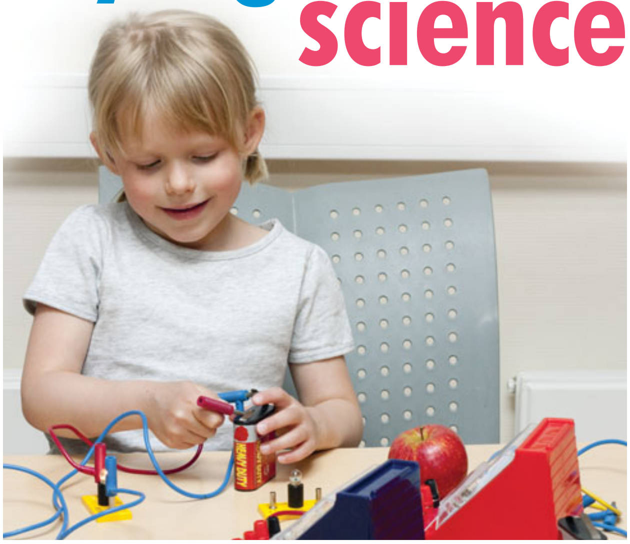
Toying with science



Girls' toys have a lousy reputation when it comes to preparing kids for a science career. In our preteen years, my female friends and I mostly dabbled in arts and crafts and played board games, while our brothers honed their technical skills with chemistry sets and model planes, cars, and rockets. No wonder boys gravitated to careers in science and engineering more often than girls.

That's the conventional wisdom, anyway.

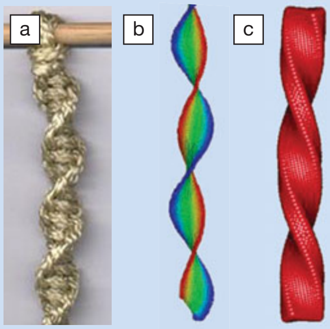
But take a closer look: Toys and activities popular with preteen girls have many surprising connections to modern themes in materials science, mathematics, chemistry, and physics, and they prepared me well for the research I pursue as an adult.

Take origami, for instance. The Japanese art of paper folding was a popular pastime for girls in the 1970s. Folding little swans and other creatures out of paper demands nimble fingers and precise sequence, geometry, and symmetry for each step in the process. Recent research has shown that this kind of spatial reasoning skill is strongly correlated with students' future success in STEM* careers.[1] What's more, origami has emerged as a focus area in materials engineering and mathematics research with a major funding initiative from the National Science Foundation (www.efri.org). Recently, my research group has begun working on models of "auto-origami" materials, which spontaneously fold into complex shapes in response to heating or other stimuli.

Macramé, the art of tying cords to make wall hangings and decorative objects, was another craft popular with girls when I was a pre-teen, and it provided me with a wonderful hands-on introduction to chirality. Knots are inherently chiral, with right- and left-handed forms, like the D- and L-mirror image enantiomers that arise in chemistry. Tying four cords in a sequence of right-handed macramé knots produces a helix that closely resembles DNA. Left-handed knots make a helix with the opposite handedness, and an even mix of alternating right-left-handed knots makes a flat, untwisted ribbon. Any difference in the density of right- and left-handed knots breaks chiral symmetry, and the imbalance—what chemists call the "enantiomeric excess"—determines the pitch of the resulting twisted shape. Experimenting with chiral structures in macramé later inspired me to study chiral symmetry-breaking in random copolymers,[2] lipid membranes,[3] and liquid crystal elastomers.[4,5]

Many other art activities taught valuable lessons in symmetry and geometry. Drawing with an Etch-a-Sketch™ made me a citizen of Flatland,[6] and I spent many happy hours navigating a stylus over a Cartesian plane with knobs controlling x and y positions. To draw a straight line at an angle required exquisite control of both knobs, demonstrating the concept of slope as rise over run and hinting at the idea of a parametrized curve. Molding clay on a potter's wheel gave me an intuitive understanding of shapes with rotational symmetry. With a Spirograph™ toy, I inserted the tip of a pen through a hole in a gear and pushed it around inside an annulus lined with gear teeth, a perfect example of rolling without slipping. I didn't know enough math then to write down equations for the resulting patterns,[7] but I discovered that if I kept the pen moving long enough, eventually I would end up back at the starting point and the pattern would repeat itself forever.

While neighborhood boys were outdoors playing touch football or shooting hoops, we girls often congregated around a table to play cards or board games. Here was another chance to learn math skills, and not just from making change with fake money. Each game move typically required throwing dice, spinning a wheel, or drawing cards from a shuffled deck; these Monte Carlo processes naturally led to curiosity about probability and statistics. A deck of playing cards also came in handy for math experimentation. I was amazed to discover that eight perfect shuffles restore a 52-card deck back to its original order, a little taste of group theory. It was fun to see the patterns that emerged with each shuffle, and when I accidentally mixed up a couple of cards, it was even more interesting to watch the error propagate.



(a) Macramé (courtesy of Elaine Lieberman, elainecraft.com). (b) Lipid membrane simulation. Reprinted with permission from Reference 3. © 2004 American Physical Society. (c) Liquid-crystal elastomer simulation. Reprinted with permission from Reference 5. © 2013 American Physical Society.

My father taught me to play chess, but none of my female friends showed any particular interest. However, I learned a lot about two-dimensional (2D) lattices by comparing a chess board, where each site has four neighbors, to a Chinese checkers board, where there are six.

My next lesson about crystal structures, unit cells, and dislocations came not in physics class, but in learning to crochet, which is similar to knitting but uses a single hook rather than a pair of

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*Science, technology, engineering, and mathematics

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long needles. My first major crochet project, a square afghan blanket, was designed with a repeated motif, which a scientist would call a unit cell with a basis. I stitched the motif over and over around the edges of the square, with dislocations forming 90° tilt boundaries along each diagonal. My next project was a circular mat stitched in concentric rings. In order to make the growing disk lie flat, it is necessary to add extra stitches in each ring to accommodate the growing circumference. Through trial and error, I learned that adding too few extra stitches induces positive Gaussian curvature, deforming the disk into a bowl, while adding too many extra stitches induces negative Gaussian curvature, making a saddle. But where to put those extra stitches? If placed randomly, they blend invisibly into the texture of the fabric, and the finished mat is round. But if extra stitches in neighboring rings are aligned one above the next, they form tilt boundaries. As a result, the edge of the disk became faceted, forming a 2D polycrystal with triangular grains emanating from the center. Much later in life, I explored how dislocations spontaneously coalesce to form grain boundaries when a 2D crystal undergoes plastic deformation,[8] and how dislocation lines in three dimensions display a morphological instability during pair annihilation.[9]

I recently learned about some exciting work on dislocation patterning by Amir Azadi and his advisor Greg Grason, both of the University of Massachusetts Amherst. Azadi used modeling and simulation to examine the spatial organization of edge dislocations in a 2D crystal confined to the shape of a spherical cap.[10] I was so excited by his project that I immediately got a ball of yarn and crocheted a cap with a dislocation pattern similar to one he had simulated. I wanted to feel it in my own hands, see the formation of facets and their effect on the crystal's equilibrium shape. I also wanted to observe the strains that result when the cap is confined to a round surface. If you see me at a conference with a crochet hook and yarn in hand, chances are I'm using them to explore how topological defects in a 2D crystal induce non-uniform Gaussian curvature.

In spite of all the other social progress that has been made toward gender equity in education and professional life, toys and activity kits for children remain largely segregated by sex. A search for "boy kit" in the toy section of a popular online retailer returns an impressive array of products featuring electric circuits, chemistry, rockets, and robots. A search for "girl kit" brings up an equally impressive array of make-it-yourself jewelry and sewing projects. As much as I worry about girls' lack of access to science toys, life is probably even harder for boys who like to have fun with crafts. Many craft kits are sold in bright pink packaging decorated with flowers, rainbows, butterflies, and photos of smiling girls, clear indications that they're intended for female hands only.

In this depressingly gender-segregated world, I found a few glimmers of hope. There's a kit for girls (note: pink packaging) to get hands-on laboratory experience with liquid–solid transitions, suspensions, and pigments, all while fabricating heart-shaped scented soaps. I'm not sure what message it sends to our girls that we have to lure them to do science by integrating experiments with a craft kit, but I'll take what I can get. Maybe the lucky girl who receives this gift will pursue a career in chemical engineering and work for Procter & Gamble. Even LEGO® now comes in girl-friendly shades of pink and purple, accompanied by dolls. Plus, some truly excellent toys such as Spirograph are sold in gender-neutral packages featuring prominent photos of both girls and boys.

What is particularly difficult to find are fiber craft projects with gender-neutral or boy-friendly themes. The best ones I found are tie-dye kits, including one designed to make T-shirts in olive drab camouflage. For once there is no pink packaging in sight. Considering that many of the world's top clothing designers are male, it does seem odd that not much is available in sewing craft kits for boys.

But the reality is, boys are more likely to receive a "Snap Circuits Junior" kit, with parts to build electronic projects such as a doorbell and a burglar alarm, while girls are more likely to get something like "Stick 'n Style Blinglets" in which they decorate round plastic bracelets with fake adhesive jewels. I can only hope that girls receiving this kit compare the flat edges of the decorative jewels with the curved surface of the bracelets and wonder why the adhesive bond holds better for smaller jewels while the larger ones fall off more easily. Further experimentation will show that for elongated jewels, their adhesive power depends sensitively on how they are oriented with respect to the bracelet's short axis when applied.

It could make a fun science fair experiment, don't you think?

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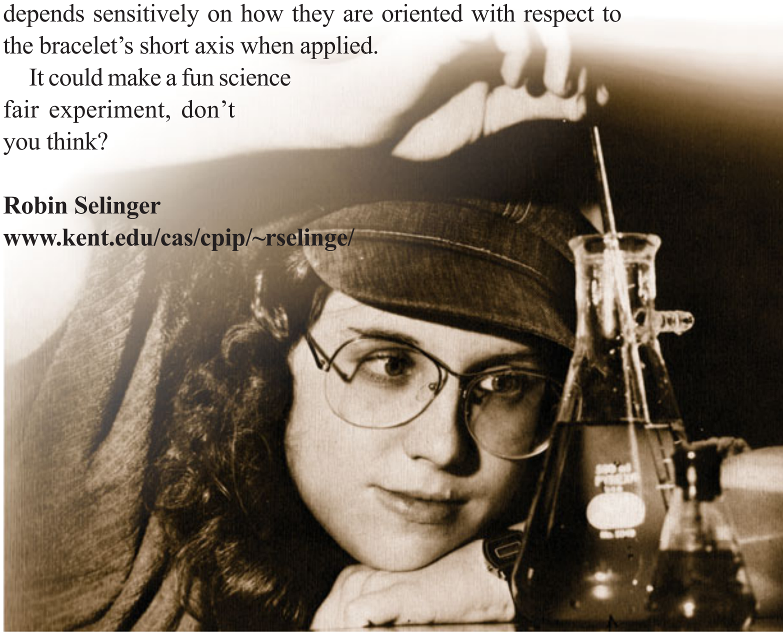

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