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Teaching with Hidden Capital: Agency in Children's Computational Explorations of Cornrow Hairstyles

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Abstract

Bourdieu and Passeron (1973) famously defined cultural capital as the accumulated cultural knowledge that confers power and status. Their original work explained many of the intangible advantages that allowed the upper class to obtain better status jobs, education, etc. Here we extend this concept to include "computational capital"—the concepts, skills, and other resources that facilitate participation in computing activities, education and careers. We posit that hidden sources of computational capital can be found in some cultural practices of disadvantaged groups, and that a suitable learning environment can make this capital available to its owners. In the study presented here, the cultural practice is cornrow hairstyles, and the learning environment is based on Cornrow Curves, a web applet that allows children to use math and computing principles to simulate the patterns of these braids. This paper analyzes the interactions of African-American children with Cornrow Curves, in particular their reflections on the relationship between their heritage identity and the experience of learning math and computing through cultural resources. We use Bennett's (2008) concept of "design agency" to describe the ways in which the students' creative explorations in this computational geometry converge with their cultural construction of the self.

Keywords: ethnomathematics, culturally situated design tools, design agency, graphic design, culture

Background

With funding from the National Science Foundation, the U.S. Department of Housing and Urban Development, and the U.S. Department of Education, our team developed Culturally Situated Design Tools (CSDTs) as a way to address the on-going problem of minority children's low average academic performance and engagement in math education. Many of the artifacts from these minority cultures—Native American beadwork, Latino percussion rhythms, urban graffiti—are based on underlying mathematical principles. Beadwork, for example, makes use of an iterative process. Likewise, graffiti artists carefully create 3D effects by emulating shadow, lines converging to the horizon, and other geometric tricks. CSDTs allow children to apply these mathematical principles to digital simulations of these cultural artifacts. In effect, these interactive software applications "translate" from the math/computing principles that are intuitively or informally present in these cultural practices, to the math/computing that will enable these children to have academic success and better career options. The claim that indigenous culture or "street art" includes some fairly sophisticated math concepts and practices has been controversial, and that controversy is just one part of a broader landscape we must negotiate in developing these tools, as we will describe later. The CSDT website can be considered a technological environment for ethnomathematics, that is, "the study of mathematical ideas and practices situated in their cultural context" (Eglash et al. 2006).

The importance of using ethnomathematics for the CSDTs is two-fold. First, the minority peer accusation of "acting white"—the idea that if you excel in math or science you are betraying your ethnic identity (Fordham 1991; Ogbu and Simons 1998; Fryer and Torelli 2005)—has been shown to contribute to the lower academic performance average of minority children. It is, in effect, a kind of cultural determinism in which we would like to intervene. Second, there is the myth of biological determinism—the racist claim that minority people have brains that are genetically unsuited for math. An ethnomath approach has the potential to intervene in that myth as well, since these are inherently mathematical practices that predate European contact.

However our implementation of ethnomathematics in an interactive computing environment provides another pedagogical dimension. In the past, teachers have complained about ethnomath presentations as too static. Math texts sometimes show an image of a Mayan pyramid or woven mat as if merely the sight of a geometrically complex pattern is enough. So called "multimedia" websites in which images or video appears at the click of a button do little to address this problem; there is not much difference between a series of static images in a book and a series of static images that result from clicking a mouse or even seeing a video. Such experiences might be termed "shallow interactivity." CSDTs, however, do not suffer from that limitation. Children experiment with computing parameters that control a graphical display in real time, thus establishing a deep interactive experience between hand, eye, and mind. Many math software applications have used this deeper sense of interactivity for education. *Geometer's Sketchpad*™, for example, allows children to manipulate virtual objects that respond with their defining properties (e.g., users can drag on a square or rectangle to re-size it but not alter its angles or length/width).

Such deep interaction allows students to explore properties and patterns in space and time. In contrast to selecting the correct answer, pressing the correct icon or some other shallow interaction, the student is part of a feedback loop in which the relations between their motor output (mouse movement) and the resulting sensory input (visual dynamics of the screen) are mediated by math and computing principles (to the extent that those principles are embedded in the software). In a shallow interaction model, the designs that appear on the screen are due to the agency of the software designer—the person who set up the limited number of choices. In a deeper interaction model, however, it is the students themselves—their agency constrained and enabled by those mathematical and computational principles—who create the designs that appear on the screen; for this reason we use the term "design agency" to describe this more profound feedback loop.

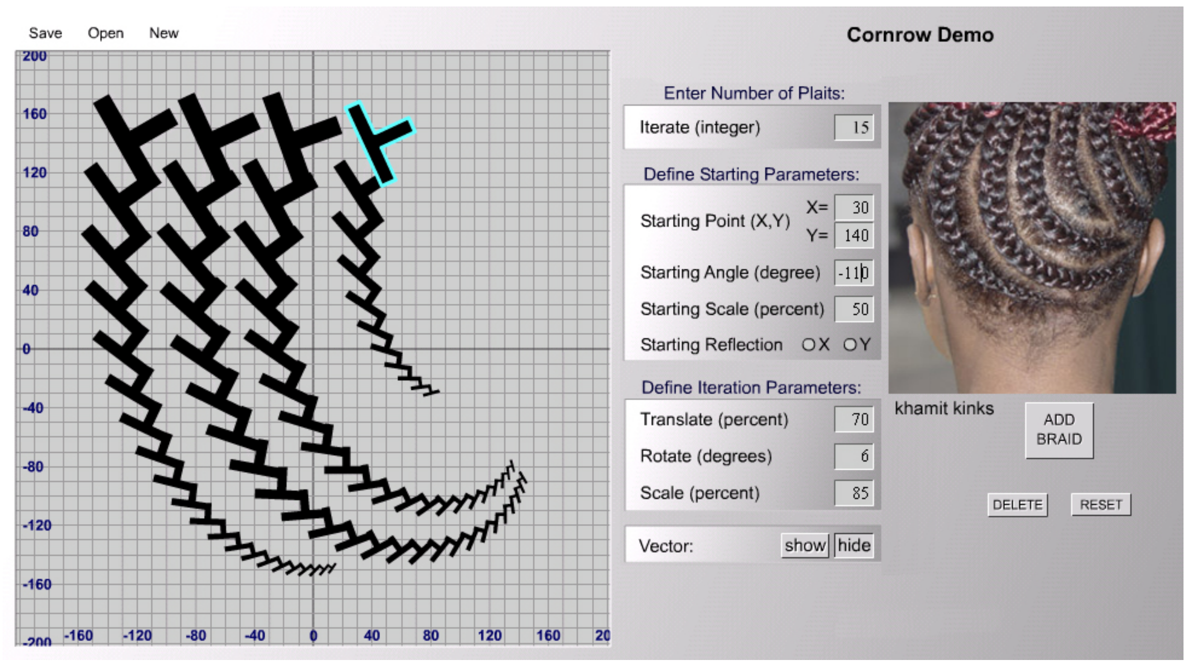
By merging interactive design tools with simulation of cultural practices, CSDTs make exploratory power available at the intersection between the students' self-construction of their own identity and their construction of mathematical and computational ideas. It is at this confluence of inward self-construction and outward understanding that we see the power of design agency.

Inculcating disadvantaged students with a sense of the value of being a producer and not solely a consumer is another crucial outcome of design agency. The extent to which the design tools are able to influence that change is not certain, but it is striking to see the difference between the primarily consumptive activities these children engage in during free time (watching videos, playing games) and these design activities. This concept was particularly well illuminated for us by a summer workshop in which, after using the design tools, grade 10 students were asked to come up with an idea for a new design tool. One group of students (all white males from low-income families) decided to focus on skateboards. We asked them to use the Internet to research artifacts that reflect designs from the skateboarding community. The images they turned in, however, were all corporate products. We then helped them find websites featuring designs created by skateboarders themselves—a fantastic array of graphics painted on the boards' fiberglass undercoat. The positive responses of these students—you could almost see the light bulb appearing over their heads—indicated that they had a new appreciation for the contrast between consumption and production.

The *Cornrow Curves* CSDT

Cornrow hairstyles offered a striking opportunity to develop a CSDT drawing on African-American culture. Like all braiding, cornrows are generated in an iterative process. However, cornrows have a remarkable repertoire of nonlinear patterns, often resulting in a complex array of logarithmic curves and other "scaling" (i.e., fractal) geometries. The CSDT based on cornrow hairstyles (*Cornrow Curves*) simulates these patterns by iterative replication of a single plait (one of the many "crossovers" making up a single braid). The *Cornrow Curves* applet locates plaits on a Cartesian grid as depicted in Figure 1. By applying various geometric transformations in each replication, the student generates the overall characteristics of the braid. For example, scaling down each plait creates a braid of shrinking size; the greater the scaling ratio the faster the braid diminishes in width. When the student introduces a slight rotation in each iteration, it causes the braid to curve. Studens use translation to make the plaits closer together or farther apart. Various transformations can also be applied to the braid as a whole. For instance, students apply reflection to make the style symmetric on both sides of the head. These kinds of operations with transformational geometry are appropriate for students in grades 9-12, and the data presented here is primarily with that age group. While the CSDT tools have been used in many geographic areas by a variety of ethnic groups, most of our data here is from work with African-American students in upstate New York, except where otherwise indicated.

Figure 1. Screenshot of *Cornrow Curves* simulation software



This description of modeling braids brings up the controversy over the claims of indigenous knowledge: are real hair stylists actually doing this math? On the one hand, they are clearly doing little numerically. In interviews, the only numbers that were mentioned by stylists was counting the number of braids to ensure symmetry—all else was a visual estimate. On the other hand, they are clearly generating braids by the same iterative process we use in the simulation. The stylist has a vision for how the braid as a whole will look, which includes its geometric characteristics—e.g., how it will shrink down in size, how it will curve, etc. To achieve that vision, she must consistently apply transformations to each plait—for example, have each plait shrink down by the appropriate amount, or rotate by the appropriate amount. These are the types of transformations that are captured in our software: in Figure 1, for example, each plait in the braid on the far left shrinks down by 92 percent, while each plait in the braid on the far right shrinks down by 85 percent. Typically that value is uniform, but some styles, such as braids with a sinusoidal oscillation ("waves"), will vary those parameters.

Our software does not yet include the capability to vary parameters as a function of the iteration; in other words, despite a fair amount of mathematical sophistication in our software we have not yet caught up with the full range of complex algorithmic practices attributable to the agency of the hair stylists. This underscores the point that just because a design method can be categorized as *visual estimate* does not mean it is mathematically unsophisticated. Perhaps one problem in recognizing this as mathematics is that its formal content is actually closer to that of computer science, where concepts like "iteration" have a stronger presence. For this reason we have recently started using the term "ethnocomputing."

Rather than attempt to convince children of one view or the other, we facilitate their own conversations about this question. Not surprisingly, the children also take various positions on the matter, with affirming responses—"I've been doing braiding my whole life but now I realize I was doing math"—as well as critical responses, such as, "I don't think this is math because they aren't using any numbers when they braid." Our view is that we should not measure success or failure in terms of how much the students become convinced of an ethnomath view, but rather that all responses are a success when children find themselves in a passionate argument about math and its relation to culture and cognition.

Children's Engagement with the *Cornrow Curves* Cultural Content

The *Cornrow Curves* website targets children and teachers. As a whole, it is structured similarly to the other CSDTs. The left-hand navigation menu has four main sections: "Cultural Background," "Tutorial," "Software," and "Teaching Materials." Children interact with the first three sections, while the "Teaching Materials" section trains teachers on how to use the other sections with their students.

When we first began the CSDT project we had a simple conception that children would use the cultural knowledge they already knew to master the math with which they had difficulty. But when we asked children about where cornrows came from they said, "Brooklyn in the 1970s." Clearly there was a need for teaching the cultural background as well as the mathematics. The cultural background section of the *Cornrow Curves* website is broken into four parts: "African Origins," "Middle Passage," "Civil War to Civil Rights," and "Hip-Hop." We typically assign one section to each of four groups, and then ask each group to read through and present what they learned to the class as a whole. Although all the students typically begin with a preference (if not obsession) for the hip-hop segment, by the end of this portion of the workshop they have generally developed a strong appreciation for the entire history.

We recently received thank-you letters from children in one classroom (23 African-American tenth grade students in Richmond, Virginia) following a *Cornrow Curves* workshop, which gave us some new insights. While we cannot view these as unbiased (just the fact that it was a thank-you letter probably influenced the content), it was interesting to note which components of the *Cornrow Curves* CSDT had caught their attention, and how they chose to write about it. Several of the students began by stating that they had no idea that cornrows had an African origin:

> *I didn't really know at first that cornrows started and came from Africa*.

> *I learned we can date it all the way back to the Nok civilization which appeared around 500 B.C.*

Others contrasted the descriptions of cornrows as signifiers of identity in some African cultures (kinship, marital status, etc.) with their perceptions of the meaning of cornrow styles in contemporary African-American culture:

> *individualistic hairstyles such as braids became more of a political statement*.

Several students also used this emphasis on original meaning to discuss what they had read on the website about hairstyles during slavery:

> *I learned that the slaves were stripped bald on their heads to hide their identity from others. But as the other people kept their hair they put their hair in cornrows to show that they were rebellious*.

Madame C.J. Walker also garnered much attention from the students:

> *She was the first black millionaire. She also donated thousands of dollars to the NAACP*.

Children also noted the contrast between the success of Walker's product—hair straightening—and the continuation of braiding practices in children's hair.

> *Children still wore cornrows after hair straightening came about*.

This is particularly significant because history lessons are typically about adults—kings, presidents, wars, etc. K-12 history texts occasionally include a small inset about children's lives (e.g., "What was it like to be a child in the American colonies?") but children themselves rarely play a role in the historical narrative itself. That they recalled this particular fact and chose to write about it—that children helped to keep the braiding tradition alive during the era of hair straightening—indicates that involving their own subjectivity in this pedagogy has a positive impact.

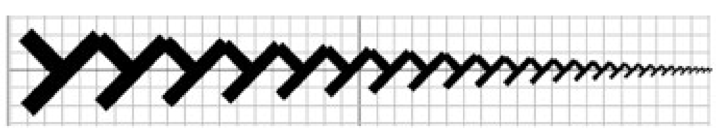
Finally, the material on the contemporary era was also mentioned, primarily in terms of celebrity names (Stevie Wonder, L'il Bow Wow, Ludacris). It was quite striking to see the material that was not commented upon by the students. Benjamin Banneker (the first black man-of-science), Francis Harper (the first black novelist), and John Biggers (the civil-rights era painter) did not appear, despite some striking images that included woodcuts showing Harper's cornrows, Banneker's afro, and Biggers' artwork. Perhaps this is simply an unsurprising indication that scientists, novelists, and painters do not have celebrity status with these students whereas millionaires do. However, several students did say they now saw contemporary hairstyles as having a "political" connection, which is likely in reference to our material on the role of the civil rights and Black Power movements in promoting cornrows, afros and similar styles.

Children's Engagement with the *Cornrow Curves* Mathematical Content

Following the cultural background section, students use an interactive tutorial to learn the role for each parameter in the simulation—how translation brings the plaits in each braid closer together or farther apart, how scaling causes each of the plaits in the braid to shrink down, and so on. The tutorial itself is a significant way to review and creatively re-present concepts that were previously covered in math class (e.g., Cartesian coordinates and transformational geometry). The tutorial teaches through discovery learning. Children iteratively enter values for each parameter, honing in on an appropriate number. Thus they develop an intuitive grasp for how to make the simulated braid in the shape they want and how to navigate through the design space. This too can be thought of in terms of design agency: by learning how to use the software, they move across the spectrum from the initial encounter with the simulation interface as a daunting alien artifact, progressing closer to the goal of complete transparency in which the interface is like a prosthetic that can be used intuitively.

The software itself then provides three categories of learning: application and reinforcement, structured inquiry, and guided inquiry. In the category of application and reinforcement, we start students with the task of simulating one of the original hairstyle designs. Typically we lead them through one design as a group before letting them choose their own style to simulate. In these exercises they are primarily reviewing, applying, and reinforcing the topics already covered in the tutorial. In the category of structured inquiry, specific math challenges can be proposed by teachers (Figure 2).

Figure 2. Structured inquiry example using a single braid



Each plait ("y" shape) in the braid is scaled down by 90% of the previous plait.

a. If the first is 1 inch wide, how wide is the second? (answer: 0.9 inches).

b. How wide is the third? (answer: 0.81 inches)

c. How wide is the nth plait? (answer: 0.9n)

Another example of structured inquiry developed spontaneously when one student created a simulation for a hairstyle with straight rows seen from the front (Figure 3):

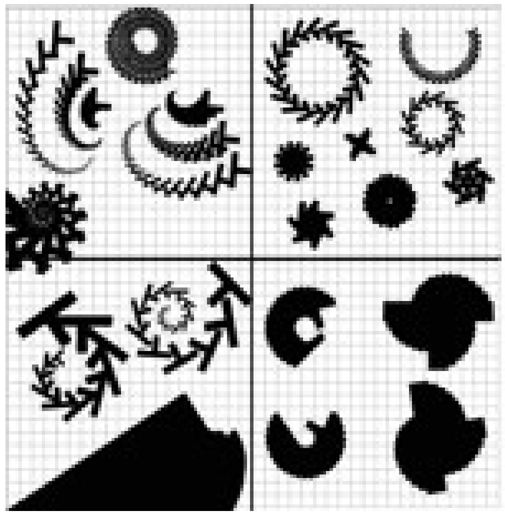
Figure 3. Structured inquiry example using multiple braids

The student first created this by eyeballing the design. We then asked her if she could develop an analytic solution (rather than just experimenting) for determining the angle at which each braid was positioned. She returned the next day and proudly said that although it took her a long time, she finally figured out a solution: there are 12 spaces between the braids on one side, which covers 90 degrees, so the braids are positioned every 7.5 degrees because 90/12 = 7.5.

Finally there is guided inquiry, in which students choose their own challenges. For example, one student wrote the following about his project displayed in Figure 4:

> *In the first quadrant, I experimented with circles and semicircles. I left the iteration dilation at 100% to create symmetrical, round shapes while changing translation and rotation to get different sizes and patterns. Smaller translations yielded tighter formations, as did larger rotations. Large enough rotations spin the piece in place, creating star-like formations. In the second and third quadrants, I looked at how changing the dilation modified a curve. Decreasing this resulted in an inward spiral which got smaller as it approached its center, while increasing it gave an outward spiral which, with enough iterations, eventually consumes the screen. The dark shape on the bottom of the third quadrant is an outward spiral which has a very small translation (it moves a distance equal to 10% of the previous piece's width) and increases in size by 112% with each iteration. In the fourth quadrant, I looked at how the T shape of the piece can change the resulting image. I found this when I compared two curves with identical statistics [sic], the only exception being their rotation in opposing directions (to the same degree). When the translation was 0, there was little apparent change in shape aside from a mirroring of the original.*

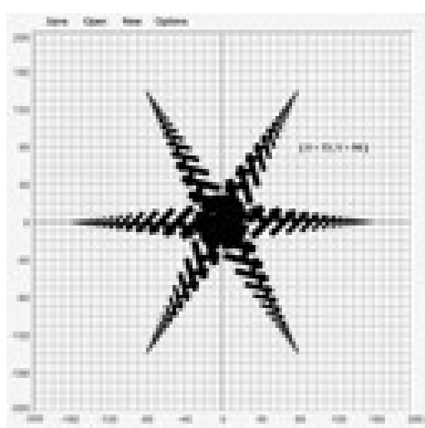
Figure 4. Guided inquiry on curved patterns



We would love to take credit for this sophisticated analysis, but the student was clearly ahead in terms of his interests in math and computing prior to the workshop. That does not necessarily mean he would continue in those fields, however. It is possible that even if we did not help him in his understanding, we helped him feel that he could go into those fields without giving up his identity.

One of the important advantages of the design tools is that they allow students of differing abilities in the same class to proceed at their own pace. Another example of guided inquiry comes from a child at the other end of the spectrum who not only was doing poorly in the class but was disrupting other students and was generally disengaged from the course. At one point he mentioned that he liked snowflakes—the first positive comment he had made. So, we ran with that, suggesting that he first investigate snowflakes with a web search. He found that they had six-fold symmetry, and we helped him determine that angle for his simulation (360/6 = 60 degrees). The rest he was able to do on his own (Figure 5).

Figure 5. Snowflake



When the other students in the class saw this they came over and gave him high-fives. His mother heard about it and she came to the computer lab and praised him. The experience completely turned him around. After that he was quite engaged in the class.

Although this example essentially ignored our many years of work attempting to offer simulations of culture rather than nature, it was a success in that it showed the design tool was flexible enough to empower this student's design agency. Math and computing were no longer a barrier, but became a bridge to his own creativity and goals.

Engendering Design Agency

The study of human agency has historically been a multidisciplinary endeavor. Psychologists generally define human agency as the freedom of individual human beings to make and act on their own choices for the betterment of their lives (Martin, Sugarman and Thompson 2003). In educational psychology, agency has been associated with Vygotsky's (1978) "Zone of Proximal Development," since we feel our agency most—those moments Csikszentmihályi (1990) defines as "flow"—when engaged in activities that are neither too challenging nor too easy. From a social science perspective, agency is more problematic, since our sense of free will often clashes with our predictable lives (the "structure/agency debate"). Both Bourdieu and Passeron's original work defining cultural capital and subsequent studies such as Willis (1981) have tried to explain how working-class children end up staying in the same socioeconomic circumstances despite opportunities to "move up" though educational systems and clear awareness that it will be self-damaging to remain in lower economic circumstances.

However, we need to make a distinction between human agency in general and what we are terming here as design agency. Our concept of design agency is more along the lines of how Pickering (1995) describes scientific inquiry: the outcome of a negotiation between people, nature and machines, rather than a one-way causal path in which humans have the goals, machines passively implement the goals, and nature passively obeys the machines.

Take, for example, graphic design. Recently, the globalization of graphic design expertise—an example of what Friedman (2005) calls the "flattening of the world" or "leveling of the playing field" —and the perennial controversy over the ease in accessibility to industry-standard design software for untrained laypeople has forced the graphic design discipline to grapple with the intertwining of human and machine agency. Many people in many nations, despite a lack of formal training in graphic design, can call themselves professional graphic designers because they have access to the same professional tools that trained graphic designers use. Some have entered into the design playing field and are competing with professional graphic designers for freelance jobs at much lower rates. Rather than resisting the flow towards lay design as a threat to professional status and job security (as some have complained), Lupton (2006) shows how professional designers can participate in this trend, introducing a "design-it-yourself" framework which does not merely toss technology in the lap of lay users, but rather facilitates the ability of the do-it-yourself (DIY) generation of desktop publishers to think more like professional graphic designers. She notes profoundly that access to technology is not enough—knowing how professional designers think is equally important.

That is not to say that technology does not play a crucial role in design agency. In any design activity, human agency could be said to be located in the capacity to think like a designer, given that design thinking is broadly conceived as "an ability to solve problems creatively" (Lawson 1997). But design agency must include—indeed can be defined as—the negotiations that occur when the constraining and enabling character of design tools and their environment combine with this human agency. We use the term "negotiations" here to signal that it is not simply a matter of envisioning a design and telling the tools to make it so. Rather, the tools fight back, they inform us—can granite be chiseled this thin? Will graphite smear too much in this style? Look at this cool effect you get if you cool the glaze too quickly!

The design process is not a one-way track from idea to product, but rather an iterative series of experiments, the constant testing of hypotheses not only on the micro-scale of tools but at the meso-scale of the emotional and social—"does this look too cheesy?"—and even the macro-scale of our cosmos: can a square enclose a circle using only a compass and straight edge? Such experimental approaches to design are common in the narratives written by the children using Cornrow Curves:

> *My first idea was to start off doing all S shapes, but then while trying the rotations and the starting angle I found out that I could not do what I had planned. Then another good idea popped into my mind. I decided to do one straight braid then a crisscross braid. This idea worked perfectly. It only took me an hour to create a whole new hairstyle.*

As noted previously, the African-American children we had in mind when developing *Cornrow Curves* have a statistically low average math performance in comparison to their white peers. Studies indicate that this is in part because they don't see math as something of their own—hence the expression *acting white* described previously. This barrier to ownership, and its resultant low motivation, blocks their agency and limits their use of math as an intellectual tool. One way to think about *Cornrow Curves* is that it offers an alternative path by embedding mathematics in a learning environment where design agency is situated with respect to their heritage culture, rather than European heritage culture (or rather than a claim for acultural universalism, which we believe is itself often interpreted as a sort of generic white American mainstream culture by many of these children).

This characterization of an alternative path to agency needs to be further qualified. One researcher in the early 1990s, for example, had minority students bring in photos from home, digitize the photos, and then conduct math exercises such as counting the number of pixels composing an object in the photo. Isn't this also embedding math learning in a culturally situated environment? Perhaps so, but it is a far cry from what we have in mind. Leaving aside, for the moment, the lack of any design agency in this example, it firmly locates mathematics in the technology and the teacher's exercises. Ethnocomputing, in contrast, locates the mathematics in the heritage identity of the student. It is a "culturally situated" mathematics in the sense of the recovery of a hidden computational capital made fungible (i.e., newly made available for activities other than hairstyling). The term "situated" for us does not merely mean "placed in" but rather implies a responsive dynamic with its own history and mode of interaction (Hendriks-Jansen 1996; Lave and Wenger 1991).

We are by no means the first authors to suggest that Bourdieu's concept of cultural capital can be applied to information technology; that idea has been well explicated. Indeed perhaps too well, as there is criticism that broader access to computing has created the myth that barriers to class mobility have been defeated (Emmison and Frow 1998). Rather, we are interested in extending what is encompassed by computational capital to include practices which encode and manipulate information but are not necessarily recognized as such (algorithms in beadwork, cryptography in graffiti, etc.). Thus while we are not opposed to Bourdieu's call for making dominant cultural capital more accessible to marginalized groups, we add a recommendation for making the marginalized groups' (computational) capital more applicable to their endeavors in dominant fields such as education, technology and design.

It is this computational capital latent in cornrow braiding that enables design agency to offer an alternative path to mathematics learning by these children. But it is not as though their cultural identity is a static, pre-defined structure which does or does not admit math. Consider, for example, the following written comment from one of the children:

> *Your influence made me want to study abroad. I'd like to go to France and study because I also have a French background. Learning about my African heritage made me want to learn more.*

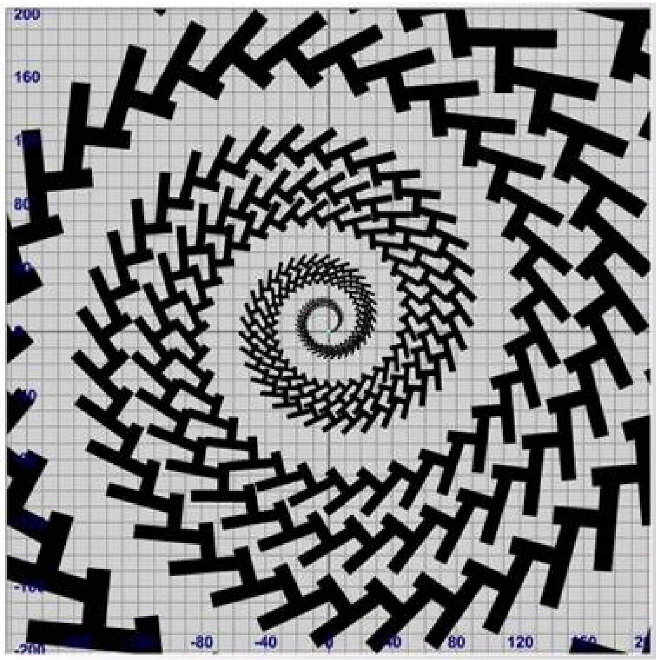
Cultural identity is something that is being actively constructed by these children (Pollock 2004), and we are offering them new tools and components that they can utilize in that identity-making process. Math and computing can now be situated alongside C.J. Walker and L'il Bow Wow as resources in their construction of the self. Design agency encompasses not only what we make but who is making it; at the same time we design things, they are designing us.

Figure 6 shows an abstract pattern simulated by a high school student whose father was from Ethiopia. The student described the pattern this way:

> *I named this [Tisissat] after the largest waterfall in Ethiopia. It shows strength and holding people together. The math is based on rotation.*

She explained to us that although she had never been to Ethiopia herself, her father had always told her about it, and his description of this waterfall was one of her favorite memories he shared with her. That she would choose to associate such an intimate part of herself with a computing design indicated that she had reached a level of comfort in which math could mingle with those memories.

Figure 6. Abstract pattern simulated by a high school student



Other aspects of the self, in addition to heritage and ethnicity, can be affected by design agency. Some of the written feedback from children indicated a shift from consumption to production, toward becoming their own intellectual agent:

> *Looking at the geometric patterns in the hair and how it related to math it made me want to find something on my own and figure out the history of it*.

Other comments have indicated students may be more actively seeking self-definition:

> *Your lesson has inspired me to further my knowledge and understanding about my culture and where I come from*.

Finally, some comments have been more practically oriented, indicating that technical careers may now seem more available:

> *It has persuaded me to want to pursue a career teaching math.*

> *I'm interested in civil engineering...but I also enjoy studying different cultures, art and their history. I was happy to know there is a way to combine the two...I think you should have a program addressing the combination, because I'm sure many other students would appreciate it.*

> *I am very interested in the engineering field and I may possibly want to pursue a career in it.*

> *I know that whatever career I choose it has to deal with computers.*

Quantitative Evaluation of Interest in IT Careers

Our previous NSF/ITWF grant evaluated the effect of CSDTs (including *Cornrow Curves* as well as others) 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. First, the Workforce Survey questioned them about their plans for taking math courses in high school, ideas about future careers, their gender, age, ethnicity and parents' education. Second, 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 (83 percent African-American and Latino) from low-income families. They used the design tools two hours per day over a two-week period; afterwards they completed the same surveys. Their collective average survey responses did show a statistically significant ($p<.05$) increase from the baseline measure. It is possible that this difference reflects an increase in positive attitudes towards information technology careers for the minority students due to their experiences using the design tools.

Qualitative Evaluation of Mathematics Achievement

Middle school teacher Adriana Magallanes in California ran a quasi-experimental study of the CSDTs for her master's thesis. Using pretest/post-test comparisons (available on our website at http://www.rpi.edu/~eglash/csdt.html) she compared the math performance of minority students in two of her pre-algebra classes, one using the design tools, and the other using conventional teaching materials. She found a statistically significant improvement ($p<.05$) in the performance scores of students using the CSDTs. Similarly, high school teacher Linda Rodrigues, also in California, compared the math grades of one group of minority students over two years; the first year without any CSDTs, the second using CSDTs. She found statistically significant improvement in the group's grades ($p<.001$) using CSDTs.

Conclusion

While we readily admit to the limitations of *Cornrow Curves*–e.g., it is only making use of transformational geometry and iteration, it limits the students to a single shape for replication and transformation, and it restricts them to entering in numeric parameter for these simple values—we believe the data indicates that it is a worthwhile teaching tool, and we expect that future improvements to this and other CSDTs will expand these capabilities. An extension that allows students to create their own algorithms, rather than merely entering values for the algorithms embedded in the software, will soon be available. Additional shapes and custom-made shapes will expand the simulation beyond cornrows and make many other design simulations available.

Yet, we believe that there is also strong value in the restrictions, and future versions must somehow compromise between expanding the limits and keeping the software pedagogically and conceptually focused. Unearthing new resources like computational capital and making them available to self-making projects such as what we have described, requires both epistemological and empirical commitments. As we have discussed, design agency is not just about freedom and limitless imagination. It is about encountering both the constraining and enabling characteristics of the worlds we inhabit—cultural, computational, physical, historical, and others—and helping to redesign them as they redesign us.

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