult to find accurate templates for the constellation-filled shrouds. If you want to go that route, you'll have to do your own research. Jeff Adkins' site has a couple of links to get you started.

  - If you are not on a budget, Digitalis Education offers domes and projection systems for sale, including planetarium software.