**Anthropology and Education**

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# Culturally Situated Design Tools: Ethnocomputing from Field Site to Classroom

**ABSTRACT** Ethnomathematics is the study of mathematical ideas and practices situated in their cultural context. Culturally Situated Design Tools (CSDTs) are web-based software applications that allow students to create simulations of cultural arts—Native American beadwork, African American cornrow hairstyles, urban graffiti, and so forth—using these underlying mathematical principles. This article is a review of the anthropological issues raised in the CSDT project: negotiating the representations of cultural knowledge during the design process with community members, negotiating pedagogical features with math teachers and their students, and reflecting on the software development itself as a cultural construction. The move from ethnomathematics to ethnocomputing results in an expressive computational medium that affords new opportunities to explore the relationships between youth identity and culture, the cultural construction of mathematics and computing, and the formation of cultural and technological hybridity. [Keywords: mathematics, computing, youth subculture, indigenous knowledge, identity]

CULTURAL ANTHROPOLOGY has always depended on acts of "translation" between emic and etic perspectives. Some of these translations have become formal subdisciplines—ethnobotoany, ethnomedicine, archaeoastronomy, and so forth. The subdiscipline of "ethnomathematics" is more recent and much more controversial. First, some ethnomathematics research provides an unusually strong challenge to the primitivist view that indigenous (i.e., band or tribal) societies had only simplistic technologies: It is one thing to claim that the natives have many herbal cures, another to claim they are well versed in graph theory or topology. The second controversy stems from the applications of ethnomathematics to contemporary K–12 mathematics education. Here, ethnomathematics enters the "culture wars" debates over classic curricula versus multiculturalist revision. Finally, ethnomathematics also participates in the "science wars" debate over the social construction of science and technology: Is math universal or does it vary from culture to culture? This article describes the role that these and other social science issues have played in the development and evaluation of a suite of computer simulations of indigenous and vernacular artifacts and practices, termed *Culturally Situated Design Tools* (CSDTs). These design tools are not only promising in their initial evaluations of impact on minority academic achievement but they also open new possibilities for anthropological research.

## ETHNOMATHEMATICS VERSUS MULTICULTURAL MATHEMATICS

Anthropologists and other researchers have revealed sophisticated mathematical concepts and practices in the activities and artifacts of many indigenous and vernacular cultures (e.g., see Ascher 1990, 2002; Closs 1986; Crump 1990; D'Ambrosio 1990; Eglash 1999; Gerdes 1991; Urton 1997; and Zaslavsky 1973; for a theoretical overview, see Eglash 1997b). These practices include geometric principles in craft work, architecture, and the arts; numeric relations found in measuring, calculation, games, divination, navigation, and astronomy; and a wide variety of other artifacts and procedures. In some cases, the "translation" to Western mathematics is direct and simple: as with counting systems and calendars, for example. In other cases, the math is "embedded" in a process—iteration in bead work, Eulerian paths in

*American Anthropologist*, Vol. 108, Issue 2, pp. 347–362, ISSN 0002-7294, electronic ISSN 1548-1433.

sand drawings, and so forth—and the act of translation is more like mathematical modeling.

What is the difference between ethnomathematics and the general practice of creating a mathematical model of a cultural phenomenon (e.g., the "mathematical anthropology" of Paul Kay [1971] and others)? The essential issue is the relation between intentionality and epistemological status. A single drop of water issuing from a watering can, for example, can be modeled mathematically, but we would not attribute knowledge of that mathematics to the average gardener. Estimating the increase in seeds required for an increased garden plot, on the other hand, would qualify. Some cases of indigenous practice are, however, not as clear-cut.

For example, in 1999–2000, a debate in *Critique of Anthropology* briefly flourished between Stefan Helmreich (1999) and Steven Lansing (2000)—over Lansing's computer models of Balinese rice irrigation. Helmreich held that Lansing's description of an evolutionary optimization in irrigation schedules "naturalized" the Balinese in ways that eliminated their intentionality. But Lansing's own book provided detailed description of the indigenous knowledge systems involved—in particular, the Tika calendar, which is clearly artificial and intentional. Should we then conclude that the Balinese have an intentional, explicit mathematics of computational optimization? That would clearly be going too far in the other direction. The epistemological status of Balinese irrigation mathematics lies somewhere between unconscious social process and deliberate, explicit knowledge.[1] Ethnomathematics research often uses the term *translation* to describe the process of modeling indigenous systems with a "Western" (i.e., mainstream, academic) mathematical representation; however, as with all translation, the success is always partial, and intentionality is one of the areas in which the process is particularly tricky.

Such subtleties can be easily lost, however, when moving from research to application in education. Given the strict regulation of standards in the United States created by the No Child Left Behind Act (Public Law 107–110), mathematics teachers are under a great deal of pressure to stick to a standardized curriculum. At the same time, the importance of making "real world" connections in math instruction, especially those making use of the heritage culture of students, has been increasingly recognized. As a result, U.S. teachers have been attracted to the area of "multicultural mathematics,"[2] which often substitutes the anthropological specificity of ethnomath for a variety of dubious shortcuts.

First, some examples from multicultural mathematics take standard First World word problems and give them a superficial Third World gloss: Rather than Dick and Jane counting marbles, "Rain Forest Mathematics" gives us Taktuk and Esteban counting coconuts (Jennings 1996). Second, it is easier to take a more literal-minded approach and use strictly numeric systems (e.g., counting) than to look at embedded mathematics (architecture, crafts, etc.), which requires modeling. Thus, there are texts such as *Multicultural Mathematics* (Nelson et al. 1993), which emphasize only Chinese, Hindu, and Muslim examples, because they have far more numeric calculations than the indigenous band and tribal societies of sub-Saharan Africa, North America, South America, and the South Pacific. Those particular Asian and Arabic "empire civilizations" produced mathematics that easily translates into the standard curriculum because they were large state societies with the labor specialization and associated tasks that tend to require extensive numeric calculations, similar to the society that the math teachers now inhabit. There is nothing wrong with including such examples in the cross-cultural mathematics repertoire; we would be remiss if we did not. But restricting curricula only to examples from these non-Western state societies merely exacerbates the "orientalist" myth of abstract Asian and Arabic minds. By the same token, there is nothing wrong with including ancient Egypt as one example of math from the African continent, but if it is implied to be the only math from Africa then it can inadvertently primitivize the rest of the continent.[3] Finally, in the few cases in which actual indigenous mathematical practices are used, most examples are restricted to lower primary school level—"African houses are shaped like cylinders"—again reinforcing primitivism, rather than opposing it.

In short, although there is much good done under the rubric of multicultural mathematics, it also runs the danger of acting as a sort of safety valve, satisfying diversity requirements without challenging the most deleterious misconceptions. There is, however, a second, more subtle area in which the multicultural math approach has run into trouble, and that is in its implicit models for identity. When asked about the reasons why they might want to include culture in mathematics class, teachers often respond by saying something like "students might relate better to examples that come from their own culture."[4] There are implicit assumptions at work in such statements—almost a folk anthropology—that maintain that we each have a specific culture, and that it is a given, static entity to which our personal identity is fused in a kind of mimetic relationship. This stands in strong contrast to the portraits of race, class, and gender hybridity offered by research in contemporary youth subculture (Davidson 1996; Gilroy 1993; Hebdige 1979; Pollock 2004). It is our contention that multicultural education that abides by this folk-anthropology and assumes a singular, static, pregiven identity will be less effective. Our goal in emphasizing the design aspect of CSDTs—the ways in which they allow students to utilize a synthesis of math, computing, and culture in creative expression—is to provide better support for students to take advantage of their "self-making" abilities in ways that can enhance academic performance.

In summary, we can contrast ethnomathematics to multicultural mathematics using the following four principles.

**1. Deep design themes.** When examined in their social context, indigenous mathematical practices are not trivial or haphazard; they often reflect deep design themes providing a cohesive structure to many of the important knowledge systems (cosmological, spiritual, medical, etc.) for that society. Examples include the pervasive use of fractal geometry in African design (Eglash 1999) and the prevalence of fourfold symmetry in Native American design (cf. Díaz 1995; Klein 1982; Witherspoon and Peterson 1995).[5]

**2. Anti-primitivist representation.** By showing sophisticated mathematical practices, not just trivial examples (e.g., "African houses are shaped like cylinders"), ethnomathematics directly challenges the epistemological stereotypes most damaging to minority ethnic groups.

**3. Translation, not just modeling.** Often indigenous designs are merely analyzed from a Western view; for example, applying the symmetry classifications from crystallography to indigenous textile patterns. Ethnomathematics also makes use of modeling, but here it attempts to use modeling to establish relations between the indigenous conceptual framework and the mathematics embedded in related indigenous designs, such that the mathematics can be seen as arising from emic rather than etic origins. This is critical in contesting biological and cultural determinism.

**4. Dynamic rather than static views of culture.** Although evidence for independent indigenous mathematics is crucial in opposing primitivism, it is also important to avoid the stereotype of indigenous peoples as historically isolated, alive only in a static past of museum displays. For this reason, ethnomathematics includes the vernacular practices of their contemporary descendents; for example, the "street mathematics" of Latino pushcart venders, graffiti art, and so forth (Nunes et al. 1993).

## FROM ETHNOMATHEMATICS TO ETHNOCOMPUTING

The computational component of this research began with the research by one of the coauthors (Ron Eglash) on modeling traditional African architecture using fractal geometry. Fractals are patterns that repeat themselves at many scales; they are usually used to model natural phenomena such as trees (branches of branches), mountains (peaks within peaks), and so forth. Both computer simulations and measurement of fractal dimension of these traditional village architectures showed several repetitions ("iterations") the same pattern at different scales: circular houses arranged in circles of circles, rectangular houses in rectangles of rectangles, and so on. Eglash's year of fieldwork in West and Central Africa (sponsored by the Fulbright program) showed that these architectural fractals result from intentional designs, not simply unconscious social dynamics, and that such iterative scaling structure can be found in other areas of African material culture—art, adornment, religion, construction, games, and so forth—often as a result of geometric algorithms known (implicitly or explicitly) by the artisans (Eglash 1997a, 1999).

Although there are many potential implications and applications of the "African Fractals" thesis, the strongest appeared to be the possibility for using this African mathematics in the classroom. With the help of a small seed grant (the AAA 2001 "Integrating Anthropology into Schools" award), and collaborators in Utah and Idaho (professor James Barta and tribal member Ed Galindo), we also began a new effort toward Native American design tools. Expanding the project to Latino ethnomathematics as well, and placing the proposed tools for all three ethnic groups under the collective title of CSDT, we applied for and received three federal grants: a Housing and Urban Development Community Outreach Partnership Centers (COPC) grant, a Department of Education Fund for the Improvement of Post-Secondary Education grant, and a National Science Foundation (NSF) Information Technology Work Force (ITWF) grant. The latter also expanded evaluation of the impact from mathematics achievement to the science and technology career pipeline: Would minority students exposed to these design tools increase their interest in information technology careers? Although ethnomathematics is an established field, the computational aspects of this research seemed to ask for a slightly different rubric: Matti Tedre of the University of Joensuu in Finland has suggested the term *ethnocomputing*, which seems a better fit (cf. Tedre et al. 2002).

The funding allowed us to hire ethnomathematics consultants at specific locales in which there was a significant population of one of our three target groups (African American, Native American, and Latino). These included faculty members at universities who were working with teachers, the teachers themselves, and community members such as elders and artisans. Together with the students, each locale constituted a field site in which we solicited ideas, gathered feedback on prototypes, evaluated student learning, and carried out professional development. This also enabled the development of a "cultural background" section for each design tool, so that students could understand the social context of the practice as well as its underlying mathematics.

## ANTHROPOLOGICAL RESEARCH AND THEORY ISSUES IN ETHNOCOMPUTING

At the same time that we carried out the application of CSDTs to the problem of minority student achievement, we also attempted to use this opportunity to explore the associated research and theory issues. In some ways these resembled any other cultural study: Representation is always a critical issue in anthropology, and like any ethnographers we grapple with the power relations and politics of shared voices. Some CSDTs, for example, concern Native American tribes, for which those considerations are heightened because of both political history and popular misrepresentations. A tool that represents a practice carried out by multiple tribes, such as the Virtual Bead Loom, must also resolve intertribal conflict over representations. Other CSDTs concern youth subculture, in that we are caught between the K–12 school demands to avoid advocacy of "inappropriate" activity (Cousins 1999) and the need to faithfully represent subculture practices such as graffiti.

What made this project somewhat different from other representations of culture was the computational aspects. On the one hand, many anthropological projects have made use of electronic media for detailed cultural portraits, but even "interactive" media are typically a matter of users pressing a button to see an image or video clip (cf. Banks 1994 for skepticism on its impact in cultural anthropology; Clarke 2004 on the impact of electronic media in archaeology representations). On the other hand, the field of "computational anthropology" has taken advantage of computer simulations ranging from population dynamics of the !Kung (Howell and Lehotay 1978) to agent-based simulations such as "Artificial Anasazi" (Axtell et al. 2002). But in such computational anthropology, there is little role for ethnographic portraits or representations of visual culture; its simulations are primarily composed of numeric variables of kinship, reproductive rates, and other demographic data. Because the CSDT project combines both the representational aspects of electronic media and the computational aspects of these simulation systems, we might classify our project as something more along the lines of "computational ethnography," combining quantitative formal modeling with the kinds of collaboratively developed cultural portraits of the classic ethnographic approach.

Computational ethnography, as we envision it here, might span the range of endeavors from social studies of technology to technological studies of societies. At the social end, ethnocomputing can act as a kind of cultural "probe": What happens when you ask traditional Afro-Cuban drummers to create a mathematical simulation of their rhythms or graffiti artists to draw on a computer screen? At the technological end, it is useful for probing our own convictions: How do we reconcile our sense that zero degrees lies along the horizontal, with the Yupik understanding that the horizontal is at 90 degrees? How do we reconcile our understanding of mathematics as a human invention with the Shoshone position that it existed before humans? Computational ethnography helps us make our own assumptions visible; we begin to see that some "self-evident" aspects of math or technology are actually choices that could have been otherwise.

The following three sections describe some of the best examples from the design tools, highlighting the ways in which the tools emerged through the "trialectic " of computing, cultural anthropology, and math education.

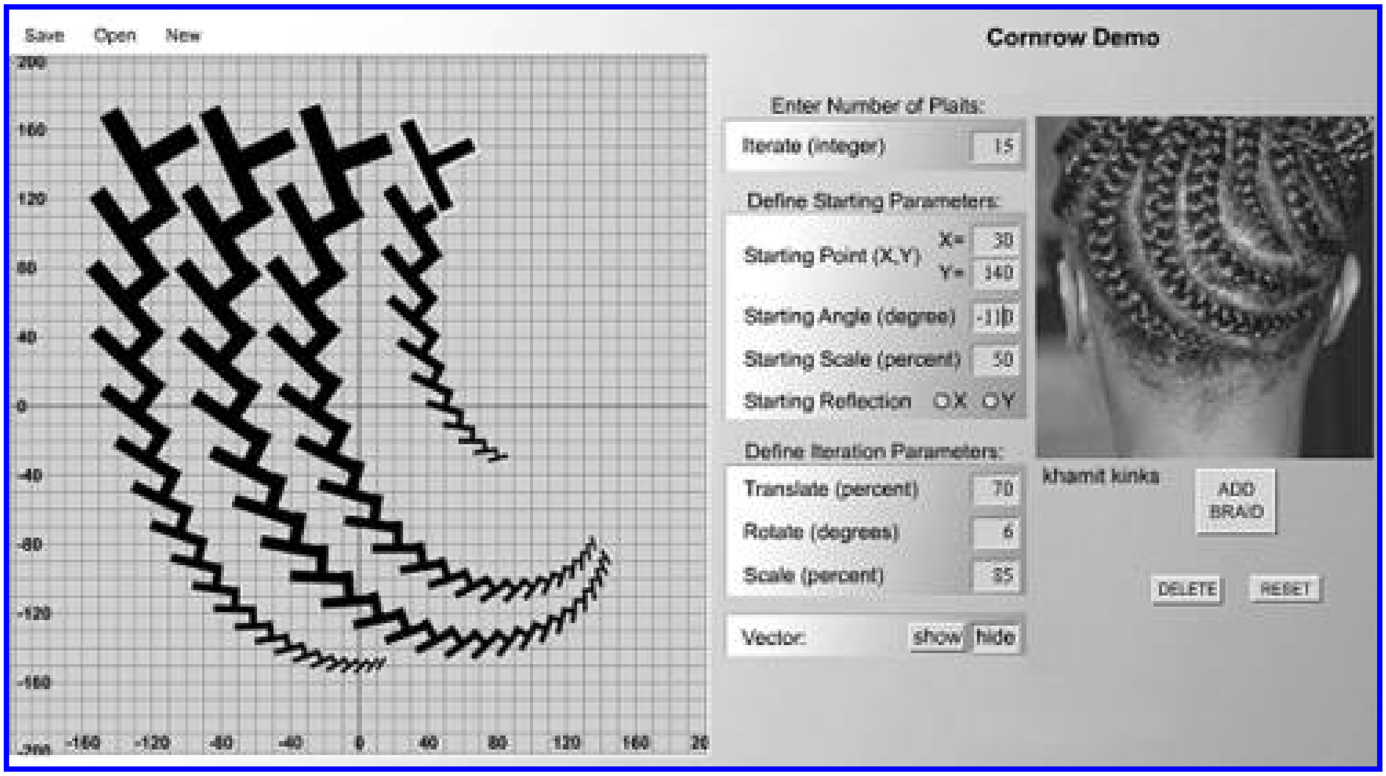
## AFRICAN AND AFRICAN AMERICAN DESIGN TOOLS

As noted previously, we began with the "African Fractals" material.[6] Presentations at meetings of the National Council of Teachers of Mathematics provided the opportunity to discuss the material with middle school and high school teachers from inner-city schools and other areas with large African American student populations. They were excited about the new perspective on African math but skeptical about its practical use in the classroom. Teachers cited the lack of fit to the K–12 standard curriculum (fractal geometry is typically a college-level course) and the lack of fit to the students' own cultural knowledge: They did not think their (predominantly) African American students knew much about Africa, and some doubted they would care about it much either.

The cultural challenge of making the connection with African American students who had little knowledge of Africa was solved by three innovations. First, following teachers' suggestions, we focused on the example of fractal patterns in cornrow hairstyles (see Figure 1). Mathematically, cornrows work as fractals because most styles allow each crisscross ("plait") of the hair to diminish progressively in size, creating many iterations of scale in a single braid. Culturally, cornrows work for these students because they are both deeply embedded in African culture (Boone 1986) and an ongoing innovative practice in contemporary African American culture. We found that very few students knew that cornrows originated in Africa, so on the design tool website we developed a historical background page. This included images and information covering the indigenous styles and their meaning in Africa, their first appearance among early African Americans in the pre–Civil War era, their survival and eventual rebirth in the civil rights movement and hip-hop culture. Finally, we also created a series of "goal images:" photos of styles for students to simulate, including both professional styles and photos the students took of themselves and their friends. This helped students to make the connection from contemporary vernacular identity to heritage identity, which then opened up a wide selection of indigenous African fractal patterns for additional simulation. The most successful has been one based on Mangbetu design (see Figure 2).

We solved the problem of curricular fit by changing the emphasis from fractal geometry to transformational geometry—each plait is given some particular rotation, translation (spacing), scaling, and reflection. Because these transforms are part of the standard curriculum, it satisfied the math teachers. Starting with the braid designs, students quickly caught on to the art of creating simulations using these controls. One of the interesting conversations among the students (primarily African American in our workshops) was speculation on whether or not hair stylists could be said to know these parameters. Some excitedly reported that they now realized they have been doing math all along and just did not know it (that you had to think about how you were rotating or scaling the plaits as you braided); others said braiding was pure unthinking intuition (although they too reported that they enjoyed using the design tool). We also found that we could also use the simulation to pose ethnomathematics research questions: As you move through a series of braids, which parameters were altered and which remained unchanged? How do hairstylists think about the same issue?

After students create a successful hairstyle simulation, we then ask them to develop their own designs using Cornrow Curves. Figures 2 and 3 show two samples of this student work. Figure 3A is from an African American student whose father came from Ethiopia; she titled this design "Tisissat" and added the comment "I named this after the largest waterfall in Ethiopia. It shows strength and


Cornrow Demo

Enter Number of Plaits:
Iterate (integer) 15

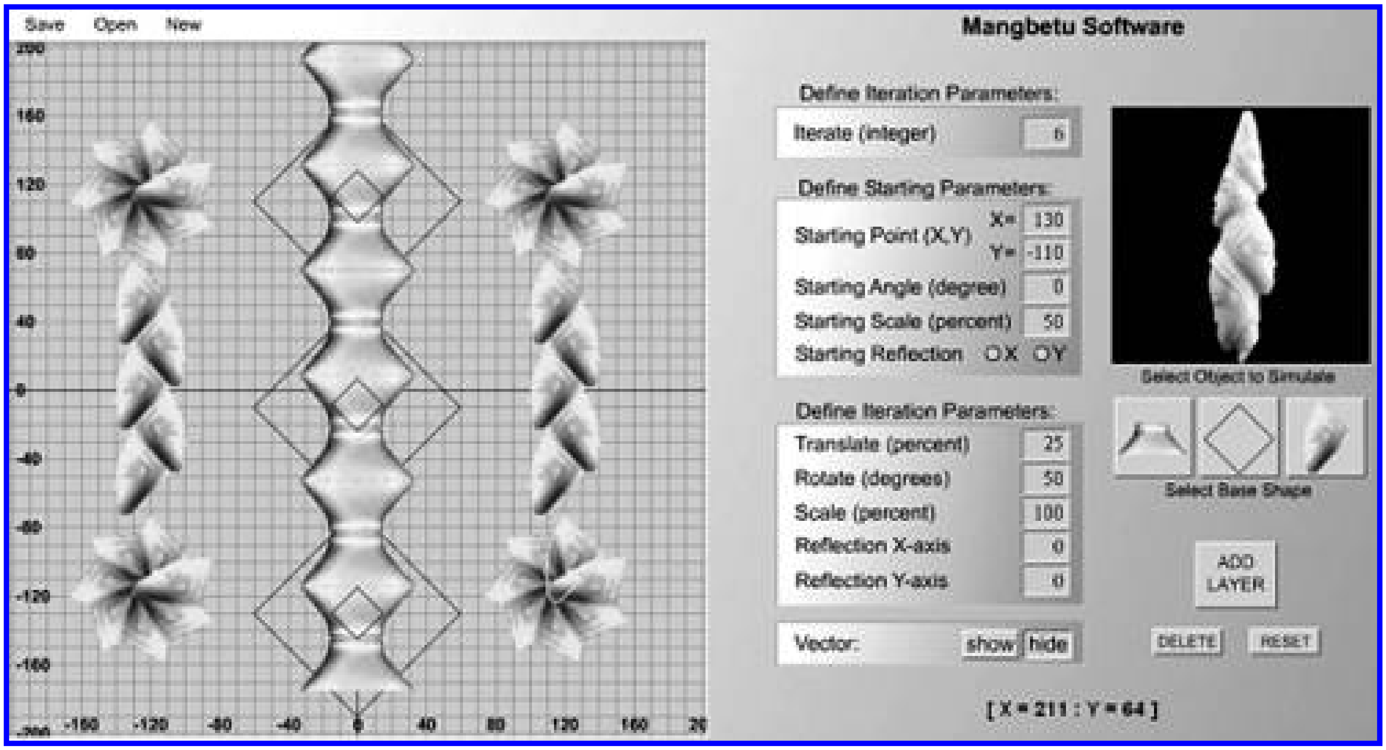
Define Starting Parameters:
Starting Point (X,Y) X= 30 Y= 140
Starting Angle (degree) -110
Starting Scale (percent) 50
Starting Reflection ○X ○Y

Define Iteration Parameters:
Translate (percent) 70
Rotate (degrees) 6
Scale (percent) 85

Vector: show hide

khamit kinks

**FIGURE 1.** Cornrow Curves: at right an original hair style selected by the student; at left the student's simulation, generated by the parameters in the center control panel.


Mangbetu Software

Define Iteration Parameters:
Iterate (integer) 6

Define Starting Parameters:
Starting Point (X,Y) X= 130 Y= -110
Starting Angle (degree) 0
Starting Scale (percent) 50
Starting Reflection ○X ○Y

Define Iteration Parameters:
Translate (percent) 25
Rotate (degrees) 50
Scale (percent) 100
Reflection X-axis 0
Reflection Y-axis 0

Vector: show hide

[ X = 211 : Y = 64 ]

**FIGURE 2.** Mangbetu Design pattern created by a student for artistic purposes rather than simulation of an artifact.

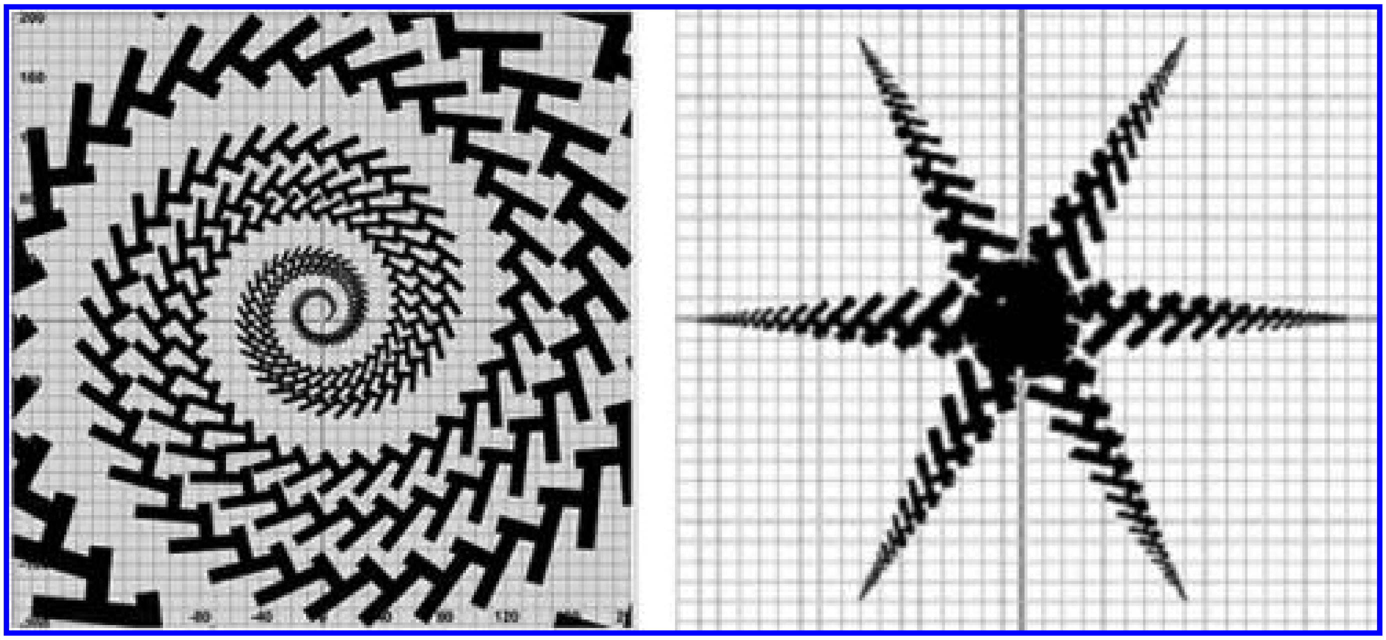


**FIGURE 3.** A. "Tisissat." B. "Snowflake."

holding people together." The second is from a student who self-identified as Puerto Rican. He was a "problem student," disrupting the class and not getting much done. He finally hit on the idea of making simulations of snowflakes. He researched real snowflakes on the web, and figured out how to get the cornrow software to make the proper angles for six-fold symmetry and the proper scaling ratios for its arms (see Figure 3B). It was an enormous triumph for him: The other students gave him high fives when they saw what he had done, his mother heard about it and came in to visit the computer lab, and it greatly improved his overall attitude. The fact that he had violated our own focus on the simulation of cultural artifacts was completely irrelevant. The fundamental goal for design tools is to empower the students' sense of ownership over math and computing; on the basis of that objective, it was a strong success.

After students have completed both the cornrow and Mangbetu software experiences, we ask them why they think they were able to use iterative scaling for both simulations. They are quick to answer that it is because both originate from the same African origins:[7] an indication that for these students math and computing has now become a potential bridge to cultural heritage, rather than a barrier against it. Reflecting on teachers' warnings that African American students might not care about African culture, it seems less a question of ethnic pride than one of context and motivation: Given a chance to incorporate some agency into their encounter—to creatively improvise with these cultural materials—these students often find it fascinating. It is not simply a matter of using a static, preformed identity to "lure" students into doing math or computing. Identity is always in a process of self-construction (Hermans 2001). That self-construction is, of course, going on regardless of our presence, but as Foucault suggested in his phrase "technologies of the self" it is constrained and enabled by the various resources at hand. Our goal is in creating a culture-enriched computational medium that offers students new opportunities in identity self-construction—opportunities that we hope will provide them with critical tools and perspectives for both social and technical domains, as well as the interrelationships between the two.

## NATIVE AMERICAN DESIGN TOOLS

Our current Native American design tools include "SimShoBan" (Eglash 2001), Yupik Navigation, Yupik Parka Patterns, Alaskan Basket Weaver, Navajo Rug Sim, and the Virtual Bead Loom (VBL). Because of space constraints, we focus on the VBL here. This portion of the project began in the spring of 2000 at the Shoshone-Bannock secondary school. We decided that the geometric patterns in Shoshone-Bannock beadwork would be a good choice for a new design tool for the following reasons:

1. It is a vibrant contemporary art form on the reservation but has deep (precolonial) historical roots.
2. The rows and columns of the loom are analogous to the deep design theme of fourfold symmetry in Native American cultures.
3. The two axes of the loom offer an analog to the Cartesian Coordinate system and thus provide a good match for standard school curricula.

In retrospect, we can see that these criteria were the same as those used to select cornrows: It connects contemporary vernacular culture, traditional heritage culture, and the standard curriculum. Back at Rensselaer, we assembled a software prototype for the VBL. The webpage begins by showing the prevalence of fourfold symmetry in Native

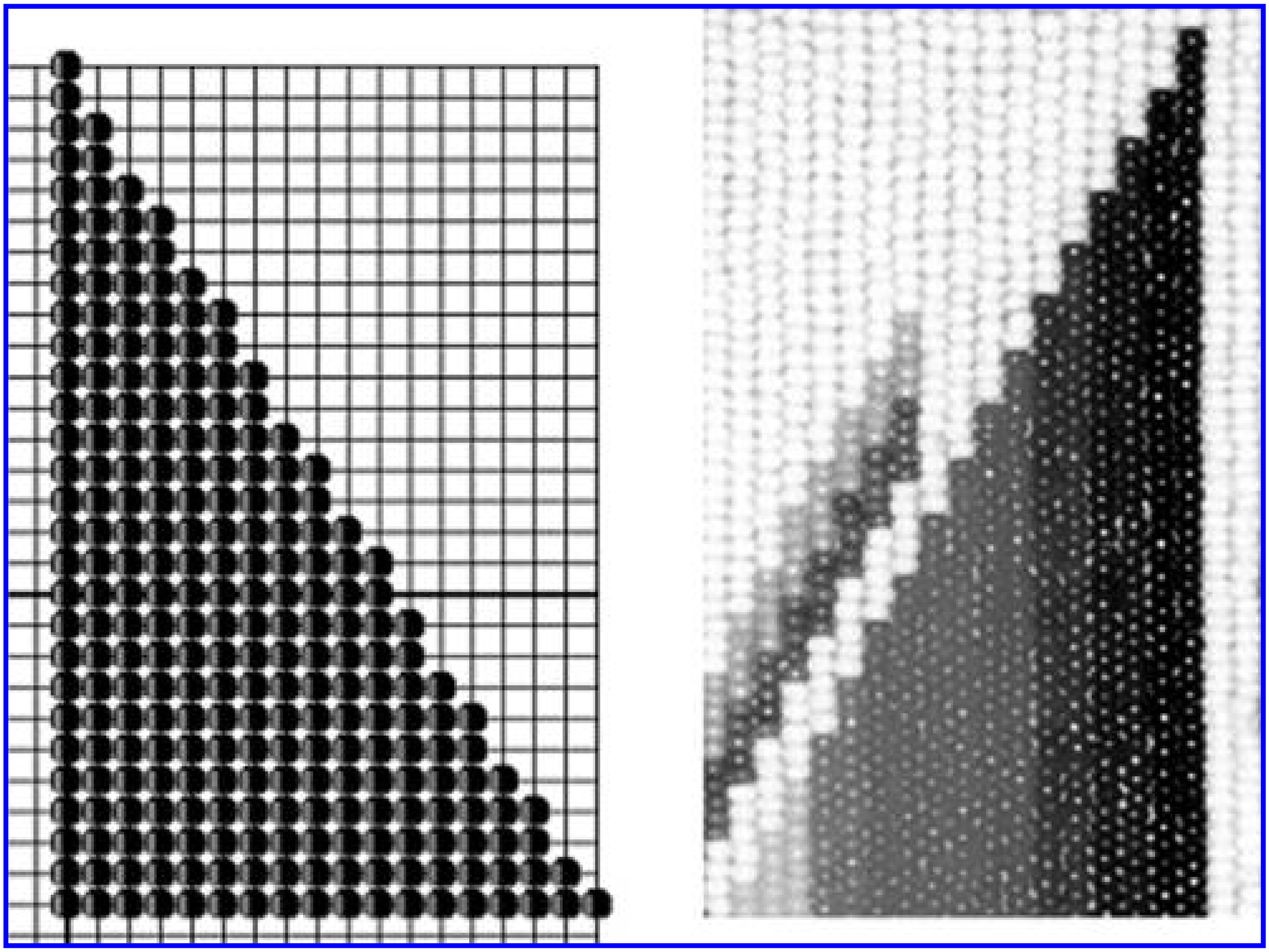


**FIGURE 4.** A comparison of uneven steps in a Virtual Bead Loom triangle (left) and even steps in Shoshone-Bannock beadwork (right).

American design in general and for the bead loom in particular. The web-based software allows the user to enter $x$, $y$ coordinates for bead positions; together with color choice, this allows the creation of patterns similar to those on the traditional loom. We also put together a “cultural background” section showing how the concept of a Cartesian layout can be seen in a wide variety of native designs: Navajo sand paintings, Yupik parka decoration, Pawnee drum design, and other manifestations of the “Four Winds” concept. One native student who had at first been skeptical about combining technology with native design suddenly “got it”—realized the ethnomath claim that Native Americans had developed an analog to the Cartesian coordinate system—and said “They will never let you get away with this.” We asked, “Who won’t let us get away this?” and she replied “White people” (conversation with authors, November 4 2000).

However, the prototype only allowed creation of a pattern with single beads. This was clearly too tedious, and so after discussion with potential users, we introduced shape tools—enter two coordinate pairs for a line, three coordinates pairs to get a triangle, and so forth. But these virtual bead triangles often had uneven edges, whereas the original Shoshone-Bannock beadwork always had perfectly regular edges (see Figure 4). It turned out that our programmer, STS graduate student Lane DeNicola, had looked up a standard “scanning algorithm” for the triangle generation; however, somehow the traditional beadworkers had algorithms in their heads that produced a different result. After a few conversations with beadworkers, it became clear that they were using iterative rules—for example, “subtract three beads from the left each time you move up one row.” We developed a second tool for creating triangles—this one using iteration—but kept the first in the VBL as well for comparison. This has provided a powerful learning opportunity: If you tell someone that there is such a thing as a “Shoshone algorithm,” they may balk at the suggestion; but let them compare the standard scanning algorithm with that used by the Shoshone beadworkers, and the ethnomathematics implications are difficult to ignore.

How should we regard this contrast between the two algorithms in terms of theories of knowledge? At one

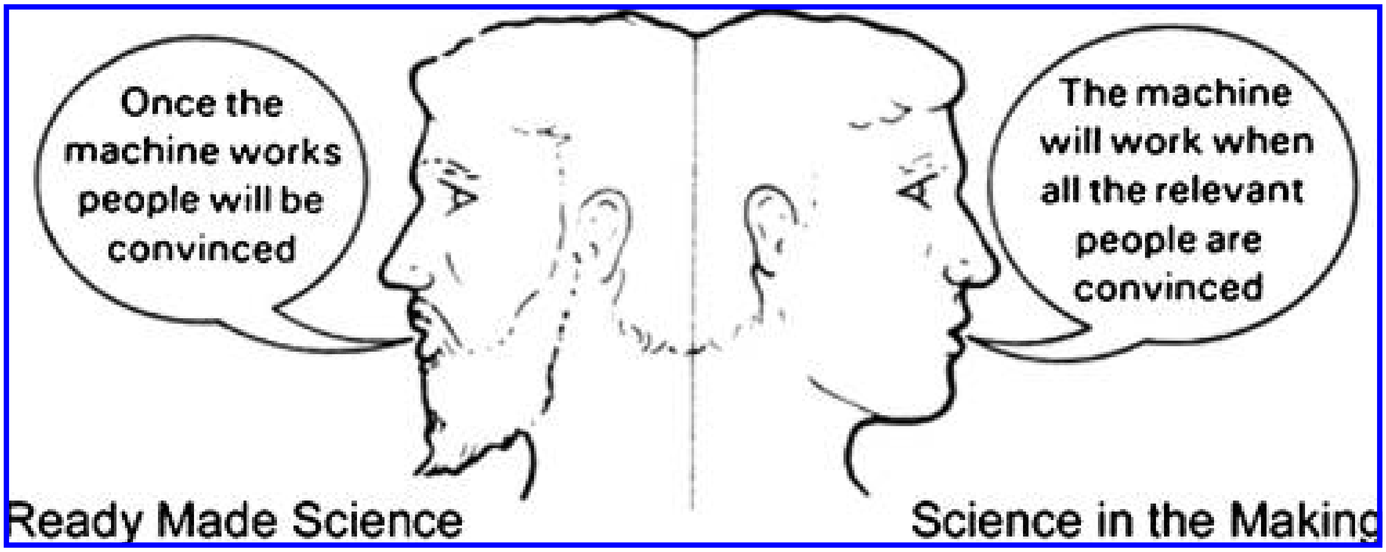


**FIGURE 5.** "Ready Made Science" versus "Science in the Making."

extreme, we could simply dismiss the difference as a failure to properly specify software design goals—after all, no one told the programmer to make sure the software only produces triangles with even stepping. At the other extreme, we could celebrate this as evidence for a mathematical version of cultural relativism, claiming that there is not one universal math but only many locally produced "maths." We reject both of these extreme positions, as neither really provides an adequate social account of technological design.

The problem with the first extreme position is nicely illustrated with the Janus figure from Bruno Latour's *Science in Action* (1987; see Figure 5). At the left is the face of "Ready Made Science," at the right is "Science in the Making." Latour produced this figure to describe an event from Tracy Kidder's *Soul of a New Machine* (1981), in which hardware engineers battle marketing, management, software, and other corporate divisions to champion their new (yet to actually work) computer design. Our first proposition—that we did not give the programmer adequate function specifications—is the view from the older Janus face at left. After the fact, it is easy to give purely technical specifications for what was required to "make it work" and thus to forget that the younger face was looking out over an uncertain terrain that was as much social as it was technical.

What of the second extreme position: that these two algorithms should be regarded as evidence for a relativist position on mathematics? Consider the "mangle," Andrew Pickering's (1995) term for the ways in which nature, culture, and technology combine in the creation of science. Pickering shows that scientists and mathematicians are often proceeding along a line of inquiry when they run into some kind of "resistance"—a physical property is not quite what they thought it would be, a machine does not quite act the way they thought it would, and so forth. They respond with an "accommodation," a creative solution that allows the inquiry to proceed through some alternative arrangement (which rearranges social as well as technical and natural relations). These are contingent; some other arrangement might have also provided the accommodation.[8] In Pickering's framework, scientists are neither giving us a transparent window on the world nor are they merely expressing a relative truth. Rather, the products of science are a "mangle" created through contingent accommodations between (nonuniversal) people and the (universal) world they inhabit. The Shoshone bead artisans used a different algorithm because they were in a different mangle.

Universal–local contrasts also arose in some teaching situations. A math teacher at the Shoshone-Bannock school was using the bead loom in early December, so she decided to surprise the students by assigning a geometric task—a repeating series of triangles—which would lead to their generating an image of a Christmas tree. "In my little white mind," she said, "there was just one obvious way to think about that." She was amazed to see that the students reinterpreted her directions, overlaying the triangles to create "that feather pattern you see on much of the beadwork here" (conversation with authors, October 4, 2002). Here was a case in which students had used the design tool to appropriate the mathematics instruction, adapting it to suit their own cultural priorities.

One of the schools serving the Uintah-Ouray Reservation (Northern Ute) in Utah has also made significant use of the bead loom; our attempts to accommodate their view led to an interesting conflict. Following our request for user feedback, the Ute group replied that black beads were bad luck and recommended that they be eliminated from the VBL. The Shoshone-Bannock group had earlier told us that it was important to include the "four original colors" of red, black, white, and yellow, which they maintained were representative of "the four races of people on earth." Thus, we had one group rejecting black beads and another requiring

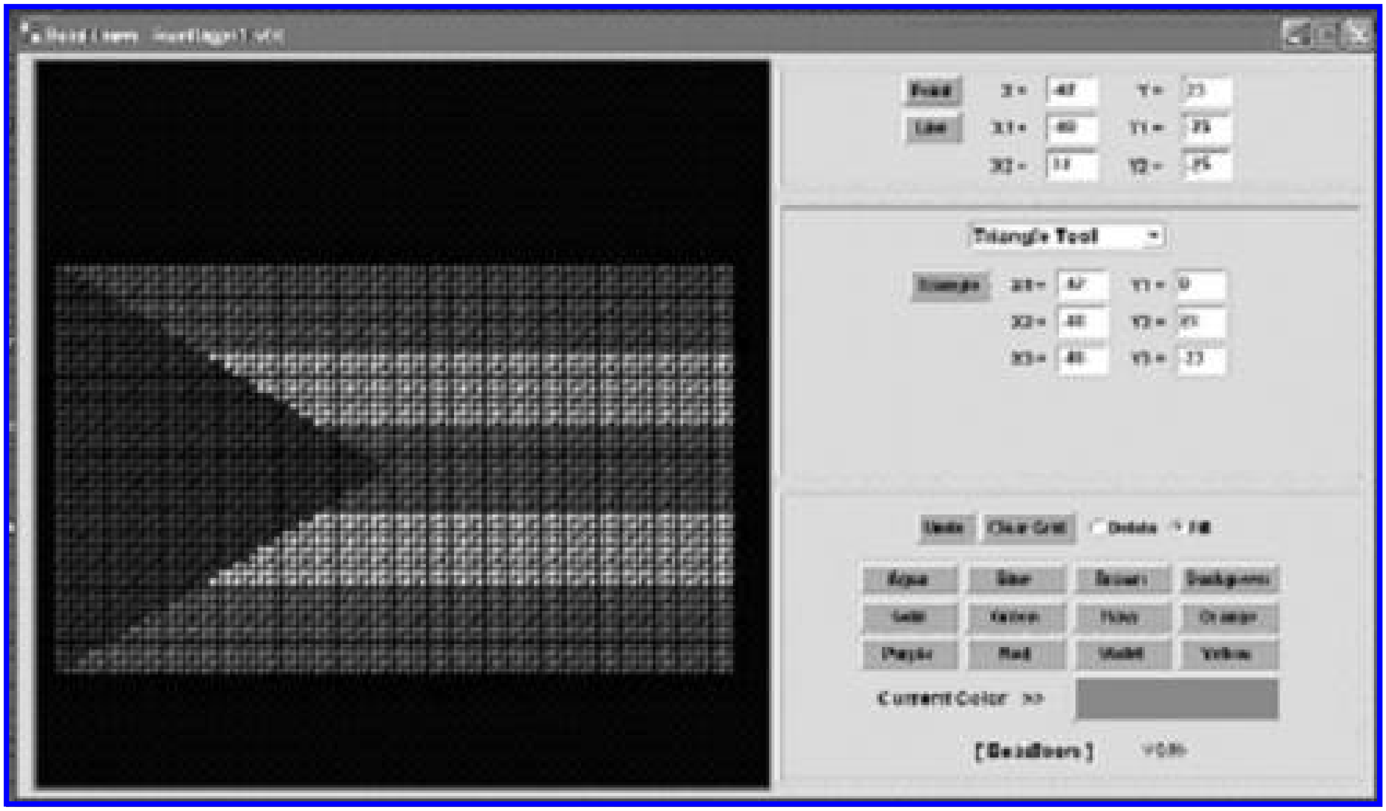


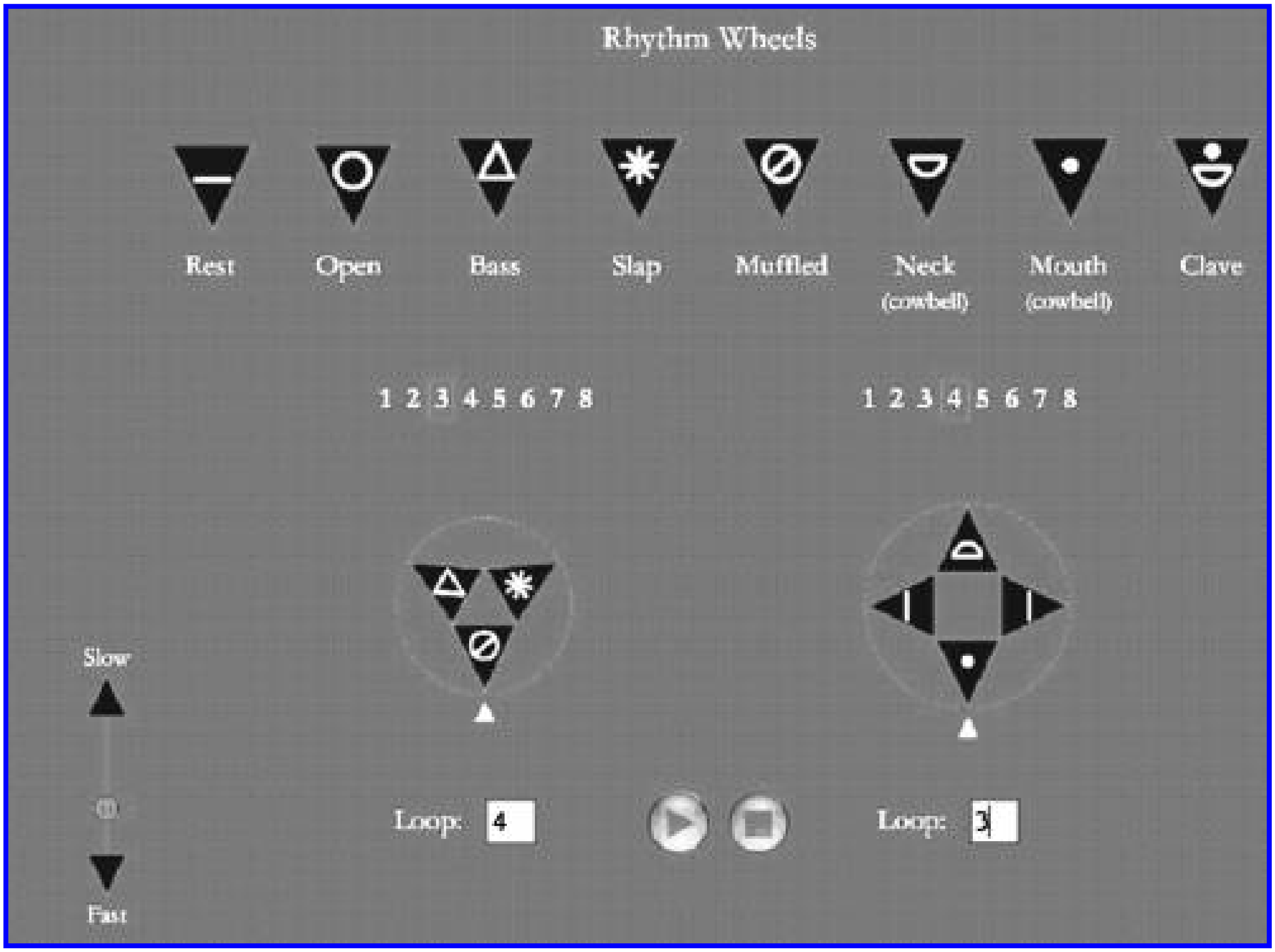
**FIGURE 6.** A Puerto Rican flag (minus its star) on the Virtual Bead Loom.

them. The solution we devised was a color mixer, which allowed users to custom make their own bead colors. This enhanced the utility for everyone and opened a new possibility for adding the mathematics of proportion (because the color mix was controlled by ratios of red, green, and blue).

The most recent tribal collaboration has been with the Onondaga Nation school in upstate New York. An exciting contribution from their group was the important historical connections with the development of the U.S. Constitution, including a photo of the 1794 Iroquois treaty wampum. They also suggested creating an option to work with virtual wampum beads rather than spherical beads. Joyce Lewis, a tribal member and math teacher at a nearby high school serving the reservation population, investigated traditional wampum and found that their height to width ratio was about 2:1—thus disrupting the one-to-one mapping of beads to integer coordinates that had made the current VBL work so well in math classrooms. We decided to offer two wampum choices: one with traditional dimension and one with a modified bead with a height to width ratio of 1:1—a sort of hybrid bead whose reconstructed identity echoed the cultural hybridity inhabited by many of the native students.

The VBL has also been used in classes with Latino, African American, and white (or "of European descent," see Preliminary Quantitative Evaluations below) majorities. It has had a high popularity with students of every ethnic background. Again, appropriation is a strong theme: We have seen several African American students from low-income urban areas use the VBL to write their initials, like the graffiti tags—a design not seen with any Native American, white, or Latino students to date. Several students of Puerto Rican descent have used the VBL to create an image of the Puerto Rican flag. One of the flags turned out to be a strong "inquiry learning" project (Brown and Campione 1994; Lewis et al. 2004). The student first looked up background information on the web and found that the triangle in the flag had to be an equilateral triangle, because it represented the equal balance of powers between judicial, legislative, and executive branches. This turned out to be a considerable mathematical challenge, because you cannot simply count the number of beads to get three equal sides: The beads along the diagonal are spaced farther apart than the beads along the vertical or horizontal, because each bead is at an intersection on a square grid. The student's innovative solution (see Figure 6) combined geometric insights with the use of a high-resolution option on the VBL.

In summary, the developmental history of the VBL is particularly helpful in illuminating how the universal and the local can be brought together into a productive tension. Through Pickering's "mangle," we can see how the algorithms of both bead workers and software programmers reflect multiple local attempts to accommodate singular universal laws. Conversely, both students and teachers accommodate the (one) software application by their (multiple) local appropriations. And appropriation itself



Loop: 4

Loop: 3

**FIGURE 7.** Rhythm Wheels.

can be more clearly seen as a two-way street, creating new hybrids in both machines and people.

## LATINO DESIGN TOOLS

We currently have two Latino design tools: (1) Precolumbian Pyramids, in which students create three-dimensional simulations of architecture from the ancient cultures of Central America and (2) Rhythm Wheels (RW), which we discuss here. RW were the result of working with elementary school children of Puerto Rican heritage in Troy, New York. Unlike African or Native American heritage, there did not seem to be any artifacts, other than the Puerto Rican flag, that the students could identify as specifically Puerto Rican. Not only was Puerto Rican society culturally heterogeneous to begin with, but it was also distant in the sense that many of these children are "Nuyorican." We finally focused on music, because that has both distinctively Puerto Rican forms and allows for the hybrid blending that is characteristic of these children's lives. The software makes use of the ratios between beats in percussion. The *bembe ostinato,* for example, has six drum beats for every eight clave beats. Thus, the two instruments go out of phase, but come back into phase after 48 beats. It is this impression of separating and reuniting the rhythms that gives the music its "hook"; thus, the existence of a Least Common Multiple (LCM) is an important part of any drummers' understanding. Because ratios and LCM is part of the standard math curriculum, this gave us an opportunity to link this ethnomathematics to the classroom.

The RW software (see Figure 7) allows a student to choose from a variety of percussion sounds (hitting the drum with the heel of the hand versus the open hand, clave, tambourine, etc.) and to then drag each sound into a position on a rotating wheel. The students (who were in fourth and fifth grade) select the number of beats per wheel (up to 16), the number of simultaneous wheels total (up to three), the number of times each wheel loops, and the speed of the wheels (all wheels must rotate at the same speed). They can also separately vary the volume of each sound for accents. There are a wide variety of rhythms that can be reproduced.

But we found that the music that is distinctively Puerto Rican—*Bomba y Plena*—was not something the children identified with as their own; that was music their parents listened to. The "favorite songs" list they generated was primarily hip-hop, with an emphasis on Spanish lyrics. The next generation of our software included both traditional and hip-hop sounds (along with the ability to mix the two together).

Meanwhile, we found that by challenging the students to make both wheels stop simultaneously (e.g., by having a three-beat wheel loop four times and a four-beat wheel loop three times), the tool allowed students to discover the concept of LCM on their own. Having students discover the concept themselves is a much richer learning experience than simply memorizing a formula. They also discovered the cultural connection: During the lesson one of the children raised her hand and said excitedly, "We could do the rhythm we learned in drumming class on this!" (observation by authors, October 15, 2003).

The drumming class was also an outcome of the software. We were fortunate in working with the Ark Community Charter School in Troy, New York, which takes a positive outlook on multicultural teaching strategies. They were interested in our report that the children did not identify with traditional percussion and were able to obtain a local arts grant to hire a percussion teacher (our COPC grant funds were used to purchase the percussion instruments). This placed the project in a more dialectical relationship: While we were working to adapt our software to reflect a more hybrid version of cultural identity, the school responded to our initial work by questioning the suppression of the more traditional version of this heritage identity and working to create an educational environment that offered room for its exploration and celebration. The project culminated in a drumming and dance performance for the parents of the children at the Troy arts center (including a brief rhythm wheels software demo by two children and the math teacher), an emotionally inspiring affirmation of the community value of this technological, academic, and cultural synthesis.

Two other classrooms with majorities of Latino students used the design tools, but they (or at least their teachers, both of whom were Latina) opted for tools from other categories. One teacher focused on the bead loom. She had both Native American and Mexican ancestry and did a wonderful job of conveying the ethnomathematics concept through the software, to the point that one student, indignant that the coordinate system was named after Descartes and not Native Americans, shouted "We've been ripped off!"[9] (conversation with authors August 5, 2003). The other teacher decided to utilize a tool based on graffiti art (Graffiti Grapher). We originally planned to place this tool under the culture category of "African American," but after interviews with various graffiti artists who insisted on its multiethnic origins and community, we decided to create a new category called "Youth Subculture." This teacher decided to use it for her primarily Latino classroom and found that students readily adapted it to express their own cultural sensibilities (see Figure 8).

## PRELIMINARY QUANTITATIVE EVALUATIONS

### *Quantitative Evaluation of Interest in IT Careers*

Our current NSF–ITWF grant evaluates the effect of CSDTs on student attitudes toward computers and IT careers. Our baseline data was generated by 175 randomly selected eighth-grade students from low-income families completing two surveys. The workforce survey questioned them about their plans for taking math courses in high school, ideas about future career, their genders, ages, ethnicities, and parents' levels of education. The Bath County Computer Attitudes Scale surveyed computer use and attitudes, including their work in mathematics on computers. In 2002, 2003, and 2004, we ran workshops with grade-8–12 minority students (primarily African American and Latino) from low-income families. They used the design tools two hours per day over a two-week period; afterward they completed the same surveys. The collective average for the 24 students surveyed in our 2002–04 Ark summer workshops (83 percent underrepresented minority students) did show a statistically significant ($p < .05$) increase from the baseline measure. It is possible that this difference reflects an increase in positive attitudes toward information technology careers for the minority students because of their experiences using the design tools.

Another study, using a similar variety of the design tools with similar exposure, consisted of 25 students, almost all of European descent. The same survey did not show a statistically significant difference in attitudes after taking the course. Although the studies are too few to draw any definitive conclusions, the contrast between minority and white students is worthy of further investigation. Although white students used all the design tools, we did not have any design tools based on European heritage. To compensate, we had students conduct Internet explorations for candidate artifacts (described in more detail in the following section, Why Do CSDTs Work?). It may be that the inclusion of design tools reflecting white heritage (however defined) might improve those scores (again see Why Do CSDTs Work? below for preliminary design tool candidates). Less formal quantitative evaluations also indicated similar increase in career aspirations among high school students at the Shoshone-Bannock reservation in Idaho and at a local elementary school for low-income minority students in Troy, New York, after exposure to culturally situated pedagogy from our team and others.

### *Qualitative Evaluation of Mathematics Achievement*

Middle school teacher Adriana Magallanes in California ran a quasi-experimental study of the VBL for her master's thesis. Using pretest–posttest comparisons (CSDT n.d.), she compared the math performance of Latino students in two of her prealgebra classes, one using the bead loom and the other using conventional teaching materials. She found a statistically significant improvement ($p < .05$) in the performance scores of students using the bead loom. High school teacher Linda Rodrigues, also in California,

**FIGURE 8.** Graffiti Grapher design from Latino student.

compared grade levels for two classes, one using the VBL and Graffiti Grapher, and one from the previous year without any design tools. She found statistically significant improvement in grades ($p < .001$) for the class using the design tools (pretest–posttest test comparisons also available from CSDT n.d.). Two other teachers have conducted evaluations of the VBL using a pretest to establish a baseline and a posttest to determine if materials made a significant impact on the students' learning. Both found statistically significant improvement ($p < .001$) in students' scores.

## WHY DO CSDTS WORK?

The question is perhaps premature. First, the teachers we have recruited for this work are extraordinary, and it is not clear that the results could be replicated with the average teacher in the average classroom. Second, we only have some suggestive preliminary results, not wide-scale testing. But assuming that using CSDTs in the classroom actually raise minority student math achievement and improve their technological career aspirations, it would be helpful to understand why. One explanation is simply that we are using a flexible computational medium, which allows students to pursue inquiry and discovery learning (Brown and Campione 1994; Lewis et al. 2004), and that the cultural component is irrelevant. We do believe that the flexibility and discovery learning aspects are critical to CSDT success, but we also see flexibility and creativity as integral to cultural identity.

Although many problems in minority student performance can be directly attributed to economic circumstances—lack of school infrastructure, classroom overcrowding, difficulties in the home environment, and so forth—there are a cluster of problems that can be described in terms of cultural barriers. Signithia Fordham (1991) and John Ogbu (1998) document the ways in which African American students perceive a forced choice between black identity and high scholastic achievement. For example, high-achieving African American students are often accused of "acting white" by their peers (Fryer and Torelli 2005). Rather than suffering from low self-esteem, many minority students maintain high self-esteem by asserting that their authentic cultural identity is in opposition to math and science. Although some researchers (cf. Ainsworth-Darnell and Downey 1998) have critiqued this framework as conflicting with the positive view of education reported on minority attitude surveys, Roslyn Mickelson (2003) has shown that there is a difference between what she terms *abstract* conceptions of education, to which all racial groups respond positively, and *concrete* conceptions of education, the responses to which differ across racial groups and correlate with disparity in academic achievement. Danny Martin (2000) reports a similar finding in African American conceptions of the "cultural ownership" of mathematics. Lois Powell (1990) found that pervasive mainstream stereotypes of scientists and mathematicians conflict with African American cultural orientation. Eglash (2002) describes conflicts in the identity of the "black nerd" in both popular imagination and reality. Additional conflicts between African American identity and mathematics education in terms of self-perception, course selection, and career guidance have been noted (cf. Boyer 1983; Hall and Post-Kammer 1987).

Similar assessment of cultural identity conflict in education has been reported for Native American students (Moore 1994), Latino students (Lockwood and Secada 1999), and Pacific Islander students (Kawakami 1995). An NSF-sponsored study of how minority students are lost in the science and technology career "pipeline" (Downey and Lucena 1997) is also consistent with these results: Many minority students with good math aptitude reported that they dropped out because their science and technology courses did not convey how this material would contribute to their concerns for social justice.

In addition to these conflicts between cultural identity and mathematics education, a second component for the poor mathematics performance in these minority groups is examined in the work of David Geary (1994). His review of cross-cultural studies indicates that although children, teachers, and parents in China and Japan tend to view difficulty with mathematics as a problem of time and effort, their U.S. counterparts attribute differences in mathematics performance to innate ability. This myth of genetic determinism then becomes a self-fulfilling prophecy, lowering expectations and excusing poor performance. In contrast, ethnomathematics directly counters this myth by showing sophisticated mathematical practices in the students' heritage cultures.

In summary, these four cultural features—the "acting white" accusation, identity conflict, social irrelevance, and myths of genetic determinism—create cultural barriers to high academic performance by minority students in subjects associated with science and technology careers. We suspect that CSDTs ameliorate these barriers. Although further study will be needed to determine which ones or to what degree, we see the following possibilities:

1. **The "acting white" phenomenon.** It is difficult to accuse someone of "acting white" if they are using materials based on black culture—difficult but not impossible. Such pedagogies always risk the accusation of being patronizing or illegitimately appropriating minority culture, and in some cases those accusations are correct.

2. **Identity conflict.** Ethnomath examples can decrease the perceived cultural distance between math and cultural identity (whether that is an experienced home culture, an imagined heritage culture, or some hybrid). The distance can be diminished from either end—that is, students might change their perception of the minority culture as more mathematical, or change their perception of mathematics as being more cultural.

3. **Social irrelevance.** Ethnomathematics is particularly effective in the context of class discussions of colonialism, primitivism, racism, and other histories of stereotypes. Its relevance is thus in its ability to provide alternative portraits. There are also practical applications of ethnomathematics to design (e.g., architecture). Here the challenges are commensurate with any such discussion (that some students will argue in favor of primitivism, or argue that such problems are in the past and therefore irrelevant, etc.).

4. **Myths of genetic determinism.** Ethnomathematics offers strong counterevidence to primitivist and ethnocentric portraits of "simple" cultures.

## CONCLUSION

CSDTs provide a potent space for students to reconfigure their relations between culture, mathematics, and technology, and for anthropologists to carry out research in these same domains. Of particular interest to us as researchers is the transition from indigenous and vernacular knowledge in situ to its public space as both education and electronic media: What is lost and what is gained in this translation? What are its politics?

One danger of this work is its potential to reify some cultural identities and make others conspicuously absent. The presence of white students in many of these classrooms has motivated us to investigate how they think of culture, including their own ideas for design tools. One obvious contrast has emerged between students who think of their whiteness in terms of a specific European ethnic heritage and those who think of it as a more generic feature, a bland homogeneous mix, or even an absence (Waters 1990). Our presentation for the Appalachian Collaborative Center for Learning and Instruction in Mathematics Education in November 2003 promoted an ongoing discussion on the possibility of using design tools for Appalachian culture, which is predominantly white but strongly marked by class as well (Stewart 1996; see Hartigan 1999 for related variants in an urban setting). Another danger is that our focus on ethnicity has set aside important aspects of gender analysis. Informal observations, for example, suggest that girls tend to prefer the cornrows and bead-loom software and that boys tend to prefer the graffiti software. The lower rate of participation of girls in the science and technology pipeline, particularly for math-oriented professions such as computer science and engineering (Commission on the Advancement of Women and Minorities in Science Engineering and Technology 2000), makes this an important frontier for our future analysis.

On the positive side, we can think about CSDTs in terms of the framework provided in the recent anthology *Appropriating Technology* (Eglash et al. 2004), which examines a wide variety of case studies in which groups at the margins of social power appropriate science and technology for purposes of resistance and even revolt. Some technologies are built to prevent user appropriation: cameras, for example, which will only work with special film from the manufacturer; some software only runs on the manufacture's platform; and so forth. There is obviously a financial advantage to creating such "lock-in" for your customers. But it is also possible to design technologies for appropriation, as we have attempted to do in the case of CSDTs.

Appropriation, however, is a much broader issue than technology design features. It is also an accusation hurled around concepts of "ownership" and "authenticity" in culture (Cuthbert 1998). Reconstituting Bourdieu's "cultural capital" as "computational capital," we then need to ask how we can make sure that CSDTs are making that capital fungible for its owners, rather than just extracting that capital from them. Should the native beadwork algorithms and cornrow equations be protected by indigenous intellectual property rights, as proposed for native biological knowledge (Brush 1993)? For the moment, we can only say that we maintain it is possible to make respectful, ethical use of those materials, given a dialogue with community representatives in which we do the following: (1) Ask permission for such use (although no one person could be said to have sufficient ownership to be the exclusive grantor); (2) contextualize presentation of the materials to show their associated histories and meanings; and (3) prioritize use by the community members themselves (in this case for education, but there are other potential applications such as architecture, graphic design, etc.).

Our preliminary data appears promising. The "trialectic" of computer media, math pedagogy, and culture provides a meeting place in which the praxis of social change and the theory of cultural critique can generate new forms of hybridity and synthesis.

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## NOTES

*Acknowledgments.* This material is based on work supported by the NSF under Grant No. 0119880.

1. To further complicate matters, intentionality itself is culturally constructed, and the Western focus on individualism may clash with indigenous concepts of "collective intentionality," particularly for structures created over several generations. See Eglash 1999 for further discussion of this issue.

2. Here we are drawing a strict contrast for comparative purposes; in the literature this distinction is often blurred, and in some cases authors include ethnomathematics as a subset of multicultural mathematics.

3. Not to mention the problems in historical accuracy: but see for comparison critique of the "Portland Baseline Essays" in Martel 1994 and Oritz de Montellano 1993.

4. Andrea Kelly, a graduate student at University of Colorado, collected a variety of such statements for her dissertation on CSDTs. On the one hand, she found that follow-up questions could "unpack" the statements and reveal more nuanced thinking; on the other hand, she found that there was still a conspicuous absence of certain frameworks. For example, few of the teachers mentioned any problems akin to cultural or biological determinism, and none mentioned anything like Fordham (1991) and Ogbu's (1998) "peer-proofing" thesis. See section Why Do CSDTs Work? below for further discussion.

5. Outside of anthropology, it is often assumed that these mathematical design themes only exist in traditional cultures, and that contemporary structures merely reflect natural laws, rationality, or efficiency. One interesting counterexample to this invisibility is Buckminster Fuller's (1963) discovery that despite their increased strength to weight and cost to volume ratios, geodesic domes were too geometrically different from the U.S. design theme of Cartesian grids in materials, construction methods, architectural aesthetics, and land plots to have popular usage.

6. In addition to several years of software development and cultural research, the following discussion makes use of fieldwork carried out from 2001–05 in summer, in-school, and after-school workshops in Albany and Troy, New York, and Chicago, Illinois, with students ranging from middle school to high school, in courses that included mathematics, art, English, and design. All students were from low-income families; the majority were African American, others were primarily Latino, although there were a few white students as well.

7. Of course iterative scaling can be used to model patterns in several other cultures as well—Southern India, for one example—but at this level of education, it is sufficient for students to have this limited answer.

8. Pickering's best example of contingency is probably the history of Leonhard Euler's formula for polyhedra. In 1752, Euler proposed a relation of vertices (V), edges (E), and faces (F) for all polyhedra: $V - E + F = 2$. In 1813, Simon Lhuilier found that the formula did not hold for polyhedra with holes going through them, but it was generally agreed to restrict the formula to polyhedra without holes. In 1815, Johan Hessel noted that a cube with a cubic hollow inside does not satisfy Euler's theorem. This produced a controversy in mathematics: Should we give up Euler's theorem or redefine polyhedra? The "monster-barrers" won out: *Polyhedra* was redefined as "surface[s] made up of polygonal faces." Then in

1865, August Mobius noted that two pyramids joined at the vertex also defies Euler's theorem. Again arose a controversy in mathematics: Should we give up Euler's theorem or re-redefine polyhedra? *Polyhedra* are then redefined as "a system of polygons such that two polygons meet at every edge and where it is possible to get from one face to the other without passing through a vertex." At each decision point, there were two viable solutions to the resistance encountered (to paraphrase Pickering, a resistance against the attempt to capture or frame mathematical agency): one of which is a path not traveled, a virtual mathematics that we could have today but do not.

9. Of course, this "triumphal chauvinism-in-reverse" (as one of the *AA* reviewers of this article termed it) is not a desirable conclusion. It may be, however, a necessary stage in some students' intellectual growth, but we hope teachers will be able to move them beyond that.

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