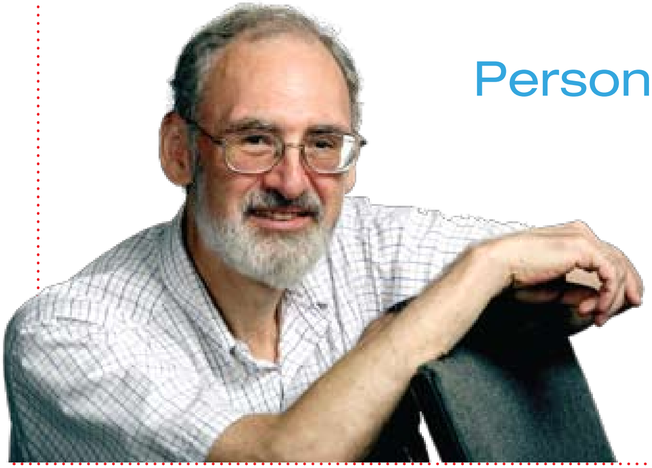
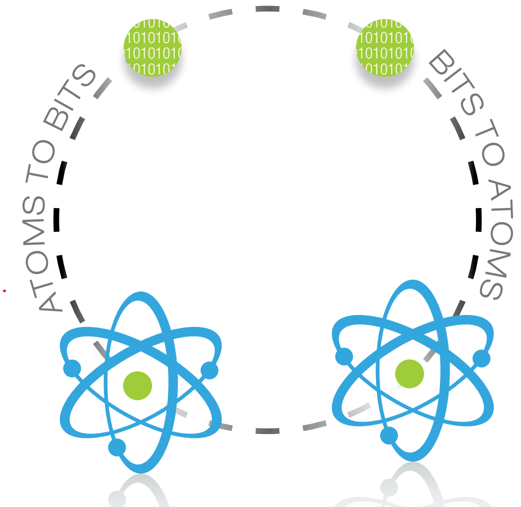


Personal Fabrication Systems: From Bits to Atoms



By Glen Bull and Joe Garofalo

Glen Bull and Joe Garofalo are co-directors of the Center for Technology and Teacher Education in the Curry School of Education at the University of Virginia. They may be reached at: gbull@virginia.edu and garofalo@virginia.edu.

Media—text, images, audio, and video—underwent a transformation from analog to digital formats during the transition from the 20th to the 21st century. Digital media can easily be replicated, downloaded, revised, edited, and reposted, and the implications of this are affecting education, government, entertainment, culture, and society.

The transition from atoms (analog media) to bits (digital media) is the first half of a digital revolution. The second half involves the round trip back from bits to atoms to enable the creation of tangible materials based on digital designs.

Teams of aerospace engineers in different countries from around the globe collaborate on development of digital designs that combine to create a physical aircraft. Computer-controlled manufacturing systems have existed for some time, just as mainframe computers existed prior to minicomputers and microcomputers. However, just as mainframe computers led to minicomputers, engineers at MIT are now employing fabrication laboratories that are the minicomputer equivalent of digital fabrication.

With support from the National Science Foundation (NSF), the MIT Center for Bits and Atoms has developed digital fabrication laboratories, or "Fab Labs," that allow individuals to create almost anything. Fab Labs include devices such as computer-controlled laser cutters and milling machines for assembling 3D structures from 2D parts.

The cost of a Fab Lab is about $50,000, making installation in sites as far flung as India, Ghana, and Costa Rica affordable. These countries are using them to fabricate technologies that address local needs. When the fabrication revolution realizes its potential for design and creation of physical objects in response to real problems, the effects may be even more profound than the transition from atoms to bits that preceded it.

And now, computer-controlled fabrication systems that are the microcomputer equivalent of MIT's Fab Labs are emerging. You can purchase a personal computer-controlled die-cutting machine that shapes paper, cardboard, and vinyl for the same price as an ink-jet printer—that is, for less than $500. The advent of personal fabrication systems makes it possible for schools to begin exploring the educational implications of the digital fabrication revolution today.

Fabrication

Teachers, especially in the elementary grades, construct a variety of materials for manipulatives, bulletin boards, etc. In fact, most schools already have mechanical die-cutting systems.

Parallel Evolution of Computing and Digital Fabrication		
$5,000,000	$50,000	$500
Mainframe	Minicomputer	Microcomputer
Computer-controlled manufacturing plants	MIT Fabrication Laboratory	Personal fabrication systems

Mechanical systems require purchasing an individual die for each premade shape. In contrast, you can use computer-controlled systems to create any shape you can imagine and draw on the computer.

We are already benefiting from this capability. In a project supported by the U.S. Department of Education, we are providing sets of physical manipulatives to teachers to facilitate math and science exploration. Teams of graduate students used to create these manipulatives by manually cutting them out with scissors, but now computer-controlled fabrication systems can automate this task.

Providing teachers with personal fabrication systems is the next logical step so they can download and fabricate the manipulatives themselves. This makes it possible to personalize manipulatives through choice of medium—cardstock, vinyl, chipboard, etc.—fabricate them on demand, and individualize them for specific instructional objectives.

Teaching

There are educational opportunities for addressing subject matter content across almost every subject and grade level. Paper engineering dates to the 13th century and has been used to illustrate a variety of topics involving natural science, astronomy, and mathematics. Today's school activities address many of these same topics.

The MIT Center for Bits and Atoms has developed digital fabrication laboratories that allow individuals to create almost anything.

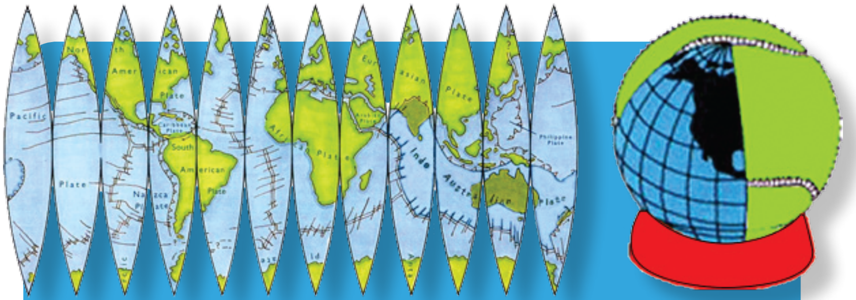
USED WITH PERMISSION, SHERRY LASSITER, MIT

Science. John Lahr, a U.S. Geological Service seismologist, and his colleague Tau R. Alpha have adapted geological and earth science resources that teachers can use to construct models for school science projects. For example, the model below of the globe depicting the Earth's major tectonic plates is designed to be assembled with the aid of a tennis ball.

Mathematics. Creation of 3D polygons can assist with the study of geometry in mathematics. The National Council of Teachers of Mathematics (NCTM) publication *Polyhedron Models for the Classroom* offers a good starting point for math projects. You can purchase this through NCTM or obtain a free PDF through the U.S. government's Educational Resources Information Center.

Teachers can use these projects to stimulate interest in math without requiring extensive math skills for basic projects, whereas advanced projects can involve extensive mathematics skills concepts.

Magnus Wenniger, author of the introduction to *Polyhedron Models for the Classroom*, now uses a program called Stella to design his projects. This program provides a 3D perspective as well as the 2D view needed for construction and assembly.



Students can transform a flat projection of the globe into a 3D depiction of the earth by applying it to the surface of a tennis ball.

Elementary grades. Teachers in elementary grades can use static cling inkjet film to produce customized Colorforms-like sets.

You can apply die-cut vinyl images and shapes to a background via static-cling, then reposition them to create new scenes. You can use characters and scenes for storyboarding projects in language arts, and historical maps and sites can facilitate social studies instruction.

Software

Existing educational software applications also lend themselves to use with personal fabrication systems. This includes software such as the Diorama Designer, the Neighborhood MapMachine, and the Neighborhood Construction Kit offered through Tom Snyder Productions.

Makers designed these programs with materials creation and development in mind. As personal fabrication systems become more widely used, This 3D model (below), derived from a 2D drawing, illustrates the conversion of linear motion to rotary motion.

USED WITH PERMSSION, TOM SNYDER PRODUCTIONS

Software such as the Neighborhood Construction Kit allows students to design 2D maps, 3D counterparts, and the corresponding Web equivalent.

other educational programs will begin to incorporate this capability.

If you would like to explore some of the possibilities now, Parent's Choice—a nonprofit organization that offers guidance on children's media—provides downloadable templates for constructing a 3D town. The free templates include 3D houses, shops, schools, libraries, and other buildings along with instructional activities developed by Peggy Stearns.

Engineering Design and Workforce Readiness

Grants from NSF and the MacArthur Foundation have made it possible to implement Fab Lab initiatives that focus on engineering design and workforce readiness. The Sustainable South Bronx project established by Majora Carter received a MacArthur grant to bring a Fab Lab to that community. Similarly, an NSF grant has allowed the Midwest Digital Fabrication Partnership to establish a Fab Lab in that area.

Personal fabrication systems are inexpensive cousins of MIT's fabrication laboratories and can be used in similar ways to encourage scientific thinking and development of authentic engineering skills. Paper engineering engages students at many levels. It involves abstract concepts and visualization, as well as problem solving in the physical world. Computer-controlled die cutters expand and extend these kinds of projects.

And there is another long-term benefit. Increased student engagement in science, technology, engineering, and mathematics (STEM) fields has been identified as an important national priority. In fact, the NSF has concluded that this will be critical to the nation's future in a competitive global economy.

Personal Fabrication Systems

A half-dozen personal fabrication system models are available, and more are likely to emerge in this fast-moving field. Graphtec offers industrial models for $15,000 or more but also offers personal fabrication systems. The principles on which manufacturers base their models are similar: More capable models simply handle thicker, larger materials.

The CraftROBO, a unit designed for personal use, may be a useful starting point. The CraftROBO Pro is a larger model that can be used in the school library or media center to produce multiple sets of materials for every child in a class. The CraftROBO costs about $300, and the CraftROBO Pro is less than $1,000.

Fabrication technologies provide exposure to many mathematical and engineering concepts. Scaffolded practice for students in upper elementary grades and above provides the opportunity to see abstract visualizations—including students' own drawings and sketches on the computer—translated into physical objects, offering an opportunity to explore these ideas at an early age in a very concrete way.

In later grades, students can study compound machines in science class, use mathematics to design their own digital models, and then fabricate their designs as three-dimensional objects. These types of activities give students direct experience with vectors and geometric transformations that are useful in many STEM-related fields.

Engineers and architects move between the digital world of the computer and the physical world, visualizing the result that occurs when a 2D drawing on the screen is transformed into a 3D object. Students in school can understand mathematical concepts by making connections between virtual and physical representations. These activities can simultaneously prepare them for 21st-century careers.

Resources

ERIC: www.eric.ed.gov
National Council of Teachers of Mathematics: www.nctm.org
Parent's Choice: http://parentschoice.org/article.cfm?art_id=254&thepage=consider_this
Stella: www.software3d.com
Sustainable South Bronx Project: http://ssbxfab.org
Tau Rho Alpha's paper models: http://jclahr.com/alaska/aeic/taurho
Tom Snyder Productions: www.tomsnyder.com