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Harmonious Integration: Tuning STEM Education with Generative Justice

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***Abstract* - STEM educational practices not only have limited success in engaging students from underrepresented groups, but also often fail to prepare future scientists and engineers with an appreciation for the social and environmental concerns that underpin their work. Rather than approaching these challenges separately, they can both be addressed by "tuning" STEM education practices to be more socially conscious. We believe that one of the issues with STEM recruitment in unrepresented groups is the lack of societal context in which STEM problems are addressed. Rather than relying on an externally imposed moral framework, we utilize the concept of generative justice to serve as a framework to inform STEM practices. Generative justice refers to an understanding of how value is generated and then circulated within a system. A generative solution to a STEM problem allows the value generated to flow from its point of generation, become augmented with STEM practices, and back to its original source. This framework allows STEM practitioners to identify the value generated within a system and then tune their practices so that maximal value is returned to the community within which they operate. This paper provides a case study of this generative STEM approach in our work on sports science within an urban environment. By starting STEM from the authentic interests and values of the community of underrepresented students, we can create a harmonious tuning between the providers of STEM outreach and its recipients, and train a new generation of scientists and engineers who are not tone deaf to the needs for social justice.**

Index Terms – Biomechanics, Diversity in STEM, Integrated STEM outreach, STEM Education.

I. INTRODUCTION

Much of our current STEM education system is like a band with off-key musical instruments: we know something is terribly wrong but it's hard to pinpoint the problem. STEM should be a symphony of progress: as one of the most powerful pursuits in human history, it has the potential to cure disease; heal the planet; and lift people from poverty. Instead, we find it tied to societal crises such as the skyrocketing rates of income inequality [1]; obesity [2]; and global environmental devastation; meanwhile STEM career recruitment is characterized by the alienation of students by race, class and gender. Rather than addressing the societal and recruitment issues as separate challenges, we have undertaken a integrative approach that seeks to solve the recruitment challenge through the incorporation of societal issues within the context of STEM education. In this manner, both of the challenges are addressed through a single, unified solution. This paper describes a case study of the approach for specific, practical application within an urban population, as well as provides a theoretical framework by which this solution of "harmonious integration" can be extended to many different STEM disciplines and social contexts.

To many scholars, the above list of problems is far too diverse. Income inequality must be addressed separately from questions of technology; forest destruction is unrelated to obesity; neither of the two is relevant to the lack of black engineers or female computer scientists. Each of these issues seems to have a different set of precipitating conditions and must be addressed individually. This is exactly the wrong way to think about a solution; as if we attempted to get the band to sound better by separately tuning each instrument to itself. But what is the unifying key?

Let's take one example of how not to tune. When we recently asked engineers how to teach high school students about what caused the Fukishima disaster, they replied "natural forces" and described lessons about Tsunamis. That is a guarantee that the next generation of scientists and engineers will also be trained to think of environmental and social disasters as driven by forces beyond their job description. A better education would start with the foundations of the disaster in the 1950s. Heims [3] describes how John von Neumann, a father of the atom bomb, used game theory and other scientific expertise to push for more nuclear weapons, culminating in Eisenhower's "atoms for peace" program [4]. Attempting to convince the public that atomic weapons were simply one facet of a beneficial "atomic age" of nuclear medicine and energy, his program helped start nuclear power plants in Iran and Canada in 1957, and later through Canadian Westinghouse, reactors were distributed to Pakistan, India, and Japan among other nations. In other words the decision to put nuclear reactors in

Japan—one of the world's most seismically active areas, as well as in the middle east where new threats arise daily—was the result of failed "tuning" by military and corporate interests. Is it any wonder that a significant number of students are not drawn to a STEM concert played in the key of death?

So how do we tune STEM to the key of life? Let's start with physicist Schrödinger's definition of life: "It is by avoiding the rapid decay into the inert state of 'equilibrium' that an organism appears so enigmatic...What an organism feeds upon is negative entropy" [5]. Like many scholars before him, from Aristotle to Marx, Schrödinger recognized that living organisms generate value that can be circulated into and back from its environment, allowing the two to mutually sustain one another. When this value is "alienated"—that is, extracted rather than circulating back to its generative source—disaster often follows: a farm that fails to compost its organic waste will quickly deplete the soil; a community whose labor is extracted with little return will quickly decay into a ghetto. Conversely technologies that facilitate the cycling of unalienated value back to its generative source can repair, heal and prosper. Technologies that allow women to have control over their own reproductive powers—e.g., birth control—are key to smaller families and less population pressure on environments and nations [6]. Software that is distributed without proprietary barriers—i.e., open source—can in many cases have better security [7], fewer bugs [8], and more humanitarian applications [9]. We call this principle of circulating unalienated value back to its generative source "Generative Justice" [10][11].

Thus "tuning" STEM with generative justice provides a wide-ranging framework: it helps us see how to bring environmental, health, and social justice issues into harmonious integration. The generative justice wiki defines it as 3 principles (generativejustice.wikispaces.com):

1. Identify what generates value. For indigenous cultures, value is generated by a spiritual interdependence of nature and community; for software developers, value emerges from their interactions with a digital ecosystem of people and technologies. For purposes of this paper, we focus mainly on youth in local sports
2. Identify the threats from external extraction of value. Both socialism and capitalism focus on extracting value from labor. Generative justice, in contrast, examines the threat posed by any external extraction of value, whether that is capital, state, or some other institution.
3. Identify ways in which extraction can be replaced by generative circulation. For organic gardening, "generative circulation" means that plant and food "waste" is composted back to the soil; so the flow of value is more local. For open source software, "generative circulation" means that source code is released to the public domain, so that the flow of value is more accessible.

Thus the working definition of generative justice: The universal right to generate unalienated value and directly participate in its benefits; the rights of value generators to create their own conditions of production; and the rights of communities of value generation to nurture self-sustaining paths for its circulation. From this perspective, underrepresentation exists because an "untuned" STEM system fails to circulate value between the world of science—including those providing the outreach—and the world of these underrepresented students, which are often black, latino and native communities. In the case of gender, research shows that girls often avoid STEM because they do not see it as one of the "helping professions" [12][13]. Similar effects occur for ethnic identity: black, latino and native students who do not see the value put into science as circulating back to their communities will often accuse their peers who are accomplished as "acting white" [14]. In contrast, for majority students, the present STEM educational methods can be viewed as a "value proposition." Their work goes into the classroom, and rewarding careers and STEM benefits to their community flow back out. For these students, academic success, in general, can be seen as a source of fungible capital that allows students to succeed in their identities, careers and community.

Therefore reaching underrepresented students is not a matter of "duping" them into thinking that STEM brings value to their communities when it does not. Our solution, rather, is to take up the challenge of actually facilitating this value circulation. The change starts with how we diversify the types of capital that students can utilize for engagement in the STEM fields. Just as how the educational fields currently place a value on students who possess a predisposed inclination toward STEM careers, new outreach techniques must be developed that respect the forms of capital that are possessed by students from underrepresented groups. In the past much of our work has focused on craft production: STEM lessons that brought together schools with local Navajo weavers, African textile fabricators, and even cornrow braiding practices [15-18]. In this paper we describe a new set of activities based on the idea that youth sports can also be a location in which unalienated value generation can circulate within the context of academics and local engagement in the STEM pipeline. By tuning STEM outreach to a diverse population using generative justice, diverse outreach can be achieved.

We caution that it is all too easy to skip over the challenges of authentic value circulation and reduce such interactions to facile exercises, such as as "relevant" math word problems. Even in the case where an authentic connection is made, there are temptations to immediately return to the vision of a "STEM pipeline" as something like an oil pipeline, meant only for extracting talent and moving it elsewhere. Robotics clubs, for example, often use prohibitively expensive kits. One group admirably addressed this problem with a low-cost kit [19]. Yet, they report that their robotics competitions, like those of most robotics groups, were located at university campuses. Premiering these events in locations both geographically and culturally distant from low-income communities greatly diminishes the attendance by members of those underrepresented students' community. We are sensitive to the idea that these students need to be encouraged to think about college, and we *do* offer field trips to our own campus. But restricting STEM program public events to only elite locations helps to send the message that STEM value is made only for export.

A STEM approach that is tuned with generative justice is one that strives to circulate value back to its generators: the students, their community and even the surrounding environment. For example, in one school we found that many of the students identified various types of Caribbean music (reggae, bomba) as part of their heritage. In response we developed our "rhythm wheels" software [15] in which students could play these percussion rhythms using Least Common Multiple relationships. When the principal heard that children were increasing their math skills based on this cultural influence, she applied for a local grant and obtained a set of professional percussion instruments and a drumming instructor. The project ended with a community performance in which children used drumming, dance and computer-generated rhythms all on the same stage. In sum: rather than viewing cultural connections as "sugar coating" or "bait" to extract STEM talent, we need to think about how STEM can help return value in its authentic or unalienated form. In general, we can summarize the advantages of this kind of generative approach as follows:

- Students with a pre-existing interest in STEM are not accused of "acting white" [14] since the activities are related to local culture.
- Students without a pre-existing interest in STEM now have more diverse forms of capital (interest in heritage, crafts, sports, community service, etc.) to become engaged in the STEM activities.
- Rather than extracting STEM talent, both STEM value and those local forms of cultural or ecological value are recirculated back to the community in accessible and unalienated forms.
- As this changes from a one-way STEM pipeline to a widened STEM circulation, students will gain an appreciation for how the role of scientists and engineers can address societal and environmental concerns.

The case study described in this paper below was based on scientific analyses of sports performance conducted by low-income urban black and Latino youth. Next we will provide details on the practice and process of the program, as well as highlight salient qualitative outcomes. We conclude with a discussion on how to extend that example to other areas.

II. METHODS: DIY BIOMECHANICS LAB AS GENERATIVE JUSTICE

Through using STEM principles as a tool for understanding and improving athletic performance, we have created an inclusive outreach program that channels students passion for sports into authentic or "unalienated" STEM programming [20]. Because bringing up professional sports gets us back into the commodified world of media corporations, it is important to carefully distinguish our approach from the usual approach in which a celebrity is used to bait youth into STEM through superficial connections between math and sports, e.g., using the arc of a basketball as an illustration for teaching projectile motion. Children can easily identify these approaches as pandering or marketing schemes. Instead, our students are mentored by a team of community-based professional basketball coaches, scientists and athletes who share a passion for basketball with the students. This integrative mentor team is orchestrated through the partnership with a grass-roots nonprofit, 4th Family Incorporated (www.4thfamily.org). This partnership between community leaders and scientists elevates the sports science connection from one that may seem pandering to one that is authentically rooted in collaboration. By allowing STEM education to emerge naturally from the students' own interest in improving their athletic performance, the students begin to feel a sense of ownership over the results of the experiments they design. We found that we can "tune" our STEM education practices to these cultural values through the following steps:

1. The introduction of STEM concepts through the use of technologies for measuring biomechanics: real-world measures of force, jump height, dribble rate, EMG, etc. within the context of sports. Rather than decontextualize these measures in a physics lab, we bring the devices to the gym and integrate them into an already-existing athletic program.
2. Structure the program so that the focus is on sports and mentoring younger students, with STEM as a "natural" accompaniment. While sports was not the exclusive interest that drew students, this is quite different from recruiting students exclusively based on preexisting interest in STEM or with the "glamour" of lasers, robots or science celebrities.
3. In effect, this increases the types of student capital that are fungible within the context of STEM outreach programming.
4. Train the students in how to use scientific equipment to answer their own questions. This serves to empower the students to design their own experiments that are based on their own interests. Even when professional sports is included, the focus is not "glamour" but enters through the natural curiosity students express in understanding how professional sports players perform at an elite level [21].
5. The participants summarized their work in posters for public presentation within the community, especially local schools. The benefit of this peer-to-peer mentoring is two-fold: Not only is the value of our participants work being reinforced by the attention of the community, but it is also easily accessible to younger students who look to older students as role models.

6. Have students present their work to STEM professionals in a wide-array of venues: local K-12 schools, community spaces (e.g. boys and girls clubs), and University campuses. Presentations in both the community and university prevents the impression of a one-way pipeline, and helps open students to feedback and critiques on their work, giving them a sense of ownership of the STEM content that is now circulated rather than extracted.

   This extends the sense of hybridity that the students feel over the sports-STEM connections; their vocabulary becoming increasingly "bilingual" and practices moving fluidly between backboard layups and circuit board layouts. Their appreciation for the value of their work expands as students travel to assemblies, sports camps and college campuses to summarize and present their findings to increasingly wider audiences.

Developing experiments and investigations of their own athletic practices is something immediately accessible and meaningful to them, yet there is potential for continuing such investigations into deep technical and scientific waters; all the while staying within the participant communities. This encourages the community to engage in the STEM activities as well, and replaces the one-way pipeline with a model of unalienated value circulation in which science and sports form a kind of symbiosis. These socially conscious goals of inclusion are explicitly articulated to the students involved; their own comments and behaviors provide qualitative evidence that students increasingly adopt a positive stance towards addressing the chronic underrepresentation of groups within the STEM disciplines. At the same time we contributed to the development of a local community organization, 4th Family, which could host both sports and science activities.

III. OUTCOMES FOR A GENERATIVELY TUNED STEM OUTREACH PROGRAM

This framework has been deployed in summer and after school programs at a local urban high school. In both programs, volunteers from RPI served as mentors to assist high school students in developing their own sports science experiments. Over fifty students have participated in the summer program over the past two summers. Groups of 3-4 students used conference "poster session" formats to report their experiments; a total of fourteen posters have been presented by students at community events during the following year. Compared to experiments conducted in regular science class, these were remarkably professional, creative and engaged. Students involved in the summer program were not recruited based on a specific interest in basketball or sports; the designed posters reflect student interests in many different sports and activities. For example, one group with no basketball players decided to investigate the role of experience in being able to perform athletic activities. Instead of selecting an older athlete, such as Kobe Bryant as their example of someone with a lot of experience, they selected Dumbledore from *Harry Potter*. This is in direct contrast with groups filled with basketball players who unhesitantly picked an NBA-all star. Both groups, however, are equally engaged in learning about the topics and then communicating them to their peers. This highlights the benefit of generative tuning of STEM outreach; the students were able to direct their own research and frame it in a way that they found engaging (See Fig. 1).

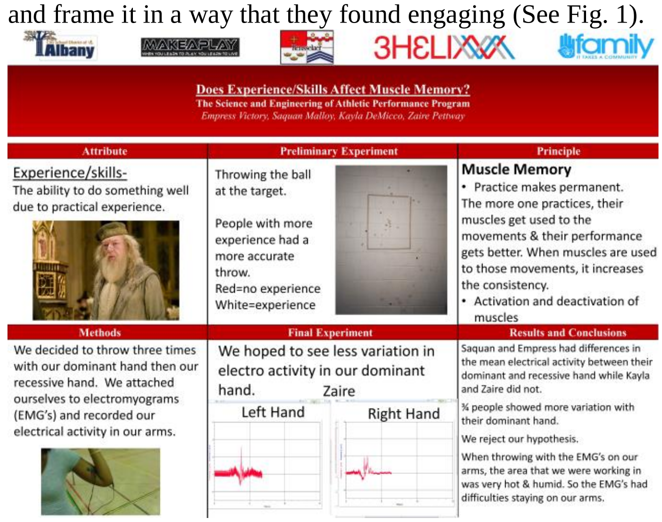

FIGURE 1
TWO POSTERS OF AGILITY OR EXPERIENCE EXPERIMENTS CONDUCTED BY GROUPS OF STUDENTS WITH TWO DIFFERENT SETS OF INTERESTS

In the after school program, we have found the most success through a partnership with the mens varsity basketball program at a local urban high school. These student-athletes connected with the program as a method to increase their own sports performance. However it is not limited to that; indeed we have recently gained students from an advanced physics class in which offered guest lectures. In the after school program, we observed the physics students as they took an active role in analyzing sports science experiments that were based on questions posed by the basketball team players. The basketball players were more familiar with the operation of the equipment, due to their longer participation in the program, and they enjoyed teaching their physics peers how to use scientific equipment. The basketball players took particular interest in using force plates to measure vertical jump height and they focused on this activity for their community-based presentations. In preparation for presenting at community events, the students worked several times with the junior varsity and freshmen teams using the equipment (See Fig. 2). This had the effect of engaging the younger students in the program and has increased the participation of this younger cohort in STEM activities.

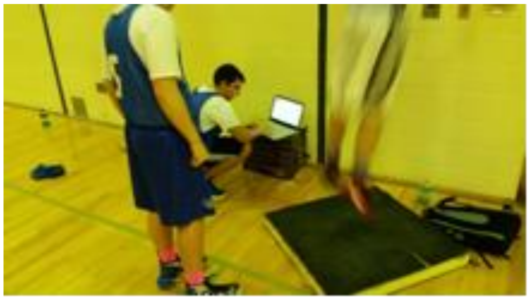

FIGURE 2
SOPHOMORES BEING INTRODUCED TO A DIY VERTICAL JUMP PLATFORM AT BASKETBALL PRACTICE

As of winter 2015, thirty of our students have presented their sports science research to over 800 younger students at various community functions, including basketball clinics, school assemblies and community centers. This was performed with our community partner, 4th Family Inc., which provided professional basketball coaches, players and trainers to ensure that the programming remained authentically grounded in basketball. Our students were excited to have their work incorporated into existing basketball programs that they knew and respected. The inclusion of these community leaders also ensured that the STEM component was not seen as a superfluous addition. The locations of these presentations made them easily accessible by community members, while the focus on basketball allowed for engagement without a preexisting interest in STEM. By enabling the students to conceive, design, build and analyze their own biomechanics experiments, and presenting these results to younger students in the community, the value generated within the community is maintained within its members.

III. DISCUSSION: EXPANDING HARMONIOUS INTEGRATION TO OTHER STEM AND SOCIAL DOMAINS

In prior work by our group, we worked primarily with value generation in indigenous craft materials. Students simulating artistic heritage practices—Navajo weaving, African adinkra stamps, Latino drum rhythms, etc.—showed statistically significant increases in comparison to control groups using similar materials without cultural dimensions [15]-[18]. Showing that these are “heritage algorithms” [18] directly contradicts both the myth of genetic determinism—that underrepresented students’ brains are somehow inferior—and the myth of cultural determinism; and that math and computing achievement is “acting white.” In some of these cases the value is directly circulated back to the community: for example, one elder Navaho weaver asked for our software so she could try out different designs. In other cases it is simply the fact that students are utilizing the work of prior generations: several weavers said they were concerned that the new generation will abandon weaving, and they were happy to see the practice live on in the new medium of computers.

In the sports case we discuss in this paper, we have found that sports can be an important example of local value generation for inner city youth. However just as Navajo weavers have their value extracted by fake blankets made by machines in China or Mexico, the value generated by youth in sports has long been extracted by corporate interests, including some in the STEM industry. Math textbooks abound with “culturally relevant” word problems that simply extract and alienate the value. Calculating the parabolic arc of a basketball appears to youth with sincere sports interests as no more authentic than would a Navajo weaver looking at a blanket woven by a machine in China. Professional sports franchises are not very effective at returning value to consumers either: the empowering aspects of sports—its opportunities for learning physical skills, social interaction and emotional development—are channeled often into forms of commodification ranging from sports apparel to media consumption such as television that actually decreases youth’s physical activity [22][23]. By using a generative framework, this passion for sports can not only help “tune” STEM outreach to reach previously disengaged youth, but help steer youth towards more authentic and empowering forms of sports itself (for example through our collaborations with 4th Family Inc.). This generated value is retained within the community in the form of STEM accessible programming for younger community youth, performed by their older peers (See Fig. 3).

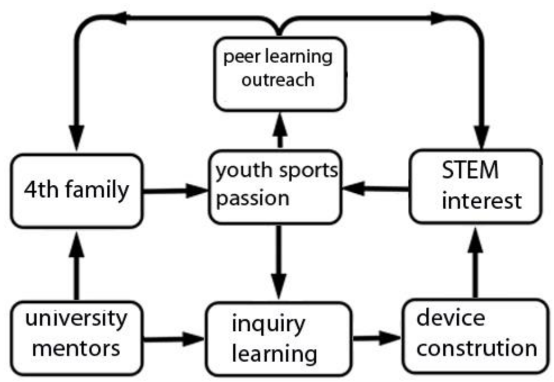

FIGURE 3
GENERATIVE STEM OUTREACH SPORTS MODEL

Such peer-to-peer learning is a powerful mode by which we can circulate the value generated by youth in our STEM outreach. But we need not stop there; the technological means of circulation are just as crucial. A company that sells biometric equipment would not necessarily be a bad approach, because the value extracted (albeit in the alienated form of money) might be returned if the quality was good and the pricing was reasonable. But we can do far more good by using an open source system that allows youth to make their own biometric equipment, gaining technical skills and pride in their craftsmanship along the way. We have posted the instructions for these projects on our website as well as have benn using them in teacher professional development workshops.

STEM education that is centered on bringing value back to its generators can be indefinitely expanded. The website for DIY sports biomechanics is embedded in a broader "culturally situated design tools" (CSDT) community. Launched online at community.csdt.rpi.edu/cms/application-contexts/diy-sports-science-lab, the website begins with material that students can read about the history of sports in relation to social justice. In our current focus on basketball, for example, students learn about the 1904 origins in which Washington DC gym teacher Edwin Henderson brings a new game, basketball, back to his school as as a civil rights tool to get his black students into college; the 1950s efforts of Celtics center, Bill Russell, and UNC coach, Dean Smith, taking on Jim Crow both on and off the basketball courts; and the recent protests against racism by the Miami Heat (Justice for Trayvon); Georgetown ("I Can't Breathe") and others. That is to say, just as we "tune" STEM lessons to better circulate value from youth, we can also tune our presentation of sports to help youth better understand how professional athletes can circulate value back to the communities that support them.

In addition to offering this historical, political and social lens on sports, the website also includes lesson plans for teachers, and—most importantly—instructions for building your own DIY biometrics equipment. Our prototype, a jump sensor based on Arduino, an open source microprocessor, allows students and teachers the opportunity to construct their own apparatus; thus avoiding the barrier of expensive equipment. Open source also allows other groups to modify and refine our original design. We hope to create a community of users and developers who can build new extensions while circulating value back to the communities of origin.

We can imagine a wide range of activities in which topics such as sports, dance, gardening, civic engagement—virtually any authentic interest on the part of the student—can be tapped into for this "generative STEM" approach. However three caveats are warranted here:

Replicating inauthentic or alienated versions

First, we caution against replicating the same inauthentic connections as we have seen in math problems for sports. The biomechanical topics that we have applied to basketball would seem to be very applicable to using for dance, however an authentic connection between the provider, the consumer, and the topic of the STEM outreach material is required for effective programming. As the group that was providing the basketball centric outreach has little interest in dance, they would not be an effective group to talk about dance. The engagement on the part of the outreach providers is key for the creation of inclusive programming. In this way, generative justice allows for a reflexive use of tuning; the providers of outreach must evaluate their own interests in order to determine what they themselves authentically connect with. Once this has been identified, it is possible to find groups of youth who share a similar passion with whom to work with. This method allows the outreach to remain authentic across different topics and disciplines.

Metatuning as a necessity

One always has to tune the tuning. Cooke [24] refers to this as "metatuning": an iterative trial and error process that is mobilized by both lower level (tuning) and higher level (metatuning) trial and error processes. For example, when we began, the students had a fairly rigid process in determining their use of the force plate for jumping. But our trial and error process gradually got better at allowing more agency on the part of students, who devised their own experiments which sometimes bore little relation to the original goal. The students' ability to "tune" their practice to their own proclivities was enhanced as we "metatuned" the pedagogy to make that possible.

Metatuning stems from critical pedagogy and game design research [25]-[28], which understands learning as a sociocultural experience that involves material (technological, spatial, logistical), social (interpersonal to societal), and conceptual (STEM knowledge) relationships. Rather than a company siphoning money from schools, or using its charity for product placement, metatuning invites a scientific, exploratory mindset to the educational field. The trial and error process of tuning pedagogy toward unalienated value can guide practices towards students' intrinsic motivations; thus engaging STEM content in meaningful ways.

For example, Cooke's development for game design programs, where students used various games development materials (from prototyping with paper and pencil to programming in CSDTs and Construct 2) showed how students ability to design meaningful games were strongly dependent on a pedagogical context that motivated for better student-ignited "tuning" trial-and-error practices. As in the case of our sports science experiments, these were best achieved when students collaborated with professors, local non-profits, peers and games development professionals. Without such a context, students in the game design program quickly gravitated toward commodified content, creating mimetic designs that further implicated them in the "collective trance" of commercial video games [29]. However, with a harmonious integrative support of professors, games development professionals, researchers, and non-profits, students designed games that resonated with their social and cultural realities and even showed signs of reflectively transforming their identities towards software developers or others in the game design profession. Several participants have actively corresponded with local games development companies that share the same sentiments; this upcoming April (2016), the students will be co-presenting their games at two games development conferences.

A cautioning against "Ghettoizing"

Finally, we caution against "ghettoizing" students such that we trap them in their own interests. A generative approach to STEM education need not start from the students' own social interests. A scientist who is passionate about her work can always help students explore its intersections with the world, and thus create pathways by which value can be circulated back to the human or non-human agencies that generated it.

III. CONCLUSION: TUNING STEM TO THE KEY OF LIFE

Tuning STEM to the key of life through a generative justice framework enables the creation of STEM outreach programs that are accessible to a diverse population of students while allowing the recirculation of unalienated value back into the community from where it was generated. This tuning takes place by incorporating student interests into the STEM activities while empowering students to answer questions that they ask with a technically-grounded STEM approach. This generative framework can be extended to encapsulate many interests of students—from basketbal to Navajo weaving to game designing— and shows potential to broaden the appeal of STEM to a diverse audience.

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