Counter-hegemonic Computing: Toward Computer Science Education for Value Generation and Emancipation

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Students' lives, both in and out of school, are full of different forms of value. Wealthy students enjoy value in the form of financial capital; their fit to hegemonic social practices; excellent health care and so on. Low-income students, especially those from African American, Native American, and Latinx communities, often lack access to those resources. But there are other forms of value that low-income students do possess. Most examples of what we will call **Counter-Hegemonic Practice (CHP)** in the African American community involve some mixture of Indigenous African heritage, contemporary innovation in the Black community, and other influences. Moving between these value forms and the computing classroom is a non-trivial task, especially if we are to avoid merely using the appearance of culture to attract students. Our objective in this paper is to provide a framework for deeper investigations into the computational potentials for CHP; its potential as a link between education and community development; and a more dignified role for its utilization in the CS classroom. We report on a series of collaborative engagements with CHP, largely focused on African American communities.

CCS Concepts: • **Social and professional topics** → *Professional topics*;

Additional Key Words and Phrases: Justice-centered computing, counter-hegemonic, music, video games, making

ACM Reference format:
Ron Eglash, Audrey Bennett, Laquana Cooke, William Babbitt, and Michael Lachney. 2021. Counter-hegemonic Computing: Toward Computer Science Education for Value Generation and Emancipation. *ACM Trans. Comput. Educ.* 21, 4, Article 29 (October 2021), 30 pages.
https://doi.org/10.1145/3449024

This work was supported in part by a National Science Foundation STEM+C grant #DRL-1640014, University of Michigan, West Chester University of Pennsylvania, Rensselaer Polytechnic Institute, and Michigan State University. All opinions stated or implied in this document are those of the authors and not their respective institutions or the National Science Foundation.

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1946-6226/2021/10-ART29 $15.00
https://doi.org/10.1145/3449024

1 INTRODUCTION

The inclusion of cultural and social dimensions in CS education, often referred to as **Culturally Responsive Computing (CRC),** spans a wide range of content and techniques [76]. This includes the use of vernacular knowledge such as hip hop [66]; the use of Indigenous knowledge such as weaving [85], the use of cultural aesthetics [40], the use of socially relevant problems [75], and so on. In some cases, CRC resembles what Baker et al. call the "operationalization of culture" [2]. This approach models culture as a problem in **human computer interaction (HCI)** in which we optimize the "fit" between individuals and information systems. There are indeed cases in which treating culture as a personal attribute, modeled such that the learning system is customized for fit, can be beneficial. But such frameworks may miss issues of power and social justice in computing education. The purpose of this paper is to provide an alternative framework, one that puts the relation of culture to the broader implications of CS education at the center. We term this counter-hegemonic computing.

In this introduction we detail three principles for defining counter-hegemonic computing. The first is having two levels of analysis (individual and social). The second principle is the inclusion of both negative and positive frames of reference (not just what biases to avoid, but also what CS should actively promote). The third principle examines what we term **Counter-Hegemonic Practices (CHP),** which ranges from Indigenous cultural heritage to contemporary vernacular innovations, to other forms of resistance and alterity. This principle describes the use of computing for emancipating CHP value, nurturing its potential computational dimensions and their possible contributions in schools, communities, and beyond.

Next, we build out some basic theory for understanding and engaging with relationships between CHP and CS education. We focus on the question: Why are CHP forms of value often so difficult to incorporate into CS education, in comparison to their hegemonic counterparts? After considering alternative hypotheses, we posit that *understanding counter-hegemonic algorithmic structures may require a different approach than those of hegemonic origin.* We introduce three research questions about understanding these structures and describe in general terms how we have used ethnocomputational methodologies to address them.

The main body of the paper then illustrates those methods, using three case studies of the relations between African American CHP and computing education: 1) a theoretical, historical, and empirical overview of the computational dimensions of Black music; 2) an empirical study and analysis of the CHP of Black youth in video game design and education; and 3) a set of investigations of Black CHP in maker communities and classroom activities. We end by using these three cases to answer our initial research questions and support our hypothesis that translating CHP into computing education requires its own theories and methodologies that can interact with, but are uniquely distinct from, those of hegemonic origins.

1.1 Two Levels of Analysis in Counter-hegemonic Computing

In their cultural fit approach, Baker et al. [2] begin with the inability of facial recognition systems to see non-white faces:

> The risk of lower model quality for some groups is not unique to education. For example, Buolamwini and Gebru evaluated several commercial facial recognition systems, finding that classification accuracy was significantly worse for people of color and even worse for women of color… (p. 1) [16].

Other scholars have questioned the limits of this "optimal fit" level of analysis. Ruha Benjamin, remarking on the same study, asks "what does it mean to be included, and hence more accurately identifiable, in an unjust set of social relationships?" [5] (pg. 124). She goes on to explain the ways in which designing more accurate facial recognition allows "officials to become more adept at criminalizing Black people". Applying a similar view to the design of CS education, we can see that there can be two levels of analysis. The first would simply ask about fit: designing a learning system to better fit an individual's racial or cultural identity. But the second level asks how learning systems are formed and operated within the context of hegemonic forces, and how that might be redesigned or transformed such that the interactions constitute a counter-hegemonic force.

1.2 Adopting Both Negative and Positive Frames of Reference in Counter-hegemonic Computing

"How do we create an oppositional worldview… that exists not only as that struggle which opposes dehumanization, but as that movement which enables creative, expansive self-actualization? Opposition is not enough." — Bell Hooks (p. 15) [50]

Above we describe our first principle of counter-hegemonic computing: the inclusion of two levels of analysis. At one level there must be a fit to the students' learning preferences, interests and motivations. But there must also be a second level that situates the first in relation to hegemony. While it is not unusual to see such framings, they are often only oppositional or negative, in the sense that they only tell us what *not* to do with the technology. For example, in their excellent essay "It's about Power", Vakil and Higgs similarly suggest that our vision for ethics in CS education should be broadened to the second level, but they only provide specifics for what should be critiqued [94]:

> How does racial bias shape artificial intelligence (AI) algorithms? How do theoretical advances in cryptography lay the foundation for mass surveillance? Why are engineers at Google and Microsoft raising concerns about their companies' entanglements with the Pentagon and Immigration and Customs Enforcement (ICE)?

Of course, Benjamin, Vakil, Higgs and others are correct when they insist that any counter-hegemonic approach must *include* negative, critical analysis. But we propose that it should not be limited to that. Unless counter-hegemonic computing can offer a positive, transformative vision, its critiques may ring hollow. A focus on negatives and bias may make the field less attractive to underrepresented students. Even for majority students, exclusively negative critiques may reinforce the stereotype that if you do go into computing, you should be expected to set aside social justice issues.

Finally, we note that avoiding the focus exclusively on negatives should not be limited to the technical, it should also include the social, or we risk reinforcing ethnic reification, isolation and hostility. For example, if the only message to white students is that they should feel guilt and shame, we risk driving them towards "white pride" movements of the alt-right. Thus counter-hegemonic computing must also support positive social bridges and hybridities; a lively sense of intersectional identity in the context of the entire socioeconomic ecosystem [37, 54].

As an instance of such positive framing, consider George Boole, the (White) inventor of what became Boolean algebra, the math that forms the basis for every digital circuit in existence. At age 16 he became his family's only financial support, and he never forgot his working class roots. He championed causes such as an end to the 7-day working week (a benefit we now call "the weekend"). In his 1855 address to the Cuvierian Society he proposed that humanity has benefitted from global, multicultural intellectual contributions "from every nation and kindred of men that has occupied a place in history, and with many others, of whose names and deeds no record survives" (p. 190) [25]. He championed other forms of social progress as well, including animal welfare, education for the poor, and support for women's causes. Yet courses in computing, mathematics, and digital circuits that cite his foundational technical role rarely mention this aspect of his work, nor is he cited by any social justice education materials to our knowledge. We propose that the counter-hegemonic focus on positive frames of reference may help the inclusion of such examples.

Thus, the positive frame of reference for counter-hegemonic computing is not simply delineating "the right" application of technology; it is creating a more expansive understanding of the intersections of power, identity and possibility in the sociotechnical landscape. What kinds of research might contribute to the development of a counter-hegemonic framework for CS education? How can that research be turned into educational practice? How might counter-hegemonic computing education feed back into the communities it endeavors to serve, diversifying the outputs of the STEM pipeline, not just its human inputs?

1.3 Value Emancipation in Counter-hegemonic Computing

So far, we have described counter-hegemonic computing in terms of two principles: the need for two levels of analysis, and the need for both positive and negative frames of reference. In this section we introduce the third and final principle, that of value emancipation.

Students' lives, both in and out of school, are full of different forms of value. Wealthy students enjoy value in the form of financial capital, obviously, but also in forms of social capital such as a network of high achieving peers. They enjoy forms of ecological capital such as a neighborhood free of pollution and full of gardens. And wealthy students, unencumbered by financial insecurity, are more likely to be contemplating **computer science (CS)** itself as a form of value: not the means to an end, but an enjoyable pursuit for its own sake.

At the other end of the **socioeconomic status (SES)** spectrum, low-income students, especially those from African American, Native American, and Latinx communities, often lack access to those resources. But there are other forms of value—sometimes hidden, sometimes hiding in the light—those low-income students do possess. Referred to in the literature by terms such as *counter-hegemonic* [43], *subcultural* [48], *oppositional readings* [46], and so on, they are often in evidence when a teacher says, "stop doing that and get back to work". These value forms do not easily align with academic structures. For example, despite the important development skills of listening and responding that one finds in rap cypher, this type of activity is often deemed counter to traditional classroom management [66]. To phrase the problem in CS terminology, there is no API that can easily provide teachers and students with the means to ensure interoperability between these forms of value and the CS classroom. For the wealthy, in contrast, no API is needed: the culture of the mainstream runs as a native application.

Most examples of what we will call **counter-hegemonic practice (CHP)** in African American communities involve some mixture of Indigenous African heritage, contemporary innovation in the Black community, and other influences. That it lacks ethnic purity and embraces hybridity is part of its appeal in multicultural classrooms: consider the ways that common forms of CHP—musical forms from soul to hip hop to reggae, fashion styles, graffiti, Djing, breakdancing, and beatboxing—have been eagerly engaged by youth from all ethnic backgrounds around the world. A more subtle (and less multicultural) example would be the Black linguistic traditions that gave rise to the magnetic cadence of Martin Luther King jr.; the subversive linguistics of rap and spoken word; the literary tradition of signifyin' [39], and the unique voice that constitutes Black Twitter [13].

The existence of CHP has not gone unnoticed in educational communities; indeed, many of the examples of culturally responsive computing cited in our first paragraph are utilizing it. For example, Ryoo et al. describe DietSens, a program in which mobile phones and web servers were used to systematically collect and interpret data about issues important to them and their communities, and a video game project in which students took on issues ranging from undocumented workers to gay marriage [83]. But even in these excellent examples the computational significance of CHP itself is not examined. Allowing children to decide for themselves what to analyze or express adds an important democratic element, but it may also limit the analysis to what children know and understand, and thus hold back from fully contesting hegemony. What roles can researchers play in expanding our understanding of CHP in relation to computation, in an emancipatory approach to these hidden, dismissed or unacknowledged information forms?

In summary: we have defined the basis of counter-hegemonic computing in three principles: including two levels of analysis; including both critique and positive frames of reference; and the goal of empowering the emancipation of CHP value. We will continue in the next section by outlining a theory of CHP and how best to develop its relation to CS education. Next, we explain our research questions and methods for moving between the CHP and classroom worlds. This process requires careful attention to the similarities, differences, and potential incommensurabilities of epistemic systems. This is followed by three results from these engagements of CHP in the context of CS education: the computational implications of Black music traditions and its development as educational software; the developing of a "meta-tuning" framework for Black youth's counter-hegemonic game development; and engagements with Black hairstyle traditions in the context of maker fabrications. Finally, we discuss how these case studies might help researchers and practitioners develop forms of CS education that embody the three principles of counter-hegemonic computing: consideration of culture at both individual and social justice levels of analysis; consideration of both negative and positive frames of reference; and the utilization of CHP as forms of empowerment. We posit that if these are carried out appropriately, CS can create a more significant role for CHP, one in which there are research practices formulated for the study of its computational potential, applications by which it is utilized in community development, and integration in which CS education incorporates CHP computing research and application with the dignity it deserves.

2 THEORY

In a recent study on integrating CHP into a high school CS education course, we found that the teacher struggled to maintain deep connections between the cultural material (Afrofuturism for example), and more traditional computing content throughout the course [24]. That is not true of all cultural materials: in fact, social examples are common in CS: creating a sorting system for party invitations, a database for a bookseller, and so on. Why does the incorporation of CHP forms of value seem more difficult? Let us consider three hypotheses:

1. Music, dance, vocal cadence and other CHP domains are simply not possible to use in CS.
2. They are possible to use, and they tend to be restricted to White cultural references simply due to instructor demographics (White teachers use what is familiar to them).
3. They are possible to use, but their absence is not simply a matter of instructor choice. There is something computationally distinct about CHP that requires better understanding before they can be applied.

The first hypothesis claims that CHP cultural forms are simply impossible to use in computing. It's fine to use Black speech, music and arts in the shallow sense—" create a program listing rap artists alphabetically"—but their actual content cannot be used in ways that also innovate and motivate CS. But examples abound in CS from White arts and music. A Boolean search for "Shakespeare and computing" shows 35,200 hits; and "Picasso and computing" yields over 4 million.

Publications for “computation and Mozart” include computational neuroscience [55], symbolic computing [95], interactive evolutionary computation [90], and “the Mozart effect” [53]. Dances used to illustrate CS algorithms tend to include only European examples: “insert-sort using Romanian folk dance, shell-sort using Hungarian folk dance, merge-sort using German folk dance, select-sort using Gipsy folk dance, bubble-sort using Csángó folk dance, and quick-sort using Székely folk dance” (p. 184) [56]. We have a contradiction: White artistic production and media are extolled for their deep connection to CS. So, the first hypothesis is incorrect.

The second hypothesis is that cultural forms like music and dance are indeed relevant to CS education, and that we ended up using European forms because of demographics: White instructors are drawing from Romanian, German and other sources simply because we tend to use what is familiar to us. According to that hypothesis, the choice of which culture happens to be selected will not make any difference to CS lesson content. The European folk dance examples work especially well for testing that hypothesis. It is true that any dance form can be analyzed for its algorithmic structure. But the fact that there is resonance between these particular styles of dance in Europe, and the particular kinds of algorithms that Europeans see as foundational to computing, may not be coincidental. We posit that there are distinctive computational characteristics of CHP itself; that *CHP is not “less computational”; rather, understanding counter-hegemonic algorithmic structures requires a different approach than those of hegemonic origin.*

Thus, we favor hypothesis #3. While this is only suggestive, it opens further possibilities for inquiry. Could the disjuncture or ill-fit be attributable to a co-evolutionary process between hegemonic forces [21]—industrialization and colonialism—and the CS and disciplines created to support them? For example, Tedre et al. propose that “CS was born and raised in the Western world, shaped by and responding to the varying needs of Western society.”(pg. 127) [89] How would one examine the extent to which the kind of computing we have, and the way it is taught, has been made for extractive economies? In what ways is the top-down regulation imposed by plantations, factories and the prison-industrial complex, as well as colonial and settler colonial expansion out from Europe into Africa, South America, North America, and elsewhere embedded in CS technologies and styles of thinking?

Consider, for example, that the first widely published model for deskilling of labor was the description of the pin factory in Adam Smith’s *Wealth of Nations*, and that this specific example was cited by Charles Babbage as his inspiration for the mechanisms for the first computer [14]. Daston [22] and Gray and Suri [44] note that much of the history of computation is intertwined with labor in this way: economic demands are reflected in machine design, and machines increase the pressure for human roles in deskilled and alienated forms. Could this be one reason that the regulatory order imposed by the conductor of a symphony, certain European folk dances, modernist architecture, and other hegemonic cultural norms enjoy such compatible fit to what we regard as basic computing structures? CHP, we propose, might inspire other kinds of computing if that value could be emancipated; freed to become the kinds of pedagogy, community development and innovation that would form a generative economy [36].

That is not to say that there is no overlap between hegemonic and counter-hegemonic computational worlds. Indeed, one can read the history of computing as a pull between these top-down and bottom-up tensions [93]. In the 1950s, computer systems were conceived as what historian Paul Edwards called “The Closed World”: a military-inspired top-down control system [28]. It was only with gradual reluctance that we moved to more bottom-up, collective systems: from a single central processor to parallel computing; from single thread coding to multi-threaded; from procedural to object-oriented languages; from AI as expert systems to deep learning; from the isolated database in an elite mainframe to the sprawling polyphonic democratization of the world wide web [47].

Indeed, Black cultural influences can often be found in the bottom-up side of that tension. For example, despite the fact that it is rarely mentioned in the literature, the Scratch visual programming language was named for the Black socio-technical innovation of scratching records, with its associations to "remix" in the CHP of hip-hop and the "remix" of Scratch projects [59]. But the logo for Scratch is not a black artist on turntables, it is "Scratchy the cat": once successfully translated, Black contributions tend to be erased and sanitized for White consumption. This combined effect of translation/erasure of Black cultural contributions to computing is not limited to Scratch. Consider the origins of decentralized computing work at MIT described by Stewart Brand:

> A book that inspired Negroponte and the Architecture Machine Group was called Architecture Without Architects, a provocative collection of photographs of beautiful vernacular—native—buildings from all over the world. Arch Mac was following that thread wherever it might lead—books without authors, films without scripts or directors. A grander scale of research, something like a Media Laboratory, seemed worth attempting.... (pg 142) [12].

Many of the examples in "Architecture without Architects" are African village self-organization. The founder of MIT's media lab, Negroponte, did not disguise this source of inspiration at the time: "Before venturing a machine intelligence position, I would like to examine the indigenous architect as an archetype…" (pg. 103) [77]. Yet that connection remains invisible in mainstream accounts of computing history e.g. [18]. There is an unacknowledged role of Black and Indigenous cultural influence in the democratizing side of CS tensions: once translated, the cultural connection is promptly erased and its value appropriated.

Of course, these days "democratization" and the web are not as comfortably juxtaposed as they were in their origins by humanitarian Tim Berners-Lee [11]. And that is true for many examples of this tension: every time an innovation offers a computational form that could bring us closer to a more collective, humanized, less alienating technology, there is a simultaneous dynamic in which it is appropriated, colonized, or commodified [97]. This is one reason why increasing the numbers of underrepresented youth in CS is so important. Who better to create the tech industry's next generation of bullshit detectors [9] than the community who coined the phrase "keepin' it real"? But CHP can go even farther: these forms provide a glimpse across the gap, a peek into the unalienated, humanized and collectivized possibilities for alternative computing means, media and methods. All students in CS can benefit from CHP; all should be educated in ways that are aspirational in their vision of computation for more just and sustainable ways of living. But how do we bridge the gap between CHP and CS in our formal and informal educational systems *without appropriation/erasure*? Below we present our experiments in the search for such frameworks for CHP: attempts at fleshing out the rich computational dimensions, maintaining their connection to the cultural contexts, and returning the value in these unalienated forms back to the communities of origin.

3 RESEARCH QUESTIONS AND METHODOLOGY

Motivating the development of our methods are three research questions regarding CHP in CS education and motivate using methods of modeling in ethnocomputing:

1. What kinds of computational potential exist in CHP; that is, how can we avoid reductive simplifications, and instead understand and interface with its rich computational beauty and sophistication? For example, we explore how the global explosion of Black music (jazz, blues, soul, funk, rap, reggae, salsa, dancehall, dub, mambo, motown, techno, gospel, zouk,

and calypso, to name but a few) might be understood from the view of HCI and neurocomputational perspectives as well as directly translated to CS lessons.

2. How can we apply this to community development, such that we are not merely masking ordinary lessons with shallow CHP appearances, but rather facilitating its empowering utilization? Here, we move from theoretical investigation to practical application at the intersections of CHP and computing. Our experiments in how generative economic forms can be facilitated by computational innovation include African, African American, Native American, and other communities.
3. How can pedagogy bring together these concepts of the computational power of CHP, and its potentials in community development, to increase the academic interest and achievement of students from underrepresented groups and underserved communities? Here we examine data on projects that brought together the computational potentials and community development of CHP as pedagogical structures for emancipating these value forms in the classroom.

To answer these questions, we draw on our research team's prior work in the field of ethnocomputing, which is about the computing-culture interactions in Indigenous traditions, university computing departments, artist studios, scientific laboratories, high-tech corporate firms, and anywhere else culture and computing intersect [31]. Ethnocomputing begins with the assumption that there are computational aspects in all cultures, and cultural aspects in all computing. It matters not if the device is a Navajo loom or PDP-11, what matters are the algorithmic capabilities, the advances in understanding, and the impacts on people and the planet.

Although the name sounds similar, ethnocomputing is a distinct contrast from the "ethnomodeling" approach that would position western math as universal, and nonwestern as a collection of incomplete, localized subsets (p. 75) [78]. Rather, ethnocomputing describes the interactions within ecologies of technologies, humans, nonhumans, epistemologies, and material practices. Ethnocomputing is thus useful as a critique of Western computing: for example, the ways that Native American communities on the Columbia River were displaced to create hydroelectric dams which now power and cool server farms from Microsoft, Facebook, and Google [30]. And it is useful, as we endeavor to do in this paper, for guiding us towards new computational tools and practices that empower teachers, students and community members towards more just and sustainable mediations between concrete and abstract; local and universal; social and technical.

For approximately two decades, members of our research team have been studying the relationships between CHP and the methodological approach of ethnocomputing. Eglash introduced the idea of fractal geometry as an Indigenous knowledge in Africa [33].[1] This was documented in both African material culture (fractal architecture, metal work, sculptures, textiles, hairstyles, and so on) and its conceptual systems (spiritual belief that the universe is recursively constructed; life as self-generative; recursive narrative structures in myths and symbolism, etc.). To clarify: we are not saying that advanced European knowledge merely reveals a fractal structure unknown to the artisans. We are saying that fractal geometry is a homegrown product of Africa; that it is a conscious, deliberate, deeply reflective part of African Indigenous knowledge systems. Africans invented fractals first, before Europeans; indeed, the word "fractal" did not exist until coined by Mandelbrot in the 1970s.

The fact that this does not fit the colonial model of "advanced" European STEM and "primitive" Indigenous societies is precisely why it is counter-hegemonic. Our gut instinct may be to

[1] In addition to the book *African Fractals* we recommend the TED talk as well as the software at https://csdt.org/culture/africanfractals/index.html.

object: "but they are not writing proofs and theorems on a chalkboard; they are just weaving, painting, and sculpting these recursive shapes; asking pretty questions and philosophizing about it." However, that is exactly what many professional mathematicians initially said about Mandelbrot's work: "Some of the pictures of fractals have provoked the thoughts of Mandelbrot (who is good at dreaming up pretty questions) .... I don't think that Mandelbrot has proved any theorems as a result of his investigations, but that is not what he claims to do. By his own telling, he is a philosopher of science" [58].

Mandelbrot eventually achieved grudging acceptance from STEM gatekeepers: like other innovations, once they are appropriated for military-industrial priorities they are certified as legitimate forms of computational knowledge. So, it is no wonder that CHP in its colloquial forms finds disinterest and opposition (until it too is ready to be appropriated without disturbance to hegemony). As we will describe below, fractals in cornrow hairstyles have been an exciting area in which these heritage algorithms can be developed as pedagogical CS interventions that allow translation without erasure/appropriation.

Another member of our research team, Bennett used computer simulations of African and African American designs to theorize and study how a Black cultural aesthetic might support a more robust and diverse graphic design pedagogy [6], as well as resist confining Black innovation to the past. Her more recent work examines graffiti as a case study in CHP, and the ways that hegemonic appropriation of graffiti aesthetics often convert its Black cultural ties into sanitized forms for advertising or other commodities that do not return value to the communities of origin [7, 8]. Bringing together these challenges to Eurocentric understandings of computational mathematics, the call for design innovations in pedagogy, and the cautions against extracting value without returns to the community of origin, we have taken seriously the idea that the CHP can be used to make computing education and educational technology more justice oriented.

A key tension in our work is the ability to move between knowledge practices from both worlds; to develop "translations" between the hegemonic forms of computing and the computational ideas and practices embedded in Indigenous and vernacular cultures. Traditionally, mathematical anthropologists did not think of this as translating one form of knowledge to another [57]. Rather it was a *unidirectional* flow: "my Western knowledge can model their Indigenous patterns". This work often ignores the epistemic contexts and intentions of Indigenous communities, risking the reproduction of colonial, primitivizing views. More recently, scholars in the field of ethnomathematics have challenged these unidirectional analyses with methods for modeling Indigenous and vernacular cultural practices as knowledge systems [80]. It is *bidirectional* in the sense that the model can represent knowledge on both sides (Western and Indigenous/vernacular). But it appears to maintain a colonial view: the local math merely "clarifies intrinsic cultural distinctions" while the Western version "seeks objectivity as an outside observer across cultures" (p. 75) [80]. This bidirectional method holds up the Western version as the one true universal math; all others are merely idiosyncratic subsets. These kinds of domain separations have implications beyond issues of culture: consider, for example, how a CS class might celebrate the algorithmic innovation of bitcoin, while leaving out any mention of its enormous and deadly carbon footprint [88].

In contrast to the unidirectional and bidirectional methods to modeling, ethnocomputing takes a *recursive* approach [59]. It begins with the idea that all knowledge is the result of interactions between abstract ideas and material practices, and that all actors engaged in knowledge production (from instruments to plants to humans) have agentic qualities. When we see an indigenous knowledge system it is *already* a multidirectional interaction; one between human and nonhuman agencies. The Native American agricultural focus on biodiversity, for example, is situated in computationally related conceptions of randomness—the spiritual figure of the trickster; gambling in games of chance; divination, etc.—and biodiverse diets and ecosystems make possible that cultural flourishing [29, 34]. In contrast, the European focus on monocropping is situated in technocratic frames of optimization, of squeezing as much value as possible from land and workers. Commons-based economies like those of Native Americans prevent value extraction. The validation process of Bitcoin's blockchain requires such vast amounts of electricity that it is essentially privatizing the commons, appropriating ecological resources and converting its value to crypto-capital for a small elite.

Thus, ethnocomputing avoids the tendency to position Western math and computing as more complete or universal. Each side has different sets of characteristics. Moving between those worlds is not simply a matter of translation; it requires use of *trading zones*. This metaphor refers to the ways in which different cultures historically carried out exchanges even in the absence of a common language. Peter Galison used the trading zone metaphor to explain how radar was developed during WWII [38]. Theoretical physicists had no idea how to build the apparatus; radio engineers had no idea how to theorize the functionalities needed. Their diagrams, naming conventions, modes of conceptualizations were all different, and yet radar was indeed invented. Just like any trading post, there were pidgins, creoles, hybrid gestures and so on that made exchanges productive for both sides. Historical examples of trading zones include oppressive regimes (e.g., Native American fur trade under colonialism). But Indigenous people have their own histories, and these include many profound examples where trade routes brought together peaceful and egalitarian exchanges. When Jimmy Wales described the inspirations for Wikipedia, he cited Raymond's "Cathedral and the Bazaar", which named Indigenous trading networks and cross-cultural markets of the ancient world as models for how "a great babbling bazaar of differing agendas and approaches" can be voluntary and productive for all.

The question is, how do we ensure that the computing exchange for CHP becomes more like a voluntary bazaar, and less like colonial forced trade? With this in mind, we have been developing trading zones for ethnocomputing: a series of examples and experiments with CHP, largely focused on African American communities, that used these methods of ethnocomputational modeling to design CS educational experiences and forms of community engagement for youth and adults. We detail three cases to further explore the relationships between CHP and CS education: 1) a theoretical and historical investigation of the computational significance of Black music, with examples of its application in classrooms; 2) an empirical investigation of counter-hegemonic practices in video game design and education; and 3) an empirical investigation of counter-hegemonic practices in maker activities. Before getting into each case, we describe the data used to explain each.

The first section of our results, "Black music and counter-hegemonic computing", begins with a theoretical analysis from Eglash and Bennett. How did the music of a small group of the enslaved grow to overtake nearly every musical form on the planet? Rooted in historical overviews and comparisons of Black music and digital computing, the section shows how the demarcations set up by the professional computing disciplines give the false impression that European classical music has the most computational relevance, and Black music the least. As a result, we overlook the implications of Black music's popularity and its relevance to computational mathematics, neuroscience and other fields. Putting this to practical purpose in math and computing education software, we describe some investigations of Rhythm Wheels, in which students can both create and learn with these audio heritage algorithms [35]. The second section of the results, "CHP in CS Education through Gaming", is based on Laquana Cooke's work as Director of the iCamp summer academy, an interdisciplinary, project-based program that offers Philadelphia high school students' hands-on workshops in games and web development. Drawing on her experiences designing and implementing the academy, the section engages in readings and analyses of student-created artifacts (largely video games) as sources for both hegemonic and counter-hegemonic value.

Cooke shows how she employed the concept of *meta-tuning* as Director of the program to think about the differential outcomes for students as they learn computing by "tuning" designs for either hegemonic or counter-hegemonic priorities. The final section, "CHP in CS Education through Making" is based on Bill Babbitt and Michael Lachney's efforts [59, 60] to highlight the expertise and knowledge of Black entrepreneurs and cosmetologists during a library maker program called the Generative Cosmetology Lab. This section details their processes of designing culturally and computationally rich activities that engaged the counter-hegemonic value of the African American Natural Hair Movement (a type of independent maker movement, in and of itself) as a foundation for CS and engineering education. In the focus group transcript with adults who helped to facilitate the program (or just showed up out of personal interest), they found that the Lab's emphasis on these CHPs allowed the program's activities and framework to be disseminated and further developed by racial justice groups in the neighborhood where the library is located.

4 FIELDWORK AND RESULTS

4.1 Black Music and Counter-hegemonic Computing

Like groups such as the wonderful EarSketch team [67], we have endeavored to use music to teach computing. One way to think of that is bait: we can better tempt some students into the STEM pipeline if we offer something they enjoy, such as creating music. But that fails to do justice to the idea that computing *already* exists in the heritage culture in the forms of musical practice themselves. To fully grasp that idea, it is useful to contemplate other such cases. Consider, for example, how developmental biologists, systems biologists and others now describe the genetic regulatory network: not as merely capable of being modeled by a computer, or as metaphorically computational, but quite literally as "the genomic computer" [52]. DNA is not a rare exception; indeed, the entire field of computational biology is dedicated to discovering the information processing capabilities in a variety of such cases: biochemical networks, transport networks, and carbohydrate networks to name a few [19]. This view of brain neurons as analog computers brings the argument full circle, as they can inspire new AI methods ("neuromorphic computing"). Here we make a similar argument for Black music traditions.

Extending our understanding of computing beyond laptops and mainframes has required scientists to reconsider our abandonment of analog computing [92]. Contrary to common belief, there is no theoretical reason why analog computing cannot be just as effective. Indeed, with the limits of Moore's law rapidly approaching, some scholars have turned to analog neuromorphic computing as the future [23, 87].

We are taught that "digital is discrete, analog is continuous", but that is not an accurate way to understand the difference. If you use an oscilloscope to look at the signal from your mouse or other digital device, you will see that the binary code is actually a digital square wave of zero volts and five volts. It is digital, but physically represented as a continuous signal. Conversely, the analog system of music is composed of discrete notes. A more accurate way to think about the difference between analog and digital is as follows: Digital symbols conduct representation by arbitrary assignment. We simply agree that "cat" refers to a furry animal; that $ represents money; and so on. Analog, on the other hand, is representation by proportion [32]. The more excited I am, the louder I get. The physical parameter changes (decibels) are mapping out the "meaning" parameter changes (communicating excitement). That might seem like a trivial part of communication, until you think about vocal inflections like pitch, wavering, hoarseness, hesitation, and so on—an entire universe of paralinguistic audio expression. And that is precisely what makes music so powerful, because it taps into that part of the brain by using these analog proportionalities [32].

Holding that thought for the moment, consider the history of digital computing. If we look at the history of UNIX, we see the evolution of almost every contemporary computer operating system. The original "research UNIX" became BSD, which mutated into Apple's OS for your mac and iPhone; the PlayStation OS for gaming, much of the internet backbone, and so on. Before DOS and Windows, Microsoft began with Xenix, which was essentially UNIX re-branded. In many cases UNIX was rewritten from scratch, so that the ideas could be used without violating copyright. That's the case for Minix, which provided the file system and some crucial ideas for the Linux kernel, whose descendants run pretty much all of the internet not run by BSD. You can see an image of the whole UNIX family tree in Figure 1 below.

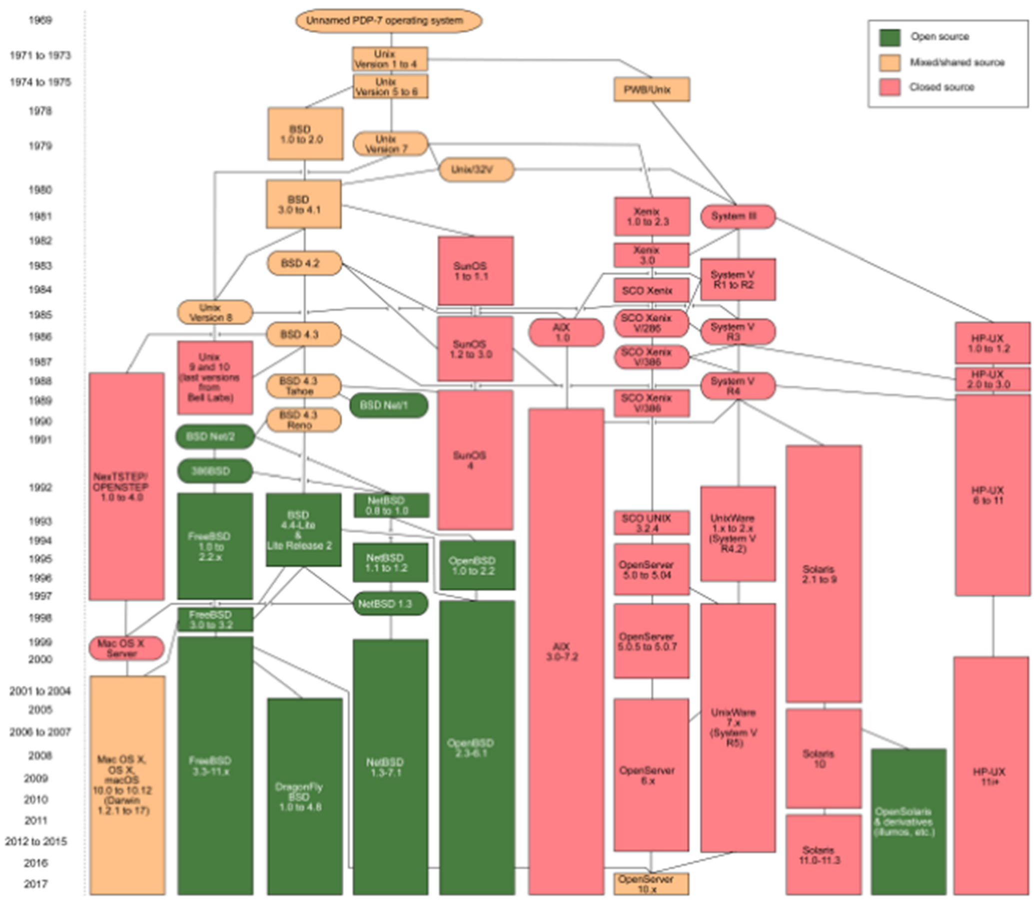

Fig. 1. The UNIX family tree. Attribution: Eraserhead1, Infinity0, Sav_vas – Levenez.

And here (Figure 2) is a similar evolutionary diagram for the Black music family tree. Starting from West African roots, we have the work songs of enslaved Africans; the spiritual renaissance of gospel; the secular mutations of blues, ragtime, swing, jazz, rock, soul, funk and rap; the Caribbean and Latin American explosions of mambo, salsa, samba, zouk, reggae, Afro-Cuban, reggaeton, and so on. From Coltrane and Miles to Gangnam styles; Black music is the Unix of the global rhythmic network.

UNIX was the operating system that gave birth to all other operating systems; its metaphorical DNA (whether directly or re-written from scratch) is part of a grand computing heritage that nearly everyone uses on a daily basis. Why? Take away all the variations and at its core you have a fundamental mesh between what digital computation needs, and what system architecture provides.

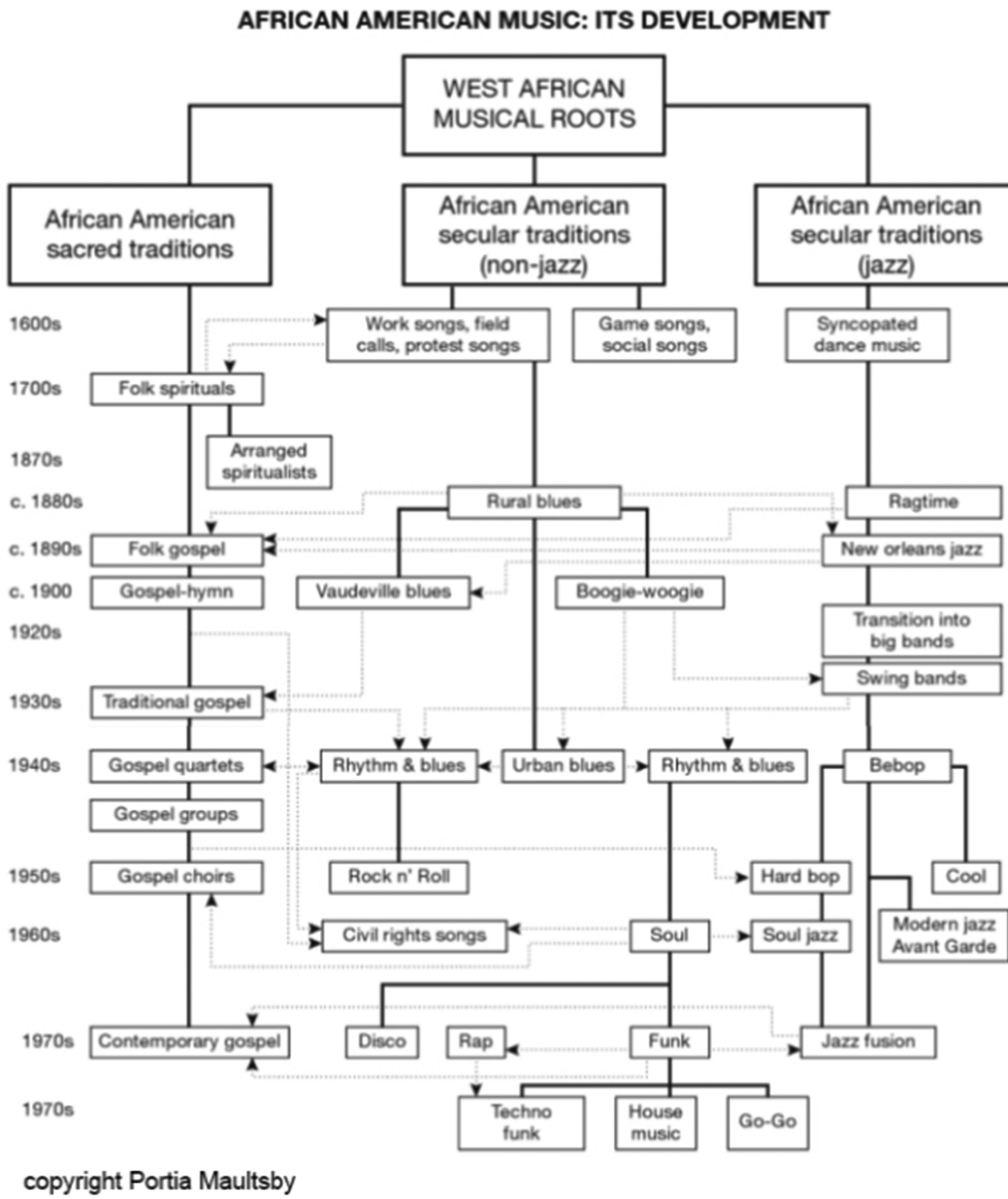

Fig. 2. The Black music family tree. By permission of Portia Maultsby.

Now we can finally ask the same question about Black music: why was it so phenomenally successful? How is it that an obscure bunch of folk songs by the enslaved evolved into the world's most popular musical forms? Recall that music reaches the brain through its analog channels. Our emotional intelligence–the limbic system in the brain; the neuroendocrine system linking the brain with the secretion of hormones; indeed, the entire facial and bodily apparatus of affect communication–is mostly analog. And therein lies the answer to our question. Just as Unix entered and took over the digital ecosystem over the last 50 years, African traditions did the same for a global analog communication system called "music" over the last 200 years. They hacked the

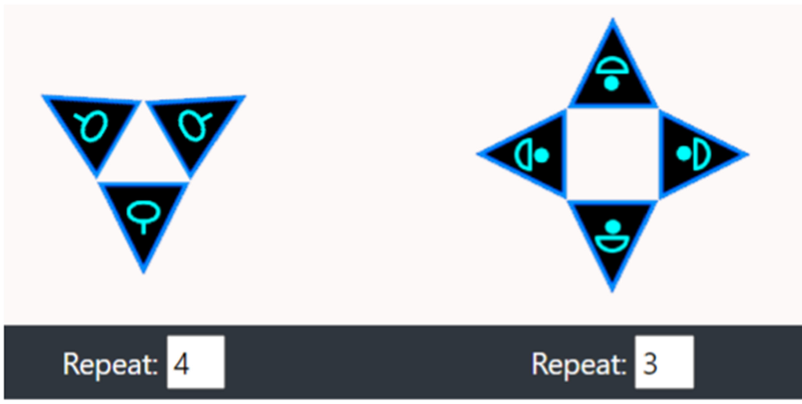

Fig. 3. Student's rhythm wheels interface using the LCM of 3 and 4. In this case the student dragged in 3 "scratch" sounds from rap and 4 clave sounds from Caribbean drumming. Both wheels will create 12 beats total.

limbic system of our shared brains through juke joints, radio waves, recording studios and peer to peer file sharing. Take away all the variations and at its core you have a fundamental mesh between what analog cognition needs, and what music architecture provides. We know why that mesh works for UNIX; we barely understand why that's the case for Black music.

Previously we suggested that rather than dismiss CHP as a poor fit to CS lessons, we explore the possibility that it is computational in other ways not yet understood. Like hypotheses regarding the computational power of genomic networks or neural networks: an opportunity we can learn from; a potentially different way to go about computing that justifies intellectual respect and research. Some of the greatest technical problems of our era–the failure of HCI to provide pleasurable, profound, principled integration between human lives and computational powers–lies in the fact that the round analog pegs of our lives are constantly hammered into square digital boxes. Perhaps the computational potential of Black music could provide new insights into resolving that dilemma; into better meshing what analog cognition needs and HCI could provide.

The same goes for our practical approach to Black music in the CS classroom. The application we have developed for this, Rhythm Wheels (https://csdt.org/culture/rhythmwheels/index.html) allows students to place sounds into sections of a rotating disk (the number of wheels, number of sections per wheel, tempo, loudness and order are all under user control, either as drag and drop or blocks-based coding). One way teachers have used this is to teach **Least Common Multiple (LCM).** For example, to make a 3-beat wheel and a 4-beat wheel stop at the same time, students can discover (usually by trial and error) that if the 3-beat goes around 4 times, and the 4-beat 3 times, then both are playing 12 beats and they stop simultaneously (Figure 3).

This has two consequences: first, it makes what some might find to be a dull math lesson vastly more interesting. We have heard students excitedly describe "that's just what we were doing with the music!" The project has also been valuable in community connections. In the school where we originally developed this (upstate NY), there was a large number of students with Latin-Caribbean roots (Puerto Rico, Dominican Republic, etc.). But there was almost no educational connection to that culture. The Rhythm Wheels success in math class inspired the school to seek and gain a grant to purchase drums and drumming instruction; and the students presented their simulations as part of the year's closing ceremony that included drumming and dancing. But the website also helps students understand that LCM is well known to musicians using the polyrhythmic heritage of Black culture. You can feel when the two cycles drift apart and come back together; that is what

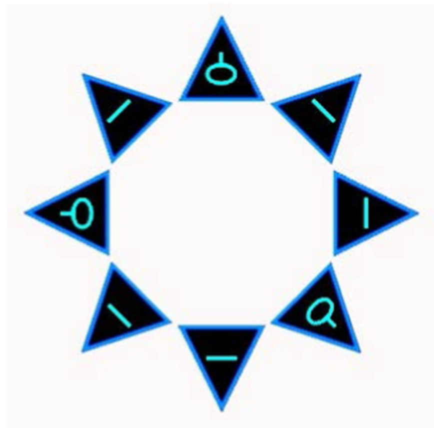

Fig. 4. the African rhythm D(3,8) in rhythm wheels (dash indicates silence).

gives the music its "hook". Several scholars have noted the resonance between these intertwining polyrhythms–in particular the role of call-and-response vocals–and the egalitarian basis of Indigenous societies that requires both voluntary agency and coordination (e.g. Oloa-Biloa [78]).

We have reported elsewhere on the success in using Rhythm Wheels as part of computing classroom activities [35]. More recently we have combined this idea with animated visualization, set to music and coded by students who then use it for expressing solidarity with movements such as Black Lives Matter (e.g. https://csdt.org/culture/adinkra/software.html) and other personal expressions. There is also a feature which allows students to rap over the rhythms they create (something they did spontaneously before we added it). We also continue to explore the computational complexity of the music itself and its potential for classroom and community contributions. Future modifications will add meta-wheels for sequencing wheels. This meta level is well known in Black music studies; hip hop historian Tricia Rose refers to it as "rupture":

> Time suspensions via rhythmic breaks–points at which the baselines are isolated and suspended–are important clues in explaining sources of pleasure in Black music.... These features are not merely stylistic effects, they are aural manifestations of philosophical approaches to the social environment." (p. 67) [81].

Toussaint used a framework that is very similar to the rhythm wheels GUI to investigate what he unfortunately calls "the Euclidean algorithm" (because Euclid provided something similar for calculating Greatest Common Divisor[2]) [89]. He shows that a recursive algorithm that has been used in nuclear physics to maximize distribution of energy pluses between intervals can also be used to maximize the distribution of sounds and silences in music. Since almost every example in his paper comes from the music filtered through the Black Diaspora (origins in west Africa, influences in Brazilian, Cuban, etc.) let us offer an alternative naming and refer to this as the Diaspora algorithm. In his main example there would be three sounds distributed in a wheel of eight beats (we can symbolize this as D(3,8)).

The representation in rhythm wheels is shown in Figure 4. He summarizes "It is shown here that the structure of the Euclidean algorithm may be used to generate, very efficiently, a large family of

[2]To be more precise, Euclid's *Elements* (c. 300 BC), Book 7 (Propositions 1–2) shows how repeated subtraction can determine the GCD of two integers. The algorithm used by Toussaint uses repeated division, not subtraction, to simulate Black rhythmic patterns. Thus, there is no reason that has to be named after Euclid, given that the algorithm is not the one he described.

rhythms used as timelines (ostinatos), in sub-Saharan African music in particular, and world music in general". Toussaint notes that "In some cases the Euclidean rhythm is a rotated version of a commonly used rhythm". That is to say (correcting again for his reassignment of Black cultural capital to Europe), there are usually several different ways of ordering the same relative intervals created by any one solution to the Diaspora algorithm. But why do certain orders vastly predominate? Why did the atoke bell rhythm in Ghanaian Sohu, the tresillo in Cuban drumming, and Black-inspired rockabilly hits like "Hound Dog" all select the same *order* as well as distribution? How does this order interact with higher-level cycles (our proposed meta-cycles); with simultaneous instruments that have different cycles (and perhaps the same meta-cycles?). Explorations of the Diaspora algorithm await both students and researchers. We envision a future in which nuclear power plants are not the primary beneficiaries, and the terminology need not refer to Euclid to legitimate itself.

4.2 CHP in CS Education Through Gaming

iCamp summer academy is an interdisciplinary, project-based program that offers Philadelphia (Philly) School District high school students hands-on workshops in games and web development, as well as audio and video production. The iCamp team takes a bottom-up, decentralized approach to creating a space for youth to simultaneously contest hegemonic structures of oppression and cultural erasure, celebrate their urban Philly and cultural heritage, and hone sociotechnical skills as media producers and developers. As a residential program at a **Predominantly White Institution (PWI),** we critically (and recursively) "tune" communitarian, educational, and the social developments of our high school students, undergrad volunteers, and instructors with the aim of empowering all participants.

Pickering uses the tuning metaphor to describe the process by which one carries out any trial-and-error process [79]. Someone playing a computer game will tune their responses, gradually honing in on the winning set of behaviors. When we teach students programming for game design, we teach them to tune their game to maximize the player's enjoyment, education or other goals. Thus the student designer is "meta-tuning": trying to hone in on the design that will best facilitate the player's tuning experience. As iCamp directors, it is our responsibility to guide the activities towards critical resistance, radical joy, and other elements of emancipatory practice. But that cannot be done using didactic, authoritarian demands; we must create a space in which participants can explore (trial and error) paths towards those goals; even redefining what those goals mean along the way [79]. Thus, we are meta-tuning the meta-tuners. Henry Louis Gates identifies such nested loops in Black traditions from both African and African American communicative structures as "repetition with revision". He cites trickster stories in West Africa, and the role of figures such as Nigerian trickster Eshu (Figure 5) in "doubling the double" to escape binary dualisms; a tradition he links to Black vernacular speech styles that fold meaning back on itself, and other ways of nurturing emancipatory possibilities in reflective Black cultural traditions [39].

Gate's "doubling the double" [37] is also resonant with W.E.B. Du Bois's concept of "double consciousness" [27] and Patricia Hill Collins' "outsider within" [20]; of always working in a paradoxical space that is simultaneously alien and citizen. This recursive nesting of critique and capitulation is especially evident in iCamp's Video Game Design track. This track is designed to help students develop systems-based computational and design thinking skills. Throughout the week, students are provided with laptops and free game dev software (e.g., C2 and 3; Krita; Gimp and Audacity) to develop their games through an iterative design process: starting with ideation, moving through prototyping, coding, and playtesting phases. Comparing projects from iCamp's inaugural year in 2017 to its second year, we can see how the negotiations between hegemonic and counter hegemonic modes–both conforming to the expectations of gaming industry, marketing, and mainstream appeal as well as leaving room for subverting its techniques, goals and

Fig. 5. Eshu doubling the double. The flute blowing at right symbolizes youth flaunting authority; the beard at left the wisdom of age; the elaborate hair implies sexual (and social) reproduction. University of Iowa Stanley Museum of Art.

methods—illustrate how a meta-tuning trajectory negotiates changes in the organizational infrastructure and pedagogical practices during the camp.

This evolution began with our piloting and early commitments to a client-centered approach in 2017. We were informed by prior work on mentorship models for learning though studio experiences, such as Sheridan's emphasis on emergent leadership roles [86], and the development of professional skills for future employment opportunities. But our main focus was a client-centered approach arising from prior research in design-based youth programming. This situates youth design practices within real-world project scenarios for "client-facing deliverables" [84]. To do so we partnered with Philly-based nonprofit organizations, who pitched their frameworks for change (their goals and strategies in bettering the community) to our campers during our opening day.

Thus in 2017, student ideation was directed towards the ways in which neighboring organizations were tackling local community issues. Most students had never designed or coded games before, but struggles in designing games for social change were productive challenges, as students negotiated their desires to develop bug-free games that were also socially conscious. For example, by day 3 most games mimicked AAA games (mainstream big budget successes), with an emphasis on jump-and-run or top-down puzzle games like *Mario* and *Zelda*.

The day-to-day design activities put far more time into code-specific trial and error learning than reflecting on social justice implications or the means for incorporating that into the designs. Student-guided inquiries adjusted pedagogy: for example, students wanted to tweak their collision detection algorithms for other features, such as health and hit points. We conducted just-in-time debugging workshops, remixing resources they found online for feature design. Thus, social justice values tended to take a back seat to the technical aspects, but we wanted to support the students' own sense of priorities and were successful in getting the alpha game versions to our partner-clients in time for playtesting.

The Advocate Center's after-school youth provided an especially detailed body of feedback. For example, a Zelda-like puzzle game, *The Apple of My Eye* (see Figure 6), received positive reactions as "a cool game"; however, they did not like the "(graphic) blood," and saw no connection of the game to real social issues like "college prep and success journey." For *The College Game,* the Advocate Center testers noted that they "loved the look of the game," especially how the "protagonist is a person of color" and that it reminded them of Mario Brothers.

On day 5, iCampers analyzed the feedback and revised their games for final versions. Images below are the snapshots of the final versions of both games. Both games embodied sophisticated algorithms (various features such as level design, win-states/lose-states, health meters, and NPC-movements), maxing out Construct 2's free version of 100 lines of code. However, even after these revisions, the social justice content was rather superficial. The client's message was an afterthought, and the primary focus was to replicate the production values of commercial games (see image 6 below).

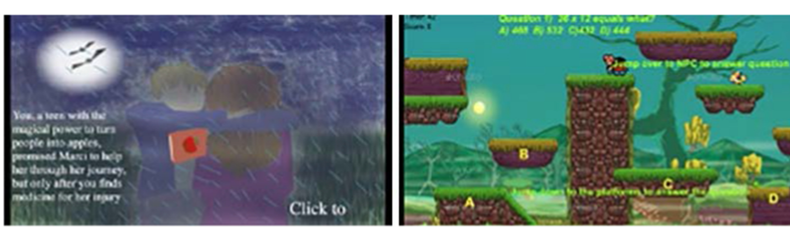

Fig. 6. iCamp 2017 examples, showing an emphasis on hegemonic design appeal: The Apple of My Eye (left); The College Game (right).

For example, the *Apple of my Eye* game had all original graphic art and animation, with an original first-person shooter narrative. After playtesting, the designer simply removed the gun from the protagonist's hand, overlaying the image with a book, and replaced images for all the sprites that had bullets and guns with apples. Their tuning process appeared to be not only guided by hegemonic appeal, but perhaps even amplifying it, as the appearance of any stereotypical elements of commercial games became the impetus for more of the same.

In iCamp 2018, we sought to re-engage the tensions between hegemonic and counter-hegemonic framing. In our post-mortem meeting after iCamp 2017, the staff reflected on the lack of social justice strengths in games and drew connections to their passion projects, i.e., other DIY media projects they worked on throughout the week. These passion projects consisted of "music videos," project bloopers and other PSAs that celebrated the rich culture of Philly. For 2018, we revised the client-based model to a "community-as-client" approach; thus, repositioning the iCampers themselves as among the clients. This meta-tuning aimed at offering a more reflective experience, making room for what appeared to be a set of pre-existing counter-hegemonic aesthetics, motivations and practices. These CHPs might be deemed inappropriate for a formal social justice organization

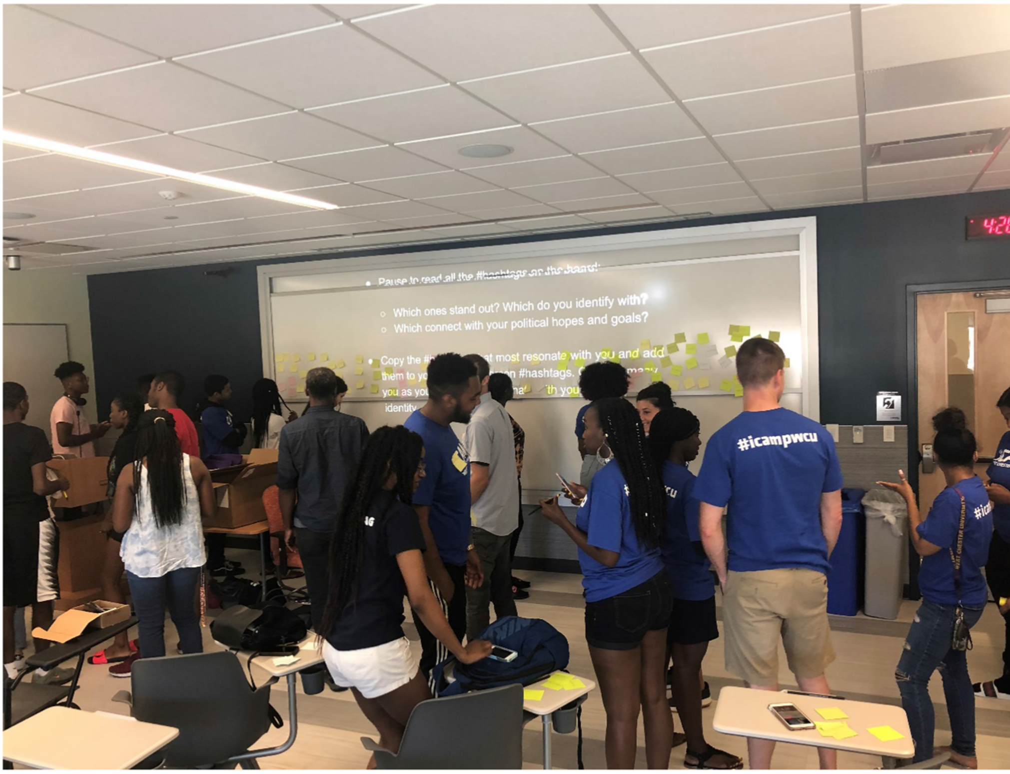

Fig. 7. iCamp 2018 early stages of "iCamper-community-as-client," Hashtag Activity.

but had a rich set of personal meanings for student designers, and thus needed to be engaged on their own terms, rather than used in an instrumental way to serve the (albeit morally admirable) purposes of external groups.

Through this "iCamper-community-as-a-client" approach, pre-production began with a large "Hashtag Identity" ideation activity asking all media track iCampers to write identifiers, share with a partner, and then report out to the group. The clustering of identifiers helped iCampers give each other shared recognition as reflective thinkers and doers and empowered them to create a collaborative space for (peer-led) just-in-time feedback (Figure 7).

One game that stood out as an exemplar for CHP computing was *Conviction*, focused on Black incarceration rates. The student intentionally wanted it to be abstract and resisted everyone's attempt to have him add in imagery, character design, and so on (Figure 8). That is not to say it is impossible to combine the two but supporting this student's decision was crucial to his success in this case. The lack of scenery and characters enabled the student to spend more time with the algorithm itself, overturning expectations that moving away from industry standards would lessen CS content.

In what way does *Conviction* embody CHP? Hegemonic practices insist on design for maximizing the commercial success of products. While games like Grand Theft Auto have capitalized on violent fantasies of what is putatively Black authenticity [3], such extractive processes take from Black communities without giving back. Conviction in contrast offered a deglamorization, as it were, embodying feelings of frustration and hopelessness as minimalist gameplay. This counter-hegemonic tradition of refusal in the face of pressures to commodify or conform has a long history. Therese Nelson, the founder of the website *Black Culinary History*, points out that Black chefs such

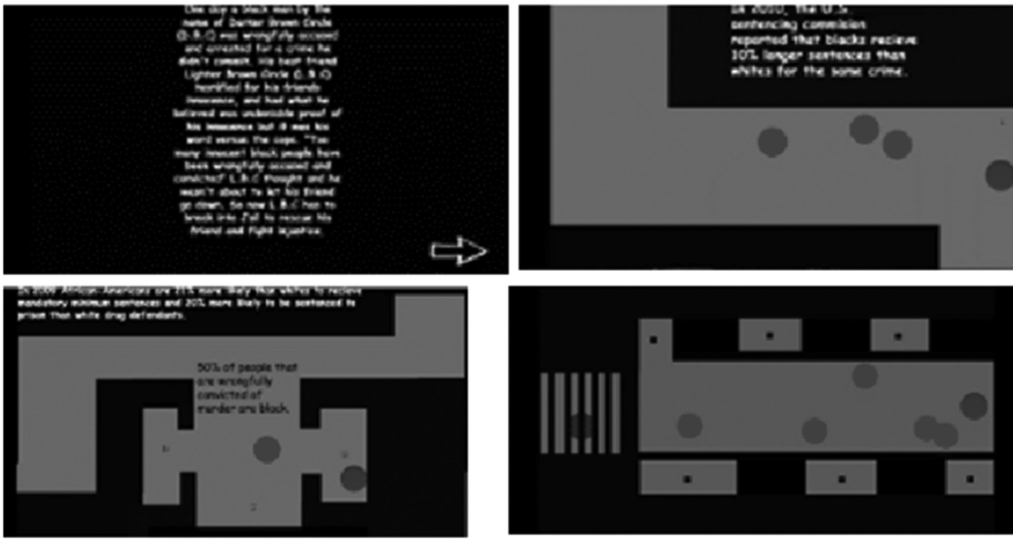

Fig. 8. Snapshots of *Conviction's* game levels, demonstrating one student's interpretation of a counter-hegemonic approach in narration and level design. From top left: Intro, Level 1, Level 2, Level 3.

as herself often had to make a choice between lucrative careers and authentic cooking [51]. Black experimental artists often formed collectives, such as Chicago's Association for the Advancement of Creative Musicians, because they refused more lucrative commercial production but (unlike the white counterpart of experimental arts) had little academic support [65]. Math educator Danny Martin writes that "right of refusal" needs to be a fundamental part of Black liberatory education, given the ways that rhetoric around inclusion can mask perpetuation of dominant practices [68]. But as these examples show, resistance does not have to be rejection: in the case of Conviction, the lack of glamourous effects created a game centered on pitting the user against a ruthless, unvarnished algorithm. The challenge for the educator was allowing this strategy to emerge in ways that felt authentic to the student.

Thus, the meta-tuning process described here[3] is one strategy for engaging the three principles of counter-hegemonic computing. It considers levels of both "fit" and hegemonic critique; it allows for both positive and negative frames of reference; and it provides a means of emancipating hidden or disregarded forms of CHP value. It both draws on CHP itself (by way of Gates, Du Bois, Collins), and better supports CHP in student game design: games that included *deeper consideration of content based on shared social issues; broadened learning space (among peers and online communities); computer science literacy beyond basic coding (abstraction and code efficiency); and self-led R&D.*

4.3 CHP in CS Education Through Making

This next case study details a trading zone between the African American natural hair movement and the maker movement. We called the program "**The Generative Cosmetology Lab" (GCL**). Its purpose was to support informal CS and engineering education in the context of hair, cosmetics, and beauty as part of a two month long teen summer program at a public library in Upstate New York. The library is located in a predominantly African American urban neighborhood. It was designed in collaboration with the library branch manager, two professional cosmetologists

[3]Meta-tuning can also be used in sinister ways; for example when the rhetoric of participation masks authoritarian agendas [42, 49].

(who were experts in natural Black hair), two high school cosmetology students, and our team of university researchers and technologists. Together, we designed the learning environment of the GCL to fit within the larger trend of installing makerspaces and supporting the maker movement at libraries [96]. The maker movement is composed of tinkers, hobbyists, technologists, and others who enjoy and utilize DIY computing and fabrication technologies to design new products, collaborate, and innovate in decentralized and bottom-up ways. Librarians, teachers, and others have sought to leverage the learning-by-doing that takes place within maker communities and makerspaces for STEM educational purposes [67], including CS [85].

At the same time, the GCL sought to confront tendencies for the maker movement's domination by White, male, and middle class (i.e., hegemonic) norms and values [64]. One of the roots of the maker movement can be found in the (relatively) ethnically homogenous Whole Earth Group. Founder Stewart Brand argued that this homogeneity was, for him, a productive feature [62, 93]. Buechley conducted a critical analysis of the pictures and representations of Make: Magazine and found that they largely reflected the cultural capital of White men [15]. As Ladson-Billings points out, by repeatedly linking signifiers of ethnic identity to certain domains, they take on a kind of conceptual whiteness: "Conceptual categories like 'school achievement,' 'middle classness,' 'maleness,' 'beauty,' 'intelligence,' and 'science' become normative categories of whiteness" (pg. 9) [63]. To challenge the conceptual whiteness of the maker movement, our goal was to design the GCL around CHP that would be relevant to the local community that the library served. We did this by building on the CHP of what is often referred to as the African American natural hair movement.

To understand what it means to approach maker activities in terms of CHP, we can start with Kobena Mercer's *Black Hair/Style Politics* [74]. He points out that Black styles such as the Afro are often referred to as "natural", but they are actually just as carefully produced, with as many products and grooming activities, as any other. By disguising choices with appeals to what is more natural, we capitulate to hegemonic forces (such as those banning LGBTQ as "unnatural"). Mercer urges us to understand Black hair styles in all forms as the freedom of Black people to express themselves in ways they see fit. In other words, the Black "natural" hair movement in the U.S. can itself be understood as a kind of maker movement, with all the implications of DIY innovation and relevance to grassroots entrepreneurship. It is not one derived from a legacy of White hobbyists, but rather grounded in the counter-hegemonic freedom for people of African descent to wear their hair how they see fit, without pressure to conform to Eurocentric standards of beauty [17], or even Afrocentric standards [74]. Black beauticians have long been conduits for anti-racist political organizing [41, 82] and sources of local wealth generation [17]. The history of anti-Black racism in the U.S. has many examples of hair discrimination, and this continues today [70]. Black children, for example, are disciplined in schools for wearing locs, cornrows, dreadlocks and heritage styles [71].

Thus designing the GCL was not a matter of "connecting" Black hair CHPs to maker practices, but rather recognizing the Black hair movement as having its own independent trajectory of innovation history and DIY fabrication, and placing those maker practices in a mutually supporting relation with the tools and techniques of the mainstream make movement. To encourage the sense of student-led process, we organized the program as a drop-in space where they could come and go as they pleased, with social, epistemic, and technological infrastructure to support both physical and digital elements of testing, design, and fabrication. We organized the sessions around three natural cosmetic activities: creating natural cosmetic products, designing cornrow braiding patterns, and analyzing hair strength. Each of these activities included design and fabrication technologies (e.g., physical hair mannequins, Arduino-based sensors, a wet bench, visual programming application, and so on). We made sure to have experts in natural hair, engineering, and computing all in the space together. For example, our engineering undergrads worked with local hairstylists to do a dry run of pH sensors with cosmetic products (Figure 9(a)) and brought

Fig. 9. Dry run of pH sensors with hair stylists (left); DIY tensile strength of hair tester (right).

together parts so that students could create a DIY apparatus for measuring hair tensile strength (Figure 9(b)). This ensured that we had some foresight in how young makers could best experience modifying typical maker tools and techniques that could fit the priorities of cosmetology explorations. At the beginning of each hour together either a professional cosmetologist, a researcher, or both would introduce some cultural background to the youths to orient the day's activity.

The first group of activities involved building and calibrating an Arduino-based pH sensor system. While that is standard maker-activity process and technology, we then have the youths bring in commercial cosmetic products from home or shopping. With Black cosmetology experts in the room, this empowers a critique of the ways in which pressures of Eurocentric standards, together with the commodification of beauty, can result in the use of damaging pH levels. The next step is to help youth make their own natural cosmetic products, using the same pH sensors to ensure healthier pH, based on plant oils and other organic sources over high-alkaline chemicals (Figure 10). Finally, they then used the pH of their own natural products as part of a mock-marketing campaign for selling their products.

The second group of activities were designed for young people to explore the scaling geometries that are embedded in cornrow braid designs, first through a physical braiding lesson on a mannequin, and then with the culturally situated design tool, Cornrow Curves [31, 60]. The goal was for young people to use CS concepts (e.g., iterative algorithms) and math concepts (e.g. transformational geometry) to describe both physical and virtual braids, contextualized by some history on the scaling patterns of African braiding and its wider significance as a source of African mathematical ideas [33]. Figure 11 shows an example from this interface.

Fig. 10. A young person measures out ingredients for their natural cosmetic product at the GCL.

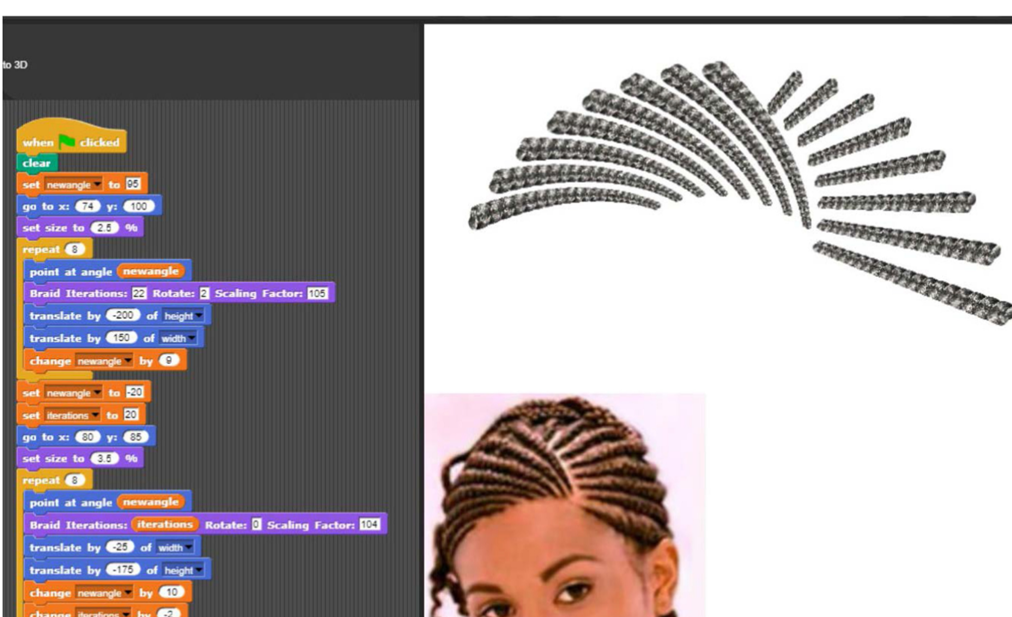

Fig. 11. Student simulation in the Cornrows Curves tool.

The third group of activities allowed the students to design experiments, test apparatus and so on to apply different chemicals to strands of hair, and then subsequently test their individual tensile strength; pulling on the strand with a spring gauge or weight unit it breaks. This activity was seen as especially important to our cosmetology and natural hair expert collaborators, who pointed out that hair damage is a major concern at the intersections of science, cosmetology and beauty commodification. While the hair strength gauge was not something that could be applied to professional use, it was well suited for our educational purposes. It required students to think about how they could collect data; to get some familiarity with what are often seen as the masculine domain of tools like vise grips; and to look at how the DIY maker approach could be applied in a lab-like setting.

To understand the repertoire of approaches in the GCL, we need to consider how the usual process of makerspace fabrications typically falls into two modes. In what Berland calls tinkering mode, the focus is on seeing what can be done with some particular part or apparatus [10]. In what Beltagui et al. call bricolage mode, one is "making do" with whatever is at hand to achieve some design or goal [4]. In what we might call counter-hegemonic making, we are looking at how fields of power are enacted upon a practice–in this case African heritage hairstyles–and exploring its contours with a repertoire of maker techniques and apparatus. Weak points in that field of power–places where CHP value might be empowered by innovation–are the targets of discovery and invention for counter-hegemonic making.

Because of the drop-in scheduling, there was a lot of fluctuation, anywhere between 5 and 14 young people per day, but in general the goal of having a voluntary makerspace predominantly (but not exclusively) occupied by young women of color was a success. Elsewhere (under more controlled learning environments) we have discussed pre and post learning comparisons for this suite of culture-based software and hardware activities [31, 60]. However, in this case we were more focused on community impacts.

Since the GCL was open to anyone, it was not uncommon for adults to stop by with children to check us out as word of the program spread around the neighborhood. One of the adults who showed up repeatedly–with and without her granddaughter–was a prominent local African American activist who does anti-racist work on critical justice and prison reform. She was particularly interested in the way we made connections between cosmetics, science, and African contexts. On the last day of the program, she sat down with the team. First, she explained its impact on her granddaughter: "As you know, I had my granddaughter here once with me and then we started talking about the make-up stuff. And, so she did a project, you know from coming here, for her school. It was a big display, which she got a 100% on [applause and laughter] but it came out of here." Next, she described how she was going to build on the work we were doing in another community engagement center, which she directed.

> *My head is spinning about how we can put all this stuff together for the community... we're doing the Black Panther because that is kind of connected to it [GCL]. So, we are going to be doing that at the library for a couple weeks to talk about issues around Black hair and Black beauty standards and that kind of stuff. So, all that came from here.*

This program began to incorporate some of the materials we had developed, in a space that had never conducted maker activities but had a strong reputation for its grassroots social justice work. Elsewhere other reinterpretations have led to collaborations with urban agriculture groups (with the aim of growing plants to be used in hair products), 3D printing mannequin heads with cornrow patterns (with the possibility of marketing a new product), and other community-oriented innovation. Here we can see how the CHP of the natural hair movement, and the empowerment of its value forms through maker exploration and innovation, allow positive racial identity development in trading zones that were developed by and for the local community.

5 DISCUSSION

CHP's very existence as a legitimate cultural production is often in doubt. Rose begins her history of hip-hop by recounting a meeting in an ethnomusicology department, where the chair declared that she must be only interested in the political dimensions of rap, since its musical attributes are non-existent [81]. Similar dismissive comments are made regarding the non-existence of architecture and design in pre-colonial Africa; the absence of poetry in spoken word; the non-artistry of graffiti; even the lack of literary value in Toni Morrison [72]. If this paper only serves to alert instructors to the existence of this rich and complex body of cultural content, we have made some progress. But of course the connections to CS pedagogy, guidelines for respectful use in the classroom, and visions for returning value to communities remain paramount.

Now we turn to reviewing these outcomes for the three questions we originally proposed:

1. What kinds of computational potentials exist in CHP; that is, how can we avoid reductive simplifications, and instead understand and interface with its rich computational beauty and sophistication?

We hope that readers will now have not only a different vision for the computational potentials of CHP, but a different perspective on methodology and goals. The objectives are not sharpening computational scalpels for dissecting Black culture. They are translating; nurturing the emergence of hidden algorithmic gems; appreciating the computational dimensions as achievements of intellect, resistance, and visions for sustainable living and equitable relationships. In the case of music, we saw that these could be translated directly into algorithmic and mathematical forms. But one cannot stop at translation, as if Western knowledge holds universal truths to which Indigenous knowledge is but an incomplete subset. We explore the neurocomputational implications for HCI: why did music of the enslaved, against all odds, "go viral" when other forms did not? We explore the computational implications: how might understanding Black music in terms of the Diaspora algorithm enable more bidirectional exchanges between cultural and computational worlds?

In the case of gaming and the Arduino-based pH sensing, the computational dimensions at first seem much more external. But there too, a counter-hegemonic perspective is crucial. What makes us assume that there is a singular maker movement, with origins in White middle class hobbyists? Why not locate equally legitimate origins in the White working class and its love of backyard mechanics or kitchen table chefs? As we begin to examine Black hairstyles as its own DIY movement, the crucial role of *repertoires* comes into focus. The broader the expanse of repertoires, the more that bricolage can become a natural mode of innovation. By eschewing the usual focus on mainstream appeal or optimization for financial gain [64], and centering instead the priorities of the Natural Hair Movement, repertoires that might not arise in your average makerspace, such as experiments with organic replacements for harsh chemicals can take center stage. There are symbiotic gains on both sides if the maker movement can adopt healthier and less ethnocentric repertoires, and the Natural Hair Movement can leverage more from the repertoires of contemporary technology.

Similarly, the gaming engagements show that Black youth can "tune" their design practices towards CHP if we can properly meta-tune the learning environment. There is no need to assume that one must replicate the kinds of heritage algorithms we find in Black music and braiding patterns, as CHP is not limited in that way. Rather, the kinds of African traditions invoked by Gates and others in explaining Black narrative forms can be seen emerging as CHP gaming practices if students are given the support to do so. Indeed, the reason for creating the general category of

CHP is to prevent such assumptions (that culture can only emerge in modeling explicit forms of visual and audio patterns). Narrative form and computational expressions of resistance, critique and alterity need to be able to co-exist side by side with heritage algorithms and fabrication techniques if we are to embrace the full repertoire of CHP forms in CS education.

2. How can we apply this to community development, such that we are not merely masking ordinary lessons with shallow CHP appearances, but rather facilitating its empowering utilization?

One of the advantages of the ethnocomputing approach is that it forefronts anti-racist possibilities. Once we stop using Western STEM as the measure of worth and allow the algorithmic and mathematical understandings embedded in CHP to emerge in their own right, the opposition to white supremacy and more subtle forms of hegemony can open doors to community collaboration. As it moves into the classroom, local advocates can see a combination of anti-racist content, student enthusiasm and academic engagement. In the case of music, our community connection took place in the form of a local education grant that enabled the purchase of physical music equipment and instruction. The case of cosmetology-based making also prospered, reappearing in another community center because of this connection. Gaming on the other hand took a more inward turn, as discussed below.

3. How can pedagogy bring together these concepts of the computational power of CHP, and its potentials in community development, to increase the academic interest and achievement of students from underrepresented groups and underserved communities?

As Cooke emphasized in her description of iCamp, student motivations are not necessarily in sync with our simplistic notions of how CHP and community aspects will intersect. The anti-racist attributes are exciting for some students ("this LCM algorithm is just like what we did with music!"); but not all. Community applications can be the key to engagement for one gamer; but for others it might feel forced. Cooke's meta-tuning framework was developed to keep instructors on the search for ways that the computational potentials of CHP can best be nurtured as CS interests and achievement. For example, in the CSDT website (https://csdt.org/) we recommend teachers allow students to make their own choices for which cultural traditions they want to select. It is not uncommon to see Black students simulating Appalachian designs, Native students making cornrows and Latinx students working with graffiti [30]. CHP should be a choice, and a journey of discovery, not an assumption about the relation between student interests and their identities.

6 CONCLUSION

Our preliminary results show promising possibilities for CHP in CS education. In scholarly literature we have shown the potential for rethinking the significance of CHP as an alternative foundation in communication theory, computational mathematics, and other areas. In community development these approaches have yielded advances in sustainable architecture, energy, health, fashion, and arts. And they have been brought together in classroom environments where this generative approach to computing education shows improvements for student interest and achievement in CS.

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Received June 2020; revised June 2021; accepted July 2021