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Decolonizing education with Anishinaabe arcs: generative STEM as a path to indigenous futurity

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Abstract
This paper introduces a generative framework in which translations of Indigenous knowledge systems can expand student agency in science, technology, engineering, and mathematics (STEM). Students move from computer simulations to physical renderings, to repurposing STEM innovation and discovery in the service of Indigenous community development. We begin with the math and computing ideas in traditional Anishinaabe arcs; describe their translation into software and physical rendering techniques, and finally their workshop implementation with a mix of Native and non-Native students. Quantitative and qualitative analyses of pre-survey and post-survey data indicate increases in students' understanding of Indigenous knowledge, their creative ability to utilize it in moving from algorithmic to physical designs, and their visions for new hybrid forms of Indigenous futurity. We use these findings to argue that culture-based education needs to shift from a vindicationist mode of admiring ancient achievements, to one that highlights students' agency in a generative relationship with cultural knowledge.

Keywords STEM education · Native American · Indigenous knowledge · Educational technology · Design agency

Introduction

While culturally responsive education has been a promising trend, it is also a tricky path to navigate. Take, for example, ethnomathematics, which endeavors to "translate" between Indigenous math concepts and their Western equivalents. Vithal and Skovsmose (1997) note similarities between ethnomathematics discourse and apartheid-era South African government education policies; there "the cultural framework of the population group" was code for restricting Black students to schools for manual labor careers (*White Paper on the Provisions of Education in South Africa* quoted in Vithal and Skovsmose 1997, p. 136). Other critics (e.g., Knijnik 2002; Hottinger 2016) warn that without contextualizing societies in specific histories and power relations, cultures become an "undistinguished

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smorgasbord" in which one grabs a bit of symmetry from an African mask, plucks Eulerian paths from Pacific Island sand drawings, and so on, just like a colonial extraction enterprise (Eglash 1997, p. 4). Indeed, Tuck and Yang (2012) note that the very term "decolonization" has too often become a loose synonym by which innocence is proclaimed, releasing authors from responsibility for how the work is historically and socially positioned with respect to actual "repatriation of Indigenous land and life" (p. 1).

With these critiques in mind, this paper is focused on the resurgence of Anishinaabe knowledge and livelihood; specifically looking at a two-day workshop with students attending a summer program sponsored by the Center for Native American Studies (CNAS) at Northern Michigan University. We examine this as a case study for the framework of "generative STEM"; an educational system in which value is not extracted, but rather circulated in unalienated forms, via science, technology, engineering, and mathematics (STEM) learning and innovation, back to the communities in which it was generated. Analyzing data from this workshop, we begin to explore how a generative cycle may not only help diversify inputs to the STEM pipeline—attracting a more diverse population because of its relevance—but can potentially diversify the outputs as well, redirecting scientific knowledge production and technological innovation away from corporate and state goals and closer to the priorities of Indigenous and disenfranchised communities.

Background on culturally situated design tools

Our study emerges from a series of collaborations between CNAS and an interdisciplinary research group that has formed around Culturally Situated Design Tools (CSDTs; csdt.org). CSDTs are a suite of online simulations, hardware kits, and other technologies that are based on the idea that math, computing, and concepts from other STEM disciplines are already embedded in Indigenous and vernacular knowledge systems and cultural designs (Eglash et al. 2006). Consistent with theory and research on *situated cognition* that explores how knowledge is always produced within culturally and physically situated contexts (Young 1993; Choi and Hannafin 1995), CSDTs represent knowledge as the result of historical relationships between individuals, communities, environments, and physical artifacts. CSDTs do not seek to impose external ideas, but rather "translate" between traditional knowledge and its in-school analogs. Educational interventions with CSDTs show statistically significant improvement in content knowledge (Eglash et al. 2011; Babbitt et al. 2015).

Often the rationale for culturally responsive STEM is that underrepresented students will be alienated if they do not see their own ancestral culture included in the content. While the young people we have worked with often show appreciation for such connections, we have found that when offered a choice of CSDTs underrepresented students do not necessarily select a tool corresponding with their own heritage (Bennett 2016). Another rationale for culturally responsive STEM is that locating sophisticated math and computing knowledge in Indigenous culture—even if not their own—directly combats harmful stereotypes of primitivism and racist myths of IQ and "math genes." Again, student responses often do show an appreciation for anti-primitivism; however, it is important to note that even when simulating patterns from their own heritage, we often see hybrid blends, for example, African American students using a Native American bead loom CSDT to create

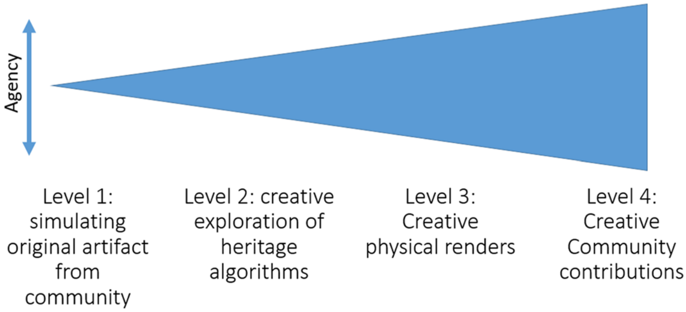

Fig. 1 The inverted funnel of expanding agency in generative STEM

graffiti tags. Students often create designs that are deliberately non-traditional, ironic, or exercise some other creative independence (as we will see below).

Thus, agentic facilitation—culture-based STEM as a canvas for expression—is at least as important as the heritage dimensions. Facilitating students' transition from virtual design to its physical rendering can further enhance this agency, especially when it involves hands-on fabrication. A final transition to the domain of community interactions—designing real-world architectures, innovations for local production, sensors for health and environment, etc.—can bring value full circle, completing a generative cycle. Rather than a funnel, reductively narrowing students' scope to a reified heritage, generative STEM works in the inverse, broadening their abilities to reflect upon the world and act as agents of change (Fig. 1).

Generative STEM is about bridges between several different domains: between the virtual and the physical; cultural knowledge and scientific knowledge; schools and communities; pasts and futures. The terms "Indigenous futurism" and "Indigenous futurity" can lend some further understanding in this regard. Tuck and Gaztambide-Fernández (2013) use the term "Indigenous futurity" as a contrast to settler futurity. They show how settler futurity is based on erasure and replacement of Indigenous groups. From the Boy Scouts' "Order of the Arrow" to the New Age White shaman, the shallow gestures of multiculturalism excuses and reifies Native absence. In contrast, Indigenous futurity puts a focus on Native people's actual presence and persistence. While they are related, futurity is not synonymous with the future but about the "ways that groups imagine and produce knowledge about futures" (Goodyear-Ka'ōpua 2018, p. 86).

Dillon (2016) coined "Indigenous futurism" in 2003 to both draw attention to the ways in which Indigenous science fiction (SF) writers, artists, game designers, and others had created new visions for Native futures, and to "recognize the qualities lauded in contemporary experimental SF as core elements of ancient Indigenous epistemologies" (p. 1). Of particular importance for the work in this report is Dillon's (2016) concept of artifacts as embodied knowledge: "For years, Native artists such as Jolene Rickard (Tuscarora), Paul Chaat Smith (Comanche), and John Mohawk (Seneca) have emphasized how Indigenous knowledge is *embodied*. As opposed to the Enlightenment impulse to abstract ideas from things, Native objects *are* information, and they convey political and aesthetic purpose simultaneously" (pp. 3–4).

In efforts to support dynamic opportunities for bottom-up knowledge production about Indigenous futures, the development of CSDTs is based on the following four principles:

(1) *Respectful contextualization:* any candidate practice or artifact must be approved by elders, artists, or other representatives of the tradition, and must be presented to students through its cultural/historical context to ensure respectful use.
(2) *Emic, not etic:* interviews with practitioners ensure that we start from their views and knowledge, rather than imposing Western meanings. This acknowledges that translations will always be partial at best; the vast depths of Indigenous knowledge cannot be simply "ported" to Western classrooms as if they are a formula in a book.
(3) *Contact zones:* the technology interface design process inhabits a "contact zone" (Haraway 2016) which, through iterative feedback, evolves toward a design acceptable to teachers, community collaborators, and students alike (Lachney 2017a).
(4) *Design agency:* student learners are not merely simulating older designs, but discovering "heritage algorithms"—algorithms found in cultural arts and designs, such as African American braiding and Native American quilting (Bennett 2016)—to deploy in the creation of new patterns of their own. A result can be the blending of localized knowledge and STEM to develop new community-relevant innovations (Bennett et al. 2016; Eglash et al. 2017; Lachney et al. 2019).

Prior CSDTs created in collaboration with Native nations included a virtual bead loom developed with a Shoshone Nation school and a virtual rug loom created with the Diné Environmental Institute (Navajo Nation). Based on these outcomes, a group which included faculty in the Hannahville Indian School and CNAS requested the development of a virtual wiigiwaam to represent a distinctly Anishinaabe CSDT, with the pedagogical aim of providing connections between Indigenous knowledge and a high school level curriculum. This became the CSDT we refer to as "Anishinaabe arcs."

Anishinaabe arcs: designing a generative tool

Despite the four principles outlined above, it is always possible for someone to approach CSDTs with an extractive mindset, using the cultural connections as if they were "sugar coating" for the bad medicine of STEM, or "cheese" to tempt student mice through the STEM maze. What we describe here does not guarantee a generative process. Rather, it is our attempt to create as many opportunities as possible for generative cycles to occur; that is to create what Lyles et al. (2016) refer to as "generative contexts." Extractive processes make labor invisible (which is how we end up purchasing things that were made by exploited workers). So our first task was to illuminate where and how the value embedded in Anishinaabe arcs was being created in the first place.

The Anishinaabeg include the Three Fires Confederacy of the Ojibwe (Chippewa), Odawa (Ottawa), and Bodwewaadomi (Potawatomi), as well as other Anishinaabemowin speaking tribes. The Ojibwe are the largest with about 330,000 people in the US and Canada as of 2010. CNAS—the Indigenous equivalent of an "external review board" in our case—was composed of Anishinaabe scholars and staff and had a long history of work with elders and Native teachers. One key teacher in this project, RunningHorse Livingston, had already mapped out some math connections to wiigiwaams.

A member of the Bad River Band of Lake Superior Chippewa, Livingston had developed a unit called "wigwametry" using circular model wiigiwaam construction to allow Native students to investigate the value of the mathematical constant PI. Informed by Livingston, CNAS, Hannahville Indian School staff, and others, we determined which lodge designs and teachings were used for sacred ceremonies, and which common forms traditionally used for housing or storage were deemed acceptable for classroom use and design experiments.

As noted above, CSDTs seek the more complex and sophisticated understandings that create the foundations for Indigenous knowledge; without that, there is no opposition to primitivist stereotypes. In 2003, CNAS staff and instructors had participated in the construction of a wiigiwaam using traditional methods, and had amassed a large amount of detailed documentation on the tree species, sapling selections, bark stripping techniques, and other material aspects of the cultural tradition, as well as the ways that concepts such as the "personhood" of trees (*naagidewnjigon*) were involved.

Several aspects gradually emerged as the key salients. One was the importance of wood microstructure; not only differentiating between species and age but even the different properties depending on wet years vs. dry years. Another was the design theme common to many Native American groups: four-fold symmetry (four quarters of the Medicine Wheel; four winds orientation, etc.) which provided an Indigenous basis for a 3D grid. The third was the iterative pattern—for example, the series of arcs making up a wiigiwaam or other structures typically change variables like width and height as you move along one axis, which fits well with the concept of heritage algorithm. As the knowledge categories became clarified, we reached out to other Anishinaabe nation citizens for additional expertise. Ryan Gorrie (Sand Point First Nation on Lake Nipigon) helped us think through some of the relations between traditional and contemporary structural language, as we describe in the implementation section below. Darrick Baxter, an Ojibwe software developer who created his own Native language app, suggested that we could translate the term "variable" using "Daa-aanjisemagan" (literal translation: "thing that could change").

We are often asked how it is possible to avoid extraction if one is translating between Indigenous knowledge and STEM. The answer is similar to that provided by abolitionist Wendell Phillips: "the price of liberty is eternal vigilance." That is to say, living in a society dedicated to value extraction means that the struggle for generative practices happen at every scale, and are always a compromise between what is ideal and what is achievable. Each of the above connections came from a lengthy process of evolving conversations, exchanges of video, simulations, in-person visits, and so on, but we have summarized them as translations between Indigenous and STEM equivalents to help readers understand how the connections look in relation to a standard STEM curriculum. Actual Indigenous knowledge systems are profoundly deep; what ends up as the "curriculum connection" is always just the tip of the iceberg. Its investigation requires a rich dialog between all parties; what we have elsewhere described as "recursive emergence" (Lachney et al. 2016). To convey this generative approach to Indigenous knowledge research, and how it can be integrated into educational technology and curriculum despite the restrictions and challenges, we will briefly describe some details from just one topic: the elegant arcs themselves.

What began as a component of wiigiwaams (i.e., arcs) soon emerged as something repeated throughout Anishinaabe design: snowshoes, canoe ribs, bows, fish traps, syrup skimmers, basket rims—all had wood bending back onto itself. CNAS language instructor Kenn Pitawanakwat translated the terminology between English and Anishinaabemowin, and audio recordings enriched the online materials such that language survival (a critical goal) could be supported in these STEM lessons. "Elasticity" for example had a clear

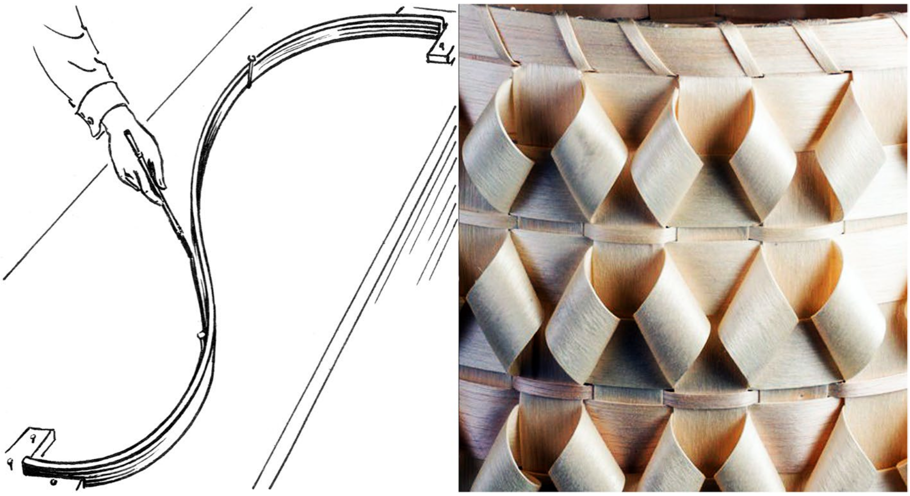

Fig. 2 A spline used to make consistent drafting curves in the Western tradition, and an example of repeating consistent wood curvatures in the Anishinaabe tradition. Basket courtesy of Kelly Church (Potawatomi–Odawa–Ojibwe)

equivalent in *zhopshkaa*, while "modulus of rupture" required Pitawanakwat to create a more complex translation as *epiichiiyimigak* ("how much weight it can take"). The physics of wood bending, viewed through an Anishinaabe lens, began to take shape. But what class of mathematical objects are those curves?

When wood bends, it is anchored at one or more points, so the resulting curve is a function of changes in the distance between anchors and the *zhopshkaa* of the wood (determined by its microstructure). This maps perfectly to a body of mathematics called Bézier curves. We usually think of math as a system of abstractions, with physical rendering as a later application. When Pierre Bézier was employed at the Renault automobile company (Rabut 2002), he developed the system of Bézier equations for a very specific application. The beautiful curves of their cars (the 1950s era *Alpine* for example) were created in part by bending thin wood strips or "splines"; a technique which had been used to model curves for ship construction for centuries (Fig. 2). In other words, Bézier was not creating abstract equations and then applying them to make shapes. He was learning to do the math that the wood was doing.[1]

This phrasing is consistent with the Anishinaabe view that might be wrongly dismissed as mysticism by mainstream scientists: that the math is first known by the wood, which teaches it to humans. The difference is that such relations are occluded by Western knowledge traditions, which keeps knowledge bound up with intellectual property rights, Platonic

[1] Another way to think about it is that the wood is an analog computer. Prior to digital computers, prediction of events such as tides or even certain calculations were carried out by measuring changes in a physical system that modeled what you wanted the equations to calculate. Dewdney (1985) provides the example of a beam anchored at one end, bending under its own weight: the deflection at the free end is proportionate to the 4th power of the length. Slide the beam in a vise to the desired length, and now you have a calculator for the 4th power of any number. Conversion to symbolic representation is not required; Dewdney points out that analog-to-analog linkages are possible (in the Renault case, wood splines to metal car curves). Thus Anishinaabe bending can also be understood within the analog computation framework.

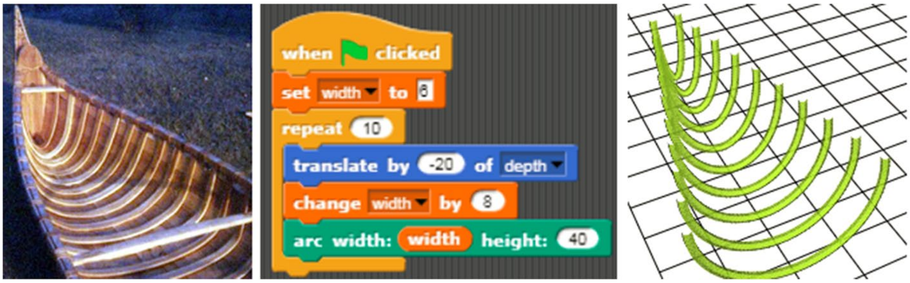

Fig. 3 From Indigenous arcs pattern, to blocks-based interface, to 3D simulation

idealism, and the "great men of history" narrative. The Anishinaabe view in which trees have *naagidewnjigon*, in contrast, is bound in concepts of nature's agentic knowing and hence ecological reciprocity (e.g., Kimmerer 2013; Usik 2015). That reciprocity means that Anishinaabe epistemologies and practices aim to minimize damage to trees or forests when the wood is harvested because trees and humans are in a generative relationship with each other. The Western extractive epistemology, in contrast, parallels environmental extraction; hence clear-cutting of forests and other damage.[2]

Bézier equations are too sophisticated for a high school curriculum, but it is important to start from a strong anti-primitivist stance when negotiating within the CSDT contact zone. As noted above, the full complexity of Indigenous knowledge creates some challenges when we think about the restricted time frames, narrow focus and didactic style of typical schools; but we did our best to find points of compromise. We determined that modeling the arcs as parabolas, with students specifying width between endpoints and height, would be the best middle ground between the cultural practices, the kind of intuitive interface most attractive to youth, and the mathematical specification most relevant to teachers.

A blocks-based coding application adapted from the visual programming environment *Snap!* (called *CSnap*) completed the interface by allowing users to specify the iterative basis of repeated arcs (Fig. 3), providing a framework for heritage algorithms. This was contextualized by a "cultural background" section of the website for Anishinaabe arcs, offering the opportunity for students to learn and discuss rich concepts like *naagidewnjigon* before, during, and after their design processes. Whether that is used in a generative pedagogy—allowing students to discuss, probe and speculate with such concepts; how they might or might not fit with contemporary concepts of sustainability for example—is not something we can control in other classrooms, but it is certainly an ideal we strive towards in our own, as we describe in the following section.

Implementation methods

During the summer of 2017, Anishinaabe arcs was used as part of the CNAS's "Reimagine STEM" summer program. We worked with 48 high school students, mainly from across Michigan, with some Southwestern students as well. Based on approximately

[2] In our introduction we maintain that a generative approach should strive towards redirecting scientific knowledge production and technology innovation away from corporate and military goals and closer to the priorities of Indigenous and disenfranchised communities. The above connection is one example; but its efficacy depends on being brought into the scope of agency for students, teachers and communities.

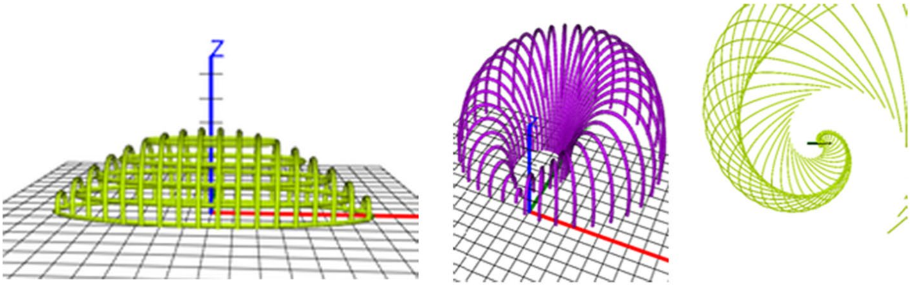

Fig. 4 A wiigiwaams simulation, and two creative reinterpretations by Native students

80% of students' responses to the ethnicity question on a survey, we estimate that the demographic makeup of students was 1/3 Native American, 1/3 Latinx, and 1/3 White and African American/Black (see the Survey Outcomes section below). During each of the 2 days, students were exposed to 1.5-h workshops (a total of 3 h per student) designed around Anishinaabe arcs.

During the first day, students divided into four groups. Each group was assigned one page from the Anishinaabe arcs cultural background section. Their assignment was to present what they learned (in their own words) to the class. Group 1 started by exploring the history of the Three Fires Confederacy alliance and other Anishinaabemowin speaking tribes. They studied their historical opposition to land grabs by settler colonialists and the U.S. government. Moving from this background to examples of contemporary Anishinaabe STEM innovators, students were particularly intrigued by learning that Ojibwe architect Douglas Cardinal was not just the first Native American architect to use computers in architectural design, but the first of any ethnicity in North America. Group 2 learned about the significance of arcs in traditional Anishinaabe designs (as we have described above); in particular, the roles of elasticity and tension for structural integrity. Group 3 reviewed the Indigenous knowledge from a materials science view, including the relation between the concept of non-human personhood and ecological sustainability in the case of harvesting wood. Group 4 examined the geometric structures and iterative patterns of arcs in Anishinaabe design, ultimately learning about the concept of heritage algorithms.

After each group presented on their part of the cultural background lesson, students began a twelve-step Anishinaabe arcs tutorial in *CSnap*. The tutorial allows students to watch a brief animation of the construction of a blocks-based script (see Fig. 3) and then practice what they saw for themselves. Following the tutorial, they moved to an open-ended design activity, where they explored the limitations and affordances of the software, gradually modifying the original algorithm by trial-and-error experimentation. They created realistic and fantastical structures at a variety of sizes and scales. Some had names that explicitly referenced Indigeneity (e.g., "Pottawatomi Crescent," "Inward Wigwam"), while others referenced what their design reminded them of: "Flowe," "Floppy Mushroom," "Trippy," and so on (Fig. 4). After the students left, we printed out these virtual designs from an overhead perspective, so that they could be laid against a physical surface and be used as templates (hole positions) for physical construction.

During an aforementioned CSDT workshop with Navajo students, we found that the Diné Environmental Institute's emphasis on sustainability caused some pushback from

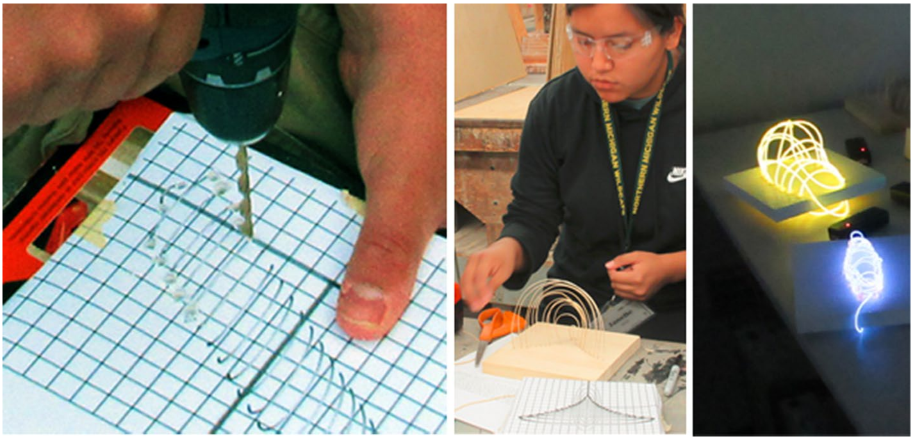

Fig. 5 Physically rendering virtual designs with paper templates

a few of the students, who said that they had no interest in environmental careers. From our view, this is a symptom of extractive STEM; students feeling that they are being pushed toward a restrictive career path. But having no facilitation of careers at all is not helpful either. For that reason, we developed three different "pathways": sustainability, design, and technology. As visualized by the "inverted funnel" in Fig. 1, allowing students to choose their own path made the Indigenous/STEM connections a bridge, rather than a barrier, to agency. Moreover, within each path were further choices. Each group was directed to a document with a collection of case studies in which Indigenous-inspired innovation occurred along that pathway. Each included both real and speculative examples of how Indigenous STEM and art professionals push the material boundaries of arcs and related technologies in new and creative ways.

For example, in the design "path" document students could view Anishinaabe designer Ryan Gorrie's arc-based contemporary architecture; accompanied by an excerpt from our interview with him in which he provided advice to students seeking a career in design. The sustainability document included a description of the enormous indoor botanical garden in Assiniboine Park created by Cheyenne Thomas and her father David Thomas of the Peguis First Nation; their design features intersecting arcs that create a leaf shape. The technology document included information about how new OLED lighting allowed for illumination from flexible surfaces. Each of the case studies also included questions for students to consider. For example, after learning about the OLED innovations, students were asked what they would suggest to an OLED company if hired to merge Anishinaabe arcs with lighting design.

After studying examples of Indigenous innovation in their assigned pathways, students were given printouts of their virtual simulations to use as templates and a set of materials that were specialized to each path. They physically rendered their virtual designs using these materials (Fig. 5). The goal of physical rendering with CSDTs is not to create designs that exactly match—if that was the case we could simply use a 3D printer—but instead to creatively explore the affordances and limitations of the materials in a "translation" process between virtual and physical. That is to say, the physical rendering process also models the distinction between labor extraction (as one would see on an assembly line) and the kind of generative practices which make artisanal crafting a beloved profession, even today (Luckman 2015).

Students in each pathway had paper printouts of an overhead view, which could be used as templates for hole placement, as well as printouts of the view they had saved when making the simulation. The sustainability pathway used flexible reeds that they stuck into blocks made out of MycoFoam, which is an easily decomposable fungus-based alternative to Styrofoam. The design pathway students used pine board; they needed to drill holes to secure flexible strands of reed to make arcs. In the technology pathway, students threaded electroluminescent wire through holes in plastic board, and then connected them to pre-made driver circuits.

After students completed their designs, they finished the workshop by returning to their computers to type out short answers to the questions: "How does your design relate to your career path? Your family or community? And, your own interests and future goals?" Some students used this opportunity to answer questions that were in the "pathway" documents, such as "How might someone use Anishinaabe arcs for other kinds of design? Furniture? Shoes? Packaging? If someone said 'your design will be used for a building' what would you like the function of the building to be? Hospital? Home? Playground? Office? Barn? Sports stadium? How would the arcs relate to its function?" Few of these specific examples were used in the replies, but the prompts did appear to help stir students' imaginations, as we report below.

Survey development

To reiterate our goals: we seek a generative STEM framework that will allow unalienated value to circulate from communities, become enhanced or enriched by science and technology, and return unalienated value back to those communities. That is to say, we seek not only to increase the diversity going into the STEM pipeline but to diversify its output as well. Our aim is to try and ensure that technologies and discoveries are directed toward local communities and not just extracted by corporate or military interests. In this particular case of working with Native and non-Native students we wanted to know if the CSDT could help move toward those goals by enhancing students' understanding of Indigenous knowledge and nurturing their agency and creativity in this STEM/culture syncretism. This can be organized as three components:

1. The ability to translate between Indigenous concepts and their Western counterparts.
2. The ability to maintain connections between those translations and the original Indigenous context and meanings, rather than extract and alienate that value.
3. The ability to circulate that unalienated value back to students' concepts of community development; their creative visions as agents of change; or some other generative sense of Indigenous futurity.

Our team designed a pre/post survey with five open-ended questions that might help detect these changes. The questions are in the first column and the rationale in the second (see Table 1). In addition, students were given the opportunity to reflect on their time spent in the workshop when responding to an open-ended prompt: "How does your design relate to your career path? Your family or community? And, your own interests and future goals?" This too spoke to Indigenous futurity but left room for students to express concepts or

Table 1 Questions and rationale for pre/post survey

Question	Rationale
1. What computing concepts can be found in Anishinaabe traditions and knowledge?	Indicator of students' ability to translate between Indigenous computational concepts and Western equivalents
2. What math concepts can be found in Anishinaabe traditions and knowledge?	Indicator of students' ability to translate between Indigenous mathematical concepts and Western equivalents
3. What is significant about the Anishinaabe tradition of bending wood into arcs?	Indicator of students' ability to connect arcs to both STEM translations and Indigenous principles (e.g. ecological reciprocity)
4. How might science and technology be used to support Anishinaabe traditions and knowledge in the twenty-first century?	Often students see STEM as something that "saves the day" for passive recipients. This question provided an opportunity to see if they could envision more hybrid or agentic relationships, without any hint from the question phrasing
5. What are some ways that Anishinaabe traditions might contribute to contemporary innovation?	The inverse of question 4; now directly asking them for a vision of Indigenous futurity

ideas we did not anticipate. We treated length and richness of the responses as indicators for degrees of engagement in the workshop.

Survey outcomes

Individually, on their own survey sheets, students answered these questions before and after the workshop. Of the 48 students we were able to match 38 pre and post surveys. Thirteen students identified as having Hispanic/Latino heritage (ten of the students identified only as Hispanic/Latino, with three students identifying as both Hispanic/Latino and White). Thirteen students identified as having Native American/Alaskan Native heritage (six students identified only as American Indian/Alaskan Native, with five identifying as both American Indian/Alaskan Native and White, one as American Indian/Alaskan Native and Pacific Islander, and one as American Indian/Alaskan Native and Hispanic/Latino). Eight students identified as White; three identified as Black/African American; and one as Haitian. This is summarized in Fig. 6.

Questions were analyzed in two ways. First, in consultation with two NSF grant funded external evaluators (Z-Score/Gullie Consultant Services 2017) a set of criteria for scoring the questions was developed: incorrect (0 points), partially correct not detailed (1 point), partially correct detailed (2 points), correct not detailed (3 points), and correct detailed (4 points). Two internal reviewers (Lachney and Babbitt) scored the questions together. Inter-rater reliability was established through using a technique of "dialogical intersubjectivity" (Saldaña 2015, p. 37): agreement and consensus is determined through "rational discourse and reciprocal criticism" (Brinkmann and Kvale 2015, p. 279).

The internal reviewers began scoring each question by looking for correct uses of keywords (e.g., iteration, translation, zhopshkaa, etc.) and ideas (e.g., sustainability, Anishinaabe cultural traditions, etc.). Second, they looked at how detailed the answers were: did students use examples and give an explanation for STEM and Anishinaabe connections

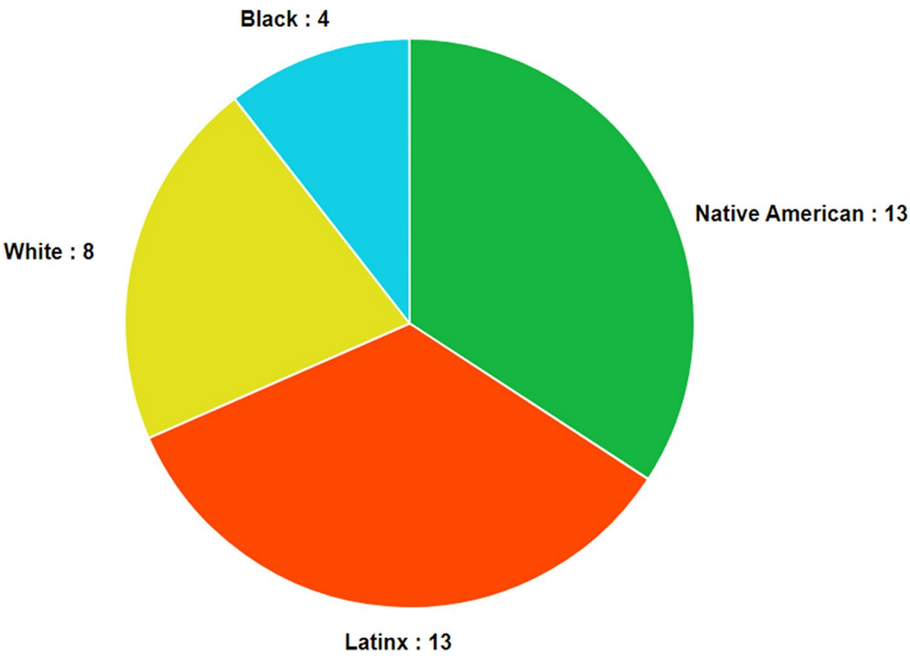

Fig. 6 Student demographics

Table 2 Anishinaabe arcs: paired samples statistics (Z-Score/Gullie Consulting Services 2017, p. 33)

	Mean	N	SD	SE mean
Pair 1				
Total pre	3.71	38	2.847	.462
Total post	11.32	38	3.662	.594

Table 3 Anishinaabe arcs: paired samples test. Sig. p < .05 (Z-Score/Gullie Consulting Services 2017, p. 33)

Paired differences	95% Confidence interval of the difference	t	df	Sig. (2-tailed)
Pair 1				
Total pre – total post	−6.224	−11.159	37	.000

or did they only provide lists of concepts and ideas. Together these two metrics allowed them to assign a score based on the scale above (see Appendix for examples). "The students' mean on the pre was 3.71, and the post was 11.32. Applying a paired samples *T* Test the difference in means was found to be statistically significant with T = −11.159, df 37, p = .000" (see Tables 2 and 3; Z-Score/Gullie Consultant Services 2017, p. 33). Based on results from this first round of quantitative analysis we decided to do a more detailed qualitative content analysis of students' responses.

Beyond these quantitative measures, a second pass looked for keywords and other forms of relevant content, grouping student answers into categories that emerged from a qualitative content analysis (i.e., via grounded theory (Strauss and Corbin 1990)). More so than the quantitative measures, these categories provided important insights into how students were interpreting the questions. For example, in question three (i.e., "What is significant about the Anishinaabe tradition of bending wood into arcs?") approximately 50% of the successful post-survey replies included something related to the concept of sustainable wood harvests; the other half focused on material science (e.g., modulus of rupture) or other concepts.

It should be noted that since this workshop took place in a larger programmatic setting, changes in students' perceptions may have been influenced by external presentations. However, the only place in which we saw specific external content mentioned was in the case of the mathematical concepts of infinity and zero, which were brought up in discussions about the Ojibwe Medicine Wheel elsewhere. Unlike the quantitative analysis, these have not been included in our qualitative findings.

What computing concepts can be found in Anishinaabe traditions and knowledge?

In our content analysis, only three of the 38 students (7%) provided answers that mentioned computing concepts in the pre-survey for question one. The answers (e.g. "3D Modeling" and "3D Graphing Tools") did not actually describe Indigenous computational thinking, and appeared to be from the brief workshop description students had been provided with. On the post-survey, 22 students (60%) provided answers with computing concepts. While mentions of 3D tools and modeling appeared in post-survey answers, they also included terms like "algorithms," "coding," "iteration," "programming," and "programming with math equations." Some post-survey replies answered in exactly the way we intended the question. For example: "Iteration is used in their traditional structures." Others elaborated on how these heritage algorithms were explored in the workshop: "The program for coding we used yesterday showed that computing concepts could be found in Anishinaabe traditions. By creating arcs we were each replicating traditional Anishinaabe arcs/buildings in our own way." A number of students jumped ahead, interpreting the question to be asking how to apply traditional Anishinaabe computing concepts in the context of contemporary computing: "Arc[s] can be used to make designs for games, building, website[s], there is a lot you can do." And one student disputed the traditional/contemporary dichotomy altogether by noting that "one of the first architects to use computers for architecture was an Anishinaabe Native."

In sum: increasing from 7 to 60%, with more accurate and thoughtful answers, the outcomes far exceeded our expectations in pre/post differences for students translating between Indigenous and Western computing concepts.

What math concepts can be found in Anishinaabe traditions and knowledge?

A notable number of students, 14 out of 38 (37%), identified math concepts on the pre-survey. This may be because translating between Western and Indigenous mathematics was not as much of a challenge as the prior computing question, or it could be that students were simply more familiar with math terms than computing terms. The majority of these answers were lists of either branches of mathematics (e.g., "Geometry," "Calculus, Algebra") or specific concepts within those branches (e.g. "*x*–*y*-*z* plane," "angle," "pattern," "slopes"). The percentage of students who identified math concepts on the post-survey increased from 37% to 82% (31 of the 38 students). Students not only were more precise in identifying connections between Anishinaabe traditions and mathematics but also gave longer and more in-depth answers. For example, "You need to know what angles or sizes [sic] when bending wood. If you don't know how this could mess the entire arc."

The post-survey answers that included math concepts fell into three categories. Comprising nine of the 31 (29%), the first group mirrored the most common style of answers in the pre-survey: lists of branches of math or phrases (e.g. "Angles, geometry"; "Graphing and parabolas"). However, even within that restriction, these lists had a greater variety of answers than those in the pre-survey. The second category (eight of the 31, or 26% of the answers) were replies that moved beyond lists and made some attempt to describe how math and mathematical thinking are embedded in Anishinaabe knowledge and traditions. Examples range from specific cases (e.g. "number of arcs for design") to broader explanations (e.g., "Scaling is a concept that can be found in Anishinaabe traditions and knowledge."). In the second category, the answers moved from a perfunctory "fill in the blank" to a more deliberate attempt at describing translations between the two knowledge systems.

The largest category of answers, 14 out of 31 (45%) went beyond general explanations that Anishinaabe knowledge has embedded mathematics. These replies had specific examples in which math is applied to traditional practices of building structures (e.g., wiigiwaam) and manipulating materials (e.g., bending wood). They are primarily about how mathematics can be used to help with planning processes; in some cases, they appeared to be referencing the virtual design experience. The answer "the arc helps see the design so we know where to start and where to end", for example, may be describing a common experience in using the software: the trial-and-error process of changing script variables means you are often looking to see where the series of arcs start and end, so that you can make further adjustments. Similarly, the answer "While creating a wigwam you need to use addition and subtraction to get your design to be accurate" may be referring to the way that subtracting or adding from the parameters in each iteration determines the overall shape of the virtual arc structure. In some cases, students seemed to gesture toward the idea that this practical use was evidence of Indigenous Anishinaabe mathematics: "Using the shape and angle of Anishinaabe arcs to create sturdy structures." However, that was not always clear in these practical application examples. Rather than imposing our own concepts of what constitutes "correct" epistemological relations between Indigenous and Western frameworks, it may be more useful to see the agentic crafting of positions invented by students as the most significant pedagogical value, as we elaborate further in the discussion section.

In sum: more than doubling the number of replies, with greater accuracy and reflections based on actual use of heritage algorithms, the change from pre to post on this question suggests that students' abilities to describe Indigenous mathematics dramatically improved.

What is significant about the Anishinaabe tradition of bending wood into arcs?

Sixteen of the 38 students, or 42%, provided relevant answers to this question about bending wood on the pre-survey, albeit often very brief. Eight students mentioned strength (e.g., "stability/strength"; "how the wood does not break"). Six replied with specific examples (e.g., "building canoes"; "wiigiwaams and canoes"). One mentioned that different tree species were selected, one mentioned chemical properties of wood, and one mentioned that math is involved in "measuring in order to get the correct length of things needed."

On the post-survey 33 of the 38 (87%) provided relevant answers. Four answers were as brief and vague as they had been on the pre-survey; the remaining 29 had much richer descriptions and stronger connections. Twenty students described Anishinaabe knowledge of wood's material properties: for example, "they were able to use arcs for many different things due to the arc's versatility, flexibility, and strength"; "It provided resistance which gave strength but without weight". Ten of the students provided specific examples of traditional arc applications, and 10 made connections to the concept of sustainable wood harvests or mentioned sustainability more broadly. Five students reflected content from a brief visit by the local Anishinaabemowin language teacher, in which he suggested that living in a round house can have mental health benefits, and three students brought in terms referencing the future (e.g., "finding new ways to improve and progress is significant also as well as the traditional arcs").

Overall, the post-surveys showed a strong increase in the number and quality of responses. We had expected responses to focus mainly on contrasting primitivist stereotypes with translations to STEM. While over 50% (20 of 38) did indeed make the connection to material science, about the same number of responses included remaining categories of sustainability, mental health, and future development. This suggests that thoughtful reflections on Indigenous knowledge applications mattered at least as much as refutations of primitivism.

In sum: more than doubling the number of replies, with greater detail and richer reflections, the change from pre to post on this question suggests that students' abilities to understand and describe the significance of Anishinaabe arcs dramatically improved.

How might science and technology be used to support Anishinaabe traditions and knowledge in the twenty-first century?

On the pre-survey, 20 of the 38 (52%) provided some form of an answer to this question. In all of these responses, students wrote of Western science offering better, stronger, faster solutions, or expressing a generalized faith that it would "make things a little more efficient" or find "New and efficient ways to make things." When a pre-survey answer referred to Anishinaabe traditions, it always implied deficiency, for example, pointing to agricultural practices such as planting and harvesting, Western science and technology could better inform such practices by "telling the time when to plant and harvest."

On the post-survey 35 out of 38 students (92%) offered answers to this question, with far more sophisticated views concerning this relationship. Answers describing science and technology in a clearly superior position, as the sole body of knowledge that could provide improvement, fell to 13 of the 38 students (34%). Nine students (24%) stated that the most helpful role for science and technology would be in learning *about* Anishinaabe knowledge. Eight (21%) students stated that Anishinaabe knowledge is still "relevant today" or "right all along," pushing back on the notion that science and technology were necessarily holding better solutions. Seven (18%) students staked out a hybrid position that Anishinaabe knowledge could be incorporated into modern inventions, and six (16%) wrote of Anishinaabe knowledge as being more sustainable. Interestingly, two students explicitly reversed the causal relation implied by the question; for example, "Anishinaabe traditions and knowledge could be used to support science and technology."

In sum: subtracting the 13 students who still put science and technology in a superior position, 22 of the 35 post-survey answers (62%) now described Indigenous ways of knowing as either potent potential hybrids or wisdom that can enrich Western science and technology, compared to zero of 20 answers (0%) in the pre-survey.

What are some ways that Anishinaabe traditions might contribute to contemporary innovation?

On the pre-survey, 13 out of 38 (34%) students provided answers to this question, which essentially asked for a sense of Indigenous futurity based in Anishinaabe traditions and knowledge. Ten of the 13 fell into one of two categories: applied knowledge or epistemological diversity. The category of applied knowledge included six (16%) answers where Anishinaabe traditions could be used to innovate the already popular acceptance of Indigenous technologies, such as canoes, and existing architectural innovations. For example, one student wrote that Anishinaabe traditions could "help with the technology of building a canoe going down a river." The category of epistemological diversity included four (11%) answers that stressed how Anishinaabe knowledge could provide new perspectives that can nourish innovation. For example, "Any way of thinking from another culture can help with innovation since it gives a different perspective to others." The other three responses included the topics of sustainability, morality, and community innovation.

On the post-survey, 31 of the 38 (82%) students responded with appropriate answers that spoke to Indigenous futurity. Not only were these answers more in-depth, but they also inspired a level of creativity not found in the pre-survey. While just one student spoke to the topic of innovating environmental sustainability on the pre-survey, this was the largest category on the post, accounting for 12 of the 38 (32%) answers. The specific areas of innovation included using Anishinaabe traditions to decrease pollution (five of the 38 (13%) answers), increase sustainable living and production (four of the 38 (11%) answers), and new ways for humans and the environment to co-exist (three of the 38 (8%) answers). Some notable examples include, "The way Anishinaabe think and go about things is different than the thought process of many others. Not only that but they know/believe that everything is alive so they are very cautious of what they take from mother earth"; "The Anishinaabe people were able to coexist with the Environment. They only used what they needed and tried to make sure they didn't harm the earth. Therefore, if contemporary innovation followed that model the environment could be saved."

Like the pre-survey, applied knowledge was also prominent, accounting for 11 of the 38 (29%) answers. While all of these answers focused on architecture, they also mixed in topics of technology design. In this category, there was an overt future orientation. For example, one student wrote that Anishinaabe traditions could "[Inspire] the colony architecture ideas for Mars. Going to Mars is a concept that scientists have aimed for years and could be made more possible by the Anishinaabe traditions." Another student also applied a case directly from our workshop: "Just like Cheyenne Thomas in the reading, she and her father created a circular facility, and if arcs were used they could easily & continuously get sunlight by the shape of it." Attached to some of these instances were examples that could also be labeled as applying traditional knowledge to design. For example, "We could use them for building more structure, new ways to make lights, more durable/reliable structures for homeless people if they moved around a lot and had nothing for shelter." Similar to the pre-survey, the epistemological diversity category was also prominent, accounting for five of the 38 (13%) responses. These post-survey answers did not vary much in length or depth from the pre-survey (e.g., "Different perspectives and styles").

In sum: more than doubling the number of replies, with greater detail and richer reflections, the change from pre to post on this question suggests that students' abilities to describe Indigenous futurity dramatically improved.

Open-ended prompt: "how does your design relate to your career path? Your family or community? And, your own interests and future goals?"

The final questions were open-ended and intended to prompt reflections on the specific design they created. 46 of 48 students responded. Sustainability was the strongest theme, with the length and depth of the reflective writing strongly correlated with demographics. Students identifying as White tended to write relatively fewer sentences, and more summary-like content, for example: "The design I made is related to my career path because buildings are being made all the time so my career can be influenced to build buildings." Students who self-identified as Native American/Alaskan Native or Hispanic/Latino (alone or with additional demographic codes) wrote the longest and most in-depth reflective narratives. They were more likely to discuss their communities and families, and often moved between poetic and practical reflections:

> I believe my design represents the two worlds I come from. One being of my Native heritage and the other of the technology era. With the completion of my structure I was able to combine two worlds and accumulate an interest in engineering. My community relies on electricity to keep schools running, businesses afloat and also to conduct heat during harsh winters. On and off reservation, the world needs electricity to maintain [sic] a efficient lifestyle. This project has taught me that I can provide and give back for my people while incorporating important traditions and teachings to create a productive environment.

Several students highlighted the transition from virtual to physical as a key value for their learning experience. For example,

> My design can relate to my career path by the inspiration I gave myself that I can create creative structures. My design had informed me about the Anishinaabe Arcs and how they are created. Due to this project, I feel that this hands on experience got me thinking about my engineering career in the future. This helped me to think about my career into engineering. I did want to become an [engineer] but this design had brought engineering to my eyes. This also can inspire my family and my community that anyone can do what they want.

And in some cases students explained how the tactile activities were important aspects of the workshop, which would have been lost if we had used a 3D printer. As one student explained,

> My design relates to the idea of being hands-on and creative on the spot, as I want to become a sign language interpreter. I found that my family could be represented in this as we are close knit, and also have the backbone of my parents who support us, like the largest arc of my design that helps keep the other parts in place. This project reflects my personal interests of sculpting using a softer material. I liked using the mushroom base as I am a very touchy/feely person, and I don't think I would have enjoyed the project as much if I had used wood or the lights.

This final reflection above highlights the tactile affordances of learning and knowing that were part of the Anishinaabe arcs workshop. This was not only meaningful for the student in an immediate sense of using "the mushroom base" but also as part of their future goal of gaining the embodied expertise to become a sign language interpreter. This and other students' reflections remind us that generative STEM aims to create plurality in the process of future making by leaving room for diversifying both who is producing STEM knowledge and the outputs of that production process.

Discussion

The differences between pre-survey and post-survey answers, for both quantitative and qualitative measures, showed increases in students' understandings of Indigenous knowledge, their ability to utilize it in moving from heritage algorithms to physical constructions, and their visions for new hybrid forms of Indigenous futurity. These findings support our initial hypothesis that Anishinaabe arcs would create the conditions for a generative cycle, where young people could engage STEM for the purposes of Indigenous futurity. Working with students' responses and reflections as part of a knowledge production process reminds us that broadening participation requires acknowledging "there may be an unlimited number of accurate descriptions, representations, and points of view" (Medin and Bang 2014, pg. 36), which will arise depending on *who* is asking the questions, conducting the research, and representing the material world. This is essentially what makes the generative translation process so important for both educational technology designers and researchers, as well as part of student engagement; it explicitly highlights pathways to see epistemic diversity and work with pluralism in knowledge production.

In an effort to have students' responses and reflections recursively inform future work, the high number of respondents expressing interest in greenhouses specifically and sustainability more generally prompted the direction of our 2018 workshop with CNAS, which will focus on the Indigenous traditions around "engineered ecosystems"—clam gardens, level control in ricing lakes, etc.—and their modern-day counterpart in aquaponic systems. STEM education need not focus exclusively on feeding "human resources" to corporations and military labs; grassroots communities can and should be direct beneficiaries of STEM innovation. We plan to use these connections to begin the development of real-world community collaborations between small scale economic enterprises, cultural practices, and STEM education. The Anishinaabe arcs workshop helped us realize that all the connections for generative STEM exist and young people are willing to be part of them. Our future engineering ecosystems program aims to make a more explicit effort to draw them together so that fully generative cycles can be established.

At a broader level, reading students' reflections and responses, especially for survey questions four and five, alerted us to a possible blind spot in work on culturally responsive education. Cultural connections in the 1960s originated primarily in what might be identified as a vindicationist tradition, which contests stereotypes of primitivism with examples of engineering in Egyptian pyramids or math in Mayan hieroglyphics. While a welcomed change, problems surfaced. First, they tended to be presented as either passive learning ("how to count to 100 in Mayan") or turned into the same old word problems with an ethnic veneer ("calculate the height of the pyramid"). Second, there was an initial over dependence on "ancient empires." This was eventually addressed by broader programs in ethnomathematics, ethnobotany, etc. such that anti-primitivist portraits were available for

Indigenous hunter-gatherer group contexts. However, the impact of such anti-primitivist content is limited, if taught at all, by passive learning methods.

In part, this is due to the impact of the "plastic shaman": White authors of pseudo-indigenous scams, ludicrous New Age claims and self-delusion (Grande 1999; Tuck and Gaztambide-Fernández 2013). And in part due to the fact that these students now inhabit the general climate of a "post-truth" era in which vindicationist claims are increasingly meaningless. Since anything can now be created by photoshop and digital trickery, merely viewing images, or even simulations, has diminished impact. We believe this is why we found patterns of replies such as question 3, where thoughtful reflections on Indigenous knowledge *applications* mattered at least as much as refutations of primitivism. Students may have heightened expectations and appreciations for seeing Indigenous knowledge deployed in real-world activities.

Given these cautions, culture-based STEM needs to shift from a vindicationist mode to one that highlights student agency in a generative relation with cultural knowledge. For example, in Eglash et al. (2017), we discuss the involvement of adult economic activities in the cycle of generative STEM. One example includes African American hairstyling salons (Lachney 2017b). This work began with students simulating cornrow patterns using the Cornrow Curves CSDT in an after-school program. As adult cosmetologists and braiders became involved in the program new culture-STEM innovations were explored. This included 3D printing of custom mannequin heads, experiments with pH meters for developing natural hair products, laser interferometry for measuring hair thickness, and other STEM innovations that could become hybrids between grassroots wealth generation and cutting-edge technological development.

Figure 1 visualized how we think of that progression: from reconstructions of Indigenous knowledge to creative explorations, to creative physical rendering, to community collaborations. For that reason, we see the persistent reference back to practical applications throughout the student writings as not a barrier to their adoption of the translation concept, but rather insight about which aspects of the translations they see as most valuable. It is important to understand that this does not *negate* the role of anti-primitivist content; in Fig. 1 each prior component is still present in the next level of agency. As one student put it, "This project has taught me that I can provide and give back for my people while incorporating important traditions and teachings to create a productive environment." To the older generation's vindicationism, the current seeks to be makers and doers as well.

Conclusion

Anishinaabe arcs—traditional wood bending practices of the Anishinaabemowin speaking peoples—occurred through a cultural synthesis of material sciences, ecological relations, and a family of mathematical curves with deep computational implications. Drawing on this synthesis as the basis for a generative STEM lesson, the contact zone of the Anishinaabe Arcs CSDT aided in the development of a learning environment that moved students from creative explorations of heritage algorithms to physical renderings that facilitate reflections on future meanings and practical applications.

Student responses indicate a potential for the generative STEM framework to move beyond the vindicationist role in which ethnomathematics and its allied disciplines were first developed. Rather than static proclamations of anti-primitivist critique, or bait to lure students into a STEM pipeline, the generative framework aims to circulate unalienated value back to the human and non-human communities of the value's origin. This necessitates two-way translations between culture and science, virtual and physical, school and community, and past and future. We encourage other groups engaged in culturally responsive STEM to nurture such opportunities for student agency, cultural resurgence, and Indigenous futurity.

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Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix

Questions	0 Points: unanswered or incorrect	1 Point: partially correct and not detailed answer	2 Points: partially correct and detailed answer	3 Points: correct and not detailed answer	4 Points: correct and detailed answer
1. What computing concepts can be found in Anishinaabe traditions and knowledge?	Blank, incorrect, or unrelated answer. For example, "The traditional ways can be improved to be more environmentally safe and efficient. Like the arcs, finding ways to use solar power could help provide illumination"	Simply listing something that relates to the workshop material, but not including the computing concepts of Algorithm, iteration, etc. For example: "3D Modeling"	A lengthy answer including some of the workshop material, but not including computing concepts. For example: "In order to put your plan in action you would need to make a structure on the computer"	Listing a correct computing concept without an answer that is comparative or deep. For example: "Iteration is used in their traditional structures"	Comparative or deep mentioning of computing concepts within the context of the workshop material. For example: "Algorithms can be found in both the modern world and the traditions of the Anishinaabe people"

Questions	0 Points: unanswered or incorrect	1 Point: partially correct and not detailed answer	2 Points: partially correct and detailed answer	3 Points: correct and not detailed answer	4 Points: correct and detailed answer
2. What math concepts can be found in Anishinaabe traditions and knowledge?	Blank, incorrect, or unrelated answer. For example: "Age, code, war/hunting parties"	Listing something that relates to the workshop material, but not including the math concepts of transformational geometry, parabola, Cartesian coordinates, etc. For example: "Calculus, engineering, trigonometry"	A lengthy answer including some of the workshop material, but not including math concepts. For example: "One math concept that can be found in Anishinaabe traditions is the building of wiigwaams etc."	Listing of a correct concept or concepts without an answer that is comparative or deep. For example: "I have found that a lot of different concepts can be found all the way from the concept of 0 and infinity to very complex construction"	Comparative or deep mentioning of math concepts within the context of the workshop material. For example: "The concept of 0 as well as infinity. The medicine wheel represents the vast complexity of our universe as humans are able to encounter single atoms as well as galaxies"
3. What is significant about the Anishinaabe tradition of bending wood into arcs?	Blank, incorrect, or unrelated answer. For example: "they use steam?"	A relatively short answer about something that relates to the workshop material, but not including relevant information that connects arcs to Anishinaabe tradition. For example: "Arcs are the strongest structures"	A lengthy answer including some of the workshop material, but not including relevant information that connects arcs to Anishinaabe tradition. For example: "Practicing this could eventually become very helpful to many people, learning to build arcs will eventually advance it bigger and better ideas"	Listing of a correct concept or concepts without an answer that is comparative or deep. For example: "I feel like arcs are an important aspect when it comes to architecture and creates strong structures"	An answer that speak to Anishinaabe traditions and the material qualities of the arcs. For example: "Wood is an ideal building material. It grows easily durable, abundant, and bendable in certain cases. Bending wood is extremely important in house building and canoe making"

Questions	0 Points: unanswered or incorrect	1 Point: partially correct and not detailed answer	2 Points: partially correct and detailed answer	3 Points: correct and not detailed answer	4 Points: correct and detailed answer
4. How might science and technology be used to support Anishinaabe traditions and knowledge in the twenty-first century?	Blank, incorrect, or unrelated answer. All of our examples are blank	A relatively short answer that relates to the workshop material, but not including detailed information about how science and technology can be used to support Anishinaabe traditions. For example: "It can be used to support by collaborating in studies with traditions"	A lengthy answer that relates to the workshop material, but not including detailed information about how science and technology can be used to support Anishinaabe traditions. For example: "Science & technology can be used to support Anishinaabe culture by updating simple structures (like the arcs)"	Listing of a correct concept or concepts without an answer that is comparative or deep For example: "Well, science and technology isn't anything new to the Anishinaabe. They have been doing these for thousands of years"	An answer that speaks to the role of science and technology in supporting Anishinaabe traditions within a global or local context. For example: "As the Earth is becoming depleted in her resources, humans must learn how to survive and thrive using as little as possible. Not just that but also considering the fact that whatever we produce is left for future generations. Things must be recycled"

Questions	0 Points: unanswered or incorrect	1 Point: partially correct and not detailed answer	2 Points: partially correct and detailed answer	3 Points: correct and not detailed answer	4 Points: correct and detailed answer
5. What are some ways that Anishinaabe traditions might contribute to contemporary innovation?	Blank, incorrect, or unrelated answer. For example: "New perspectives on various things"	A relatively short answer that relates to the workshop material, but not including detailed information about how Anishinaabe traditions continue to be innovative. For example: "Any way of thinking from another culture can help with innovation since it gives a different perspective to others"	A lengthy answer that relates to the workshop material, but not including detailed information about how Anishinaabe traditions continue to be innovative. For example: "The concepts of certain items and subjects are still there, just augmented to create a more stable and modern state in the twenty-first century"	Listing of correct concepts or ideas for innovation without an answer that is comparative or deep. For example: "We can use them in everyday life. Many of their traditions are eco-friendly, which is very important if we want to continue being a species."	An answer that speaks to the role of Anishinaabe traditions for innovating social and/or technical aspects of life within a global or local context. For example: "The traditions of high respects for earth is very important in today's terms as our earth is at risk over overpopulation. Innovations from "here on out" must consider future generations"

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