

Computational Diversions: Free Ideas

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Published online: 8 January 2011
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As I write this column, the holiday season is in full swing. It will (perhaps mercifully, from the perspective of the reader) be over by the time this is published; but the intent is nonetheless to make this particular diversion redolent with gift-giving cheer. So—just to get into the proper mood—you might want to trudge over to the closet; then fish out the twinkling lights, ornaments, menorah, little plastic reindeer, uneaten hideous fruitcake, or whatever, and set them around your reading table before proceeding any further.

In this column, I'm giving away free ideas. There's a certain sense of regret in doing this: these are small-scale project ideas that I've hoarded away for a while, hoping to see them brought to fruition. Occasionally, I've tried to assign one or another of these as special projects to students, but without success. Now, I've reached the point at which my backlog of unaccomplished ideas is so vast that it's hard for me to worry about questions of credit, or academic glory (which is in any event sort of a contradiction in terms). So, for any reader—especially a young, energetic reader—searching for a fun and perhaps ultimately publishable project idea, please do consider the possibilities presented here. My treat.

Each of the project ideas will be presented in a fairly informal, sketchy way—my hope is that this should be enough to get you started, if you're interested. Each of them can be attempted at various scales: an undergraduate (or team) could likely get something worthwhile done in a semester or two. On the other hand, each of them could potentially lead to longer-term or more ambitious implementations as well.

So, with that as introduction, let's get started.

1 Project 1: The Kaleidoscope and the Screen

Kaleidoscopes are a venerable choice of scientific toy (or “amusement”) for children. Some of them are simple, cheap affairs that you can pick up at the local science museum; others are beautifully crafted, expensive art objects. Beyond their status as fun gifts, however, kaleidoscopes are also not too hard to build: craft books such as (Bennett and

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Romig 1994) and (Newlin 1995) provide instructions (and in the former case, materials) for building your own.

The main limitation of kaleidoscopes, even for those (like myself) who admire them, is that they are ultimately limited in their visual content. Sure, the view is generally beautiful, and you can turn and twist the instrument to see all kinds of variations; but in a culture of 3D movies and high-resolution video games, the charm of the kaleidoscope feels a bit quaint. It's fun to hold the instrument, to turn it about; but after the first 20 min, what *else* can you see through it?

That's where the computer screen comes in. Suppose we begin by building a standard physical kaleidoscope tube (with its embedded mirrors), but leave out the front of the instrument with its chamber of multicolored confetti. What we'll do instead is create a computer program that brings up, on the screen, a circular region exactly the size of the kaleidoscope tube, and view that region through the tube. Thus, we have created a part-physical, part-computational scientific toy. (Fig. 1 shows a rough sketch of the idea.)

Now, our circular region could include an animation of the standard multicolored confetti; this would result in a "standard" kaleidoscope pattern as seen through the tube by the user. More fun, however, would be to experiment with animations on the computer screen that could never be seen in a standard physical instrument. Perhaps one might include animations of a ball bouncing around the circular region (rather like a pool ball on a frictionless circular table); or perhaps one might design animations in which objects materialize and disappear in the middle of the region; or perhaps one might make objects rotate about chosen points other than the center of the circular region; or perhaps one might create designs with mirror symmetries, or seven-fold symmetries, or other types of planar symmetry patterns besides the standard (six-fold) symmetry associated with the kaleidoscope tube. It would be interesting to know how these visual screen-based effects would look when seen through the device, and what effects (e.g.) turning the tube physically would have.

The possibilities of blending the physical kaleidoscope tube with a computer screen don't stop here. We might imagine, for example, using a pair of kaleidoscope tubes, one for each eye; then, by presenting carefully adjusted similar images in each circular region, we could create animations on the screen that give the illusion of objects moving toward or away from the viewer as seen on the screen. The result would be a kaleidoscope with an unaccustomed third dimension of viewing. (Sort of a combination of a kaleidoscope with the classic "View-Master" toy.) Of course, the result might look terrible, and the idea might fail spectacularly; in this case, I renounce any responsibility for the project, and blame the whole debacle on you, the reader. But it just might work.

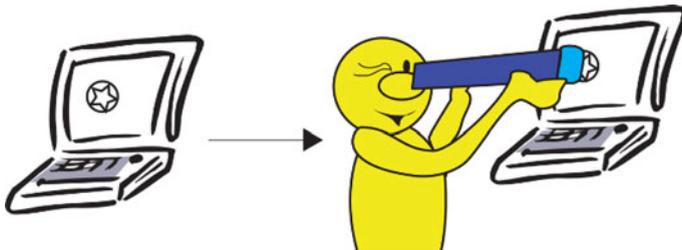


Fig. 1 A sketch to suggest the idea of the "Kaleidoscope Plus Screen" idea. A circular region on the computer screen—containing all sorts of geometric shapes, graphics, animations, and so forth—can be viewed through a homemade kaleidoscope tube

2 Project 2: An Ames Room Design Application

As long as we're on the subject of fun optical effects, we may as well proceed from the kaleidoscope to the Ames Room. The Ames Room (named after its inventor, Adelbert Ames, Jr., who constructed an example in the first half of the twentieth century¹) is a remarkable optical illusion, and can be experienced in many science museum exhibits around the world. (One popular example has been installed in the San Francisco Exploratorium.)

The idea behind the Ames Room is that it is an asymmetric, trapezoidal room; but when viewed from a particular vantage point (toward the “front” of the room), it appears to be a standard rectangular space. The viewer stationed toward the front usually views the interior of the room through a little porthole; as it happens, the actual Ames Room back wall is tilted so that one of the rear corners is much further away from the viewer than the other, and the ceiling at that corner is much higher than at the nearer corner. When two people stand at the back corners of the room, one (at the near corner) will appear giant-sized to the viewer, with their head close to the low ceiling, while the other (at the far corner) will appear shrunken. In other words, the viewer does not interpret the two people as “close” and “far”, but rather as “big” and “small”. The effect is truly miraculous, and the reader who has never seen an Ames Room is now encouraged—before continuing any further—to do an image search on the Web to see a few examples. (Better yet, the reader is encouraged to go visit the nearest science museum that has been thoughtful enough to build an Ames Room exhibit.)

Now, here's the project idea: suppose we create a software application for printing out (in paper) decorated two-dimensional folding nets that can be folded and assembled into small replicas of the Ames Room. The basic idea is not too complicated; we simply want to generate a pattern that can be folded into the characteristic polyhedron (think of it as a “distorted rectangular prism”) that constitutes the Ames Room. Even a plain, undecorated trapezoidal box can make for a fun Ames Room exhibit; if you cut a small hole in the front wall (as the viewer's porthole), and then stare into the box, you will see what looks like a standard boxlike interior. By holding the box up toward a light and placing your two forefingers behind the two far corners, you will now see what look like shadows of a “giant” (near) finger, and a “tiny” (far) finger. I know this for a fact, since I have such a small Ames Room paper replica in my lab.

But a software application for designing the room could, in fact, go much farther than this. Ideally, the application would present us with a drawing tool that we could use to produce (on the computer screen) decorations on the interior surface of the room itself: a tiled floor, windows in the back wall, perhaps a portrait between the windows. These decorative elements would be designed so that they are consistent with the Ames Room geometry: for instance, what look like normal rectangular windows in the rear wall (to the viewer) would actually be trapezoidal windows. A replica of the Mona Lisa on the Ames Room back wall would appear normal to the viewer, but would actually be distorted in a manner consistent with the shape of the wall. After being designed on the computer screen, we could now print out, on paper, the newly-decorated folding net that could be used to create a customized Ames Room. Figure 2 conveys the general idea behind the application.

¹ In trying to research the Ames Room on the Web, I find some references dating its construction to 1935, and others to 1946. I am curious about the discrepancy here; any reader who has reliable knowledge of the room's history and can explain the disagreement among the sources is encouraged to send email to this column at: http://ijcml-diversions@ccl.northwestern.edu.

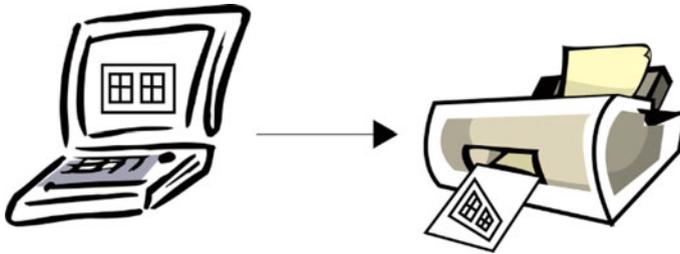


Fig. 2 A sketch to suggest the idea of the “Ames Room Designer”. Here, a normal looking back wall with a pair of windows drawn onto it, as seen on the computer screen, will handily print out as a distorted back wall that the user can employ in a paper Ames Room construction

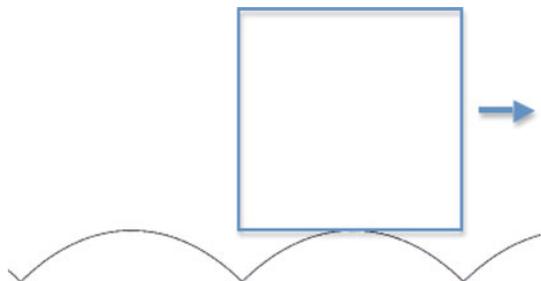
A clever design tool of this sort, then, would include a bunch of drawing tools that one could use to produce substantially enhanced illusions. Perhaps a more ambitious version of the Ames Room program would allow the user to create small paper models of furniture (chairs, a table) to be placed at particular spots within the room, and that would again intensify the illusion. A paper model of a trapezoidal table, for instance, could be placed in the room so that it appears to have a normal, rectangular top surface; or a distorted paper dresser could appear in normal guise when placed along one of the side walls of the room.

3 Project 3: A Rolling Polygon Track

One of my own favorite science-museum exhibits is the “rolling square”: a square wheel rolling on a track of inverted catenaries. The track is constructed in such a way that the center of the square moves smoothly and horizontally as the square rolls along the track. There is actually a lovely working model of the design at the Integrated Teaching and Learning Laboratory on our own campus at the University of Colorado; and an animation of the idea can be seen at the Wikipedia entry for “square wheel” (http://en.wikipedia.org/wiki/Square_wheel). Figure 3 shows a rough sketch of the idea.

There are many alternative non-circular shapes that could be used to generate a customized track for rolling. One might find a bumpy track that could work for a regular pentagonal wheel; or a track that could work for a golden rectangle; or one that could work for an ellipse of given eccentricity. A reasonable computational project, then, would be to write a program which—given a particular polygon and starting orientation—generates a pattern for a track upon which that polygon can roll smoothly. Better yet, the program should generate files that can be printed out in wood or acrylic on a laser cutter for both the

Fig. 3 A sketch (approximate, but not mathematically exact) of a square rolling smoothly along on a bumpy road made of catenaries



track and the rolling figure, so that the user can design customized rolling-polygon museum exhibits.

Clearly, not every polygon can give rise to a physically workable road of this sort: articulating the precise conditions that allow a polygon to produce a physically-realizable track would be an interesting project in itself. My own guess is that at least some non-convex polygons could, in fact, be used to produce a workable track (I might be wrong about that), and would result in an especially startling exhibit.

It should also be mentioned—while we’re on the subject—that a rolling polygon, such as a square, need not roll so that its center moves in a straight horizontal line. It ought to be possible, for example, to generate a track that would allow a square to roll so that its center moves in an appropriately-chosen circle, or back and forth along a parabola. Or one might design a non-planar track for a shape such as a cube, allowing the shape to roll about distinct axes of symmetry on different portions of the track. The possibilities for complex, surprising shape-track combinations appear to be extremely promising.

4 Project 4: A Balancing Toy Designer

The fourth and final project idea to be described here, like the kaleidoscope idea, begins with the existence of a popular type of scientific toy: namely, those charming balancing figures (typically made of wood or metal) that surprisingly stay upright. There are typical variations on this theme. One might see a model (say) of a clown figure with a narrow base that, when placed on a pedestal, manages not to fall; or a tightrope-walker that can be placed athwart a string without tipping over; or an oddly-shaped figure that can be positioned at the edge of a shelf and that does not tip over the side of the shelf despite what appears to be an ungainly “foothold”.

In all these cases, there is no real mystery to the toy’s behavior. The idea in every case is that the toy’s center of gravity is located at a position such that, when the toy tips to the side, the center of gravity moves upward; thus, the most energetically stable configuration for the toy is in its proper (“upright”) position on the shelf, string, or pedestal.

Such toys are appealing introductions to ideas of introductory physics; but it seems to me that they are far more interesting to design than to use. That is, a balancing toy is a pleasant exhibit, but it ought to be possible to make your own toy (or series of toys) and experiment with the physical constraints behind their construction.

A good balancing toy, properly regarded, is a work of art. There is a clear aesthetic dimension to the construction of these toys. After all, it isn’t enough to make the toy simply balance; you have to make it balance *unexpectedly* (a matter of human judgment). The element of surprise might be augmented by using materials of different density within the toy, or making some portions hollow. (I suppose that some constructors might consider this “cheating”, but as far as I’m concerned all’s fair in the service of science education.)

A good project idea, then, would be to make a design application that helps children create balancing toys. I am deliberately leaving many of the dimensions of this application creatively vague, but one can imagine elements of a design system for this purpose. The application might allow the user to begin with a library of representations of balancing (or near-balancing) physical forms, and then alter those in a variety of ways—e.g., by adding new elements, symmetrically placed, on the starting form. As the hypothetical form is changed, the system would keep track, by simulating its behavior under the influence of gravity, of whether it continues to balance on its contact point (with pedestal, shelf, or string). Perhaps the application might suggest the use of heavier or lighter materials for

different portions of the design; or it might suggest other operations (such as removing mass from chosen locations of the design). The application might then create templates or instructions for creating the final toy—say, in pieces of wood cut on a laser cutter. Given the remarkable expansion of inexpensive 3D printing devices, the application might even finish by printing (in plastic) a working model of the designed toy.

All of the project ideas presented here—for kaleidoscopes, Ames rooms, rolling polygons, and balancing toys—share a certain “philosophy” (if that’s not too ambitious a word) of design. That is, they all begin by looking at worthwhile science toys or exhibits, and then considering how we ourselves can shift from the stance of audience, or consumer, to the stance of the designer. Can we make a weirder kaleidoscope? A more ornate Ames Room? A more baroque rolling polygon? A personalized balancing toy? This turn of thought could be applied to many more examples of scientific artifacts and exhibits—tops, anamorphic art, shadow puppets, bubble pipes, burr puzzles, and on and on. By taking a stroll through the local science museum (and don’t forget the gift shop!) you can undoubtedly come up with projects of your own. So if you happen not to like these particular gift ideas, it should always be possible, in true post-holiday fashion, to trade them in for better ones. Or if you have gift ideas of your own, please feel welcome to send them to this column at: http://ijcml-diversions@ccl.northwestern.edu.

Acknowledgments Thanks to Ann Eisenberg for creating the sketches for Figs. 1 and 2.

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