The Impact of Incorporating Indigenous and Other Nontraditional Ways of Mathematical Knowing into a University-Level Geometry Course

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Abstract. During the Fall 2021 semester, the author taught a university-level geometry course into which they incorporated texts and discussions on mathematics and mathematical epistemology from outside of the "Western" tradition typically centered in college math curricula. Analysis of student survey responses and students' reflections on their work offer some evidence that even minimal engagement with these nontraditional perspectives, facilitated intentionally, led to increases in students' appreciation of other epistemic traditions. Though the smallness of the sample size prohibits drawing broader conclusions, the significance of some findings suggests a critical need for further study of these pedagogical practices.

I am a white-identifying male of European descent, teaching at a predominantly white four-year liberal arts university of roughly 3500 students that lies on the ancestral lands of the Cherokee/Tsalagi (ᏣᎳᎩ) or Aniyvwiya (ᎠᏂᏴᏫᏯ). These lands were stolen by European colonizers. I echo the words of my university regarding the meager impact of this simple statement: "we acknowledge that an act of recognition is not enough to overcome the settler-colonial history that has attempted to eradicate [I]ndigenous people from the history and consciousness of these lands" (University of North Carolina, Asheville Land Acknowledgment, 2019).

I offer these statements at the outset of this article for several reasons. Most evidently, these statements acknowledge the complexity of the land I live with and do my work with while paying respect to those who, historically, have called this land home. Furthermore, my identity as a white person limits what I can ethically do or say, for my lived experience does not permit me to speak as an expert on Indigenous ways of coming to know nature.

Most relevant to the focus of this article, however, is the fact that the land is the perfect starting point for a conversation on geometry. After all, the word "geometry" comes from the Ancient Greek γεωμετρία, meaning "measurement of the earth." Some of the earliest geometers in the Western/European tradition were concerned with understanding the shape of the world around them, using abstract mathematical ideas to calculate areas and volumes for engineering, agricultural, and other purposes (Greenberg, 2008. However, this Western geometric tradition is only one of many culturally-bound ways of coming to know the world, and overemphasis on Western mathematics has long served to alienate students not of European descent,

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at every educational level (Aikenhead, 2017; Cajete, 2020; Johnson, 2021; Moses & Cobb, 2001; Peralta et al., 2013).

Intentional efforts to incorporate other mathematical traditions into Western STEM curricula also begin with the land. As scholars of Indigenous ways of living in nature make clear, such ways are typically place-bound in ways that Western science, with its emphasis on generalizability, is not (Aikenhead & Michell, 2010; Cajete, 2006; Peat, 2002; Simpson, 2014). It is important, therefore, to situate this article in a specific context, geographically and institutionally.

This article is an account of my and my students' engagement with a Fall 2021 college geometry course into which I incorporated Indigenous and other nontraditional ways of mathematical knowing. My goals in teaching the class in this manner were twofold: (1) to introduce students to other mathematical ways of coming to know the world while complicating the (Western) ways with which they were already familiar, thereby, ideally, (2) strengthening students', particularly non-white students', identities as members of a mathematical community. I first describe my efforts to plan the course and then provide a brief overview of the relevant assignments and activities the students completed. I then turn to the students' responses to the non-Western elements of the course, as evidenced in pre- and post- surveys of students' perceptions and in the students' written reflections.

Despite my intentional efforts to incorporate nontraditional mathematical ideas into this course, the central focus of the course in question was still axiomatic geometry in a Western tradition. It is particularly noteworthy, therefore, that even relatively modest efforts to incorporate Indigenous ways of knowing had a measurable impact on students' mathematical worldview.

Some Notes on Terminology

Various scholars of cross-cultural science education offer definitions of the word "science" that broaden its applicability beyond European and European-influenced institutions. For instance, Japanese scholar Masakata Ogawa uses the word "science" to refer to any "rational, culturally based, empirically sound way of knowing nature that yields, in part, descriptions and explanations of nature" (1995). In a similar fashion, Tewa scholar Gregory Cajete suggests that science is "a story of the world and a practiced way of living it" (2006). It is worth noting that both of these definitions encourage a pluralistic view of ways of knowing the world, as opposed to the "anything goes" connotations of the word "relativistic."

Words like "Western" and "European" are similarly problematic, owing to the complex meanings they encapsulate: where is "The West"? Where does it begin? End? Does the term "European" apply to modern mathematical traditions ultimately influenced by the European one, like the mainstream math predominant in most industrialized nations, regardless of their geographic location? Even the seemingly straightforward and objective words "knowledge" and "mathematics" come with their own challenges, as both of these terms are strongly culturally bound. Acknowledging the relational, action-oriented focus of most Indigenous languages and epistemologies, Aikenhead and Michell (2010) use the phrase "Indigenous ways of living in nature"

(IWLN) instead of “scientific knowledge,” emphasizing a verb (“living”) in place of a noun (“knowledge”).

In the current work, for lack of better terms, I use words and phrases like “knowledge,” “ways of knowing,” “science,” “mathematics,” “Western,” and “European,” fully acknowledging the complexities entailed by these terms. I humbly ask the reader to receive these words with the same intentionality and open-mindedness with which they are written.

Preparation for the Course

Preparation to teach the course began in Summer 2021. At this time, I selected the course textbook, Marvin Jay Greenberg’s *Euclidean and non-Euclidean geometries: development and history* (2008). Though Greenberg’s text falls well within the Western/European mathematical canon, the book’s treatment of geometry in the Western tradition is supplemented by historical accounts that are uncharacteristic in their richness and scope. These accounts offer an epistemic context for the development of modern Western geometric ideas absent from most other textbooks. Moreover, the author includes an entire chapter on the philosophy of mathematics, explicitly acknowledging there the neo-Platonist foundation in which most modern Western mathematicians work. Greenberg stops short of considering Indigenous geometries, but to my knowledge no other geometry textbook in the Western tradition offers both a solid foundation for Western geometry and an intentional treatment of that geometry’s epistemic limitations.

During the summer, I also reached out to Indigenous colleagues on campus and in the community. My colleagues on campus, including a scholar from the Cherokee Nation of Oklahoma, a scholar from an Indigenous community in the Colombian Andes, and a white astronomer familiar with Indigenous ways of knowing, offered critical support by directing me to readings and other resources on Indigenous epistemology that would prove helpful in my course planning. Meeting and corresponding with the Director of Education for the nearby Museum of the Cherokee Indian, herself a member of the Eastern Band of Cherokee Indians, provided me with additional ideas for incorporating general Indigenous ways of knowing into the course. (This person recommended other members of the Cherokee community whom I could contact for more specific ideas, but I was unable to correspond directly with these persons.)

These consultations helped me to develop a list of supplementary readings that would enable students to engage with other epistemic traditions. With these resources in hand, I was able to plan class activities (some of which are described in the following section) that would facilitate students’ engagement with nontraditional ways of knowing and help them to connect these ways with ideas from the more familiar Western mathematical tradition.

Class Activities and Assignments

Eleven (11) students enrolled in the geometry course, including seven (7) male and four (4) female students. Racially and ethnically, four (4) of the male students identified as white or Caucasian and three (3) as Hispanic or Mexican American. Of the female students, three (3) identified as white or Caucasian, and one (1) as Hispanic. Ten (10) of the students were mathematics majors, including five (5) students seeking licensure to teach either middle school or high school mathematics. (The course is a required one for the latter students.) The remaining student was majoring in accounting with a math minor.

In the first week of the class, the students were asked to complete a short pre-survey (Appendix) designed to ascertain their views on some basic ideas from mathematical epistemology (Questions 1-6) and their sense of agency and membership in broader communities of mathematical practice (Questions 7-10). These questions, offered to each student in random order, would be repeated verbatim on the course's post-survey.

Despite the incorporation of non-traditional ways of knowing into the course, the course was still centered on a traditional axiomatic approach to Western geometry, and roughly 90% of class meetings were devoted to this approach. Meanwhile, nontraditional ways of knowing were the focus of five of the class meetings and throughout the semester, the students engaged with five sources centering nontraditional perspectives on scientific epistemology. While only two of these sources (Peat, 2002 and Lakoff & Núñez, 2000) concerned mathematics specifically, our class conversations helped to translate all of the texts into a mathematical context.

In Week 3, the students read Chapters 5 and 6 of *Bridging cultures: Scientific and Indigenous ways of knowing nature* (2010), by the white Canadian scholar Glen S. Aikenhead and Barren Lands Cree Nation scholar Herman Michell. This reading gave the students a basic understanding of what its authors refer to as "Indigenous ways of living in nature" (IWLN). In-class conversation on the reading focused on a few of the several characteristics of IWLN that Aikenhead and Michell highlight, namely, that these non-Western ways of coming to know are generally place-based (pp. 73-75), valid (pp. 88-90), and rational (pp. 90-91).

In Week 8, students were asked to read Michi Saagiig Nishnaabeg scholar Leanne Betasamosake Simpson's essay "Land as pedagogy: Nishnaabeg intelligence and rebellious transformation" (2014). In this work, Simpson unpacks the meaning of a traditional story of a child's coming to learn how to collect sap from maple trees through interacting with nature. Simpson makes the point forcefully that learning is strongly geographically situated; coming to know the world must take place in a particular location in the world. After a discussion of this reading, the students engaged in an activity in which they created maps of various locations on the university's campus. This place-based activity was the jumping-off point for a conversation on alternative (Western) geometries in which the "distance" between two points is not measured in fixed numerical units but rather relationally, two points being "close" if the concepts they represent are metaphorically or operationally close. As we discussed in class, the late Black mathematician and philosopher of mathematics Robert Moses adopted similar approaches in his culturally responsive math education program, The Algebra Project (Moses & Cobb, 2001).

In the same week, students read in class an excerpt from pp. 166-167 of white Scottish/Canadian scholar F. David Peat's *Blackfoot physics: A journey into the Native American universe* (2002) highlighting the ways in which both Native American and traditional Western ways of knowing approach the number 4. As Peat points out, this number is associated with balance and harmony in various Native American constructions (e.g., the sacred hoop, the medicine wheel, and the bowl of heaven), balance which is also evident in the inherent equilibrium of four coplanar points in Western geometry.

In Week 12, students engaged with two sources, a conference presentation by Káínawa First Nation scholar Leroy Little Bear on Blackfoot metaphysics (2016) and an excerpt (pp. 1-10) from the introduction to *Where mathematics comes from: How the embodied mind brings mathematics into being*, by George Lakoff and Rafael Núñez (2000), both scholars of European descent. Both of these sources gave the students fresh perspectives on "traditional" science. On the one hand, Little Bear's presentation explores ways in which Indigenous (Blackfoot) ways of knowing diverge from Western ways of knowing, highlighting specifically the holistic and locally grounded nature of Indigenous ways as opposed to the analytical and universalizing nature of Western ways. At the same time, Little Bear draws attention to convergences between the traditions, noting parallels between, for example, quantum mechanics and the Native American notion of the implicate order.

Meanwhile, even as they operate within a Western philosophical tradition, Lakoff and Núñez (2000) demonstrate the unprovability of the neo-Platonist foundation on which most modern Western mathematicians base their work. "Mathematics as we know it has been created and used by human beings," the authors begin; "[m]athematics as we know it is limited and structured by the human brain and human mental capacities. The only mathematics we know or can know is a brain-and-mind-based mathematics" (p. 1). These authors' complexification of Platonic thought helped the students to see that the challenges to the primacy of Platonic mathematics come not only from wholly without.

Throughout the semester, I was keenly aware of what I could do and what I could not do. As an expert in the Western mathematics and mathematical philosophy, I could capably "problematize" the mathematics my students were used to studying, helping them to see the pitfalls of the neo-Platonism that undergirds much of Western mathematical thought, even up to the present day. As an eager student of Indigenous ways of coming to know, I could confidently introduce my students to ideas that the authors of our readings bring to the conversation on science and math and help them to navigate these authors' ideas. Finally, I could attempt, whenever possible, to integrate ideas from our readings on Indigenous thought with more traditional Western mathematical concepts, as Peat attempts to do in his discussion of the Native American sacred hoop/medicine wheel and four points in general position.

I could not, however, speak as an Indigenous scholar, or even an expert in Indigenous epistemology, a topic in which I am myself still a novice. Moreover, even had I more expertise, some elements of Indigenous ways of knowing are not only spatially bound but temporally bound, as well. As Simpson makes clear throughout her work (2011, 2014, 2017), some stories may only be told at certain times of year, and only by certain people.

Given these limitations, my adjustments to the course were relatively modest ones. Nevertheless, the evidence to which I now turn suggests that even these modest changes resulted in measurable shifts in students' thinking about mathematics. This evidence indicates that intentional efforts, however small, to incorporate Indigenous ways of knowing into mathematical coursework may have a profound and positive impact both on students' learning and on their sense of membership in communities of mathematical practice.

Impact on Students' Learning and Identity

At the semester's end, students were invited to complete a post-course survey posing the same questions as the pre-semester completed a few months previously (see Appendix). Each student also had an opportunity to reflect on their engagement with nontraditional mathematical perspectives in two brief, related portions of a course portfolio due on the last day of the final exam period.

How did students' responses to the survey questions change from the beginning of the semester to its end? Each student was asked to provide a "codename" as an identifier, enabling a matching of pre- and post- responses while retaining anonymity. Performing a paired students' t-test on each of the ten items on the surveys shows statistically significant change at the $p<0.05$ level in a single item ("Understanding culture helps us understand science and math") and at the $p<0.10$ level in two additional items ("Mathematical ideas are discovered, not invented" and "I feel like my contributions to the body of mathematical knowledge are valued"). On the first of these items, the mean response changed from 3.455 to 4.455, suggesting that the course contributed to solid gains in students' appreciation for the cultural basis of mathematical practice. The responses to the latter two items suggest that students shifted from slightly favoring mathematical "discovery" to slightly favoring mathematical "invention" and that students came to have a greater appreciation of their own contributions to the body of mathematical knowledge. The first shift might signal a move away from neo-Platonist thought, in which an ideal mathematics inheres in the universe, waiting to be discovered, and toward a more humanistic conception of mathematics, in which math is, at least in part, socially constructed. See Table 1 for a summary analysis of all aggregate responses.

Table 1

Pre- and Post- Survey Results, Aggregate, $n = 11$

Item	Pre- survey mean	Post- survey mean	Change	p value, paired student t-test
Mathematical ideas are discovered, not invented	3.364	2.818	-0.545	0.082
Mathematical ideas vary from culture to culture	3.636	4.364	0.727	0.120
Mathematical ideas are built into the universe	3.545	3.545	0.000	1.000
Mathematics is socially constructed	3.636	3.636	0.000	1.000
Understanding culture helps us understand science and math	3.455	4.455	1.000	0.008

Table 1 Cont.

Item	Pre- survey mean	Post- survey mean	Change	*p* value, paired student *t*-test
Mathematics helps me understand the world around me	4.727	4.909	0.182	0.167
I enjoy doing mathematics	4.636	4.636	0.000	1.000
I like learning about mathematics	4.636	4.545	-0.091	0.676
I understand mathematics most easily when I work on it with others	4.091	4.091	0.000	1.000
I feel like my contributions to the body of mathematical knowledge are valued.	2.909	3.545	0.636	0.067

Disaggregating the students' response by gender shows some interesting trends. Considering male students' responses (n=7), only two items, "Mathematical ideas are discovered, not invented" and "Understanding culture…," exhibit statistically significant change at the $p<0.10$ level, and indeed $p<0.05$ for both. In fact, the change in the first item for male students only is more pronounced than it was for the class as a whole. Meanwhile, for female students (n=4), only one item, "I feel like my contributions…," demonstrated significant change at the $p<0.10$ level, and the change suggests an even more marked gain in female students' esteem of their contributions than in the class aggregately. This finding, though only modestly statistically supported here, agrees with the considerable literature on gender differences in students' perception of membership in STEM disciplinary communities. Women, especially women of color, are historically marginalized within Western STEM communities (Bello, 2018; Good et al., 2012; Moss-Racusin et al., 2012; Ong et al., 2018; & Smeding, 2012). See Table 2 for data on items showing significant change when disaggregated by gender.

Table 2

Pre- and Post- Survey Results Showing Significant Change when Disaggregated by Gender

Item	Pre- survey mean	Post- survey mean	Change	*p* value, paired student *t*-test
Mathematical ideas are discovered, not invented (MALE, *n*=7)	3.286	2.571	-0.714	0.047
Understanding culture helps us understand science and math (MALE, *n*=7)	3.286	4.143	0.857	0.017
I feel like my contributions to the body of mathematical knowledge are valued (FEMALE, *n*=4)	2.750	3.500	0.750	0.058

Finally, we can disaggregate the data by students' reported race and ethnicity. In this analysis, there are no items showing significant change at the $p<0.10$ level for the students identifying as Hispanic or Mexican American ($n=4$), but two items, "Understanding culture…" and "I feel like my contributions…," showing significant change at the $p<0.05$ level for white students ($n=7$). The change in the first item may suggest that white students may be less apt than their non-white peers, at the outset, to recognize the salience of culture in science and science education. In fact, the literature on science education clearly demonstrates non-white students' awareness of the connections between race and science. Furthermore, one of the primary motivations for centering non-Western science in mainstream curricula is to improve non-white students' participation in science (Aikenhead, 2017; Aikenhead & Michell, 2010; Cajete, 2020; Hernandez et al., 2013; Johnson, 2021; Peralta et al., 2013; & Tlali, 2017). See Table 3 for data on items showing significant change when disaggregated by race and ethnicity.

Table 3

Pre- and Post- Survey Results Showing Significant Change when Disaggregated by Race/Ethnicity

Item	**Pre- survey mean**	**Post- survey mean**	**Change**	***p* value, paired student *t*-test**
Understanding culture helps us understand science and math (WHITE, $n=7$)	3.429	4.571	1.143	0.030
I feel like my contributions to the body of mathematical knowledge are valued (WHITE, $n=7$)	2.857	3.857	1.000	0.038

Obviously, the smallness of the sample sizes in the foregoing analyses precludes our drawing more definite conclusions, particularly for the disaggregated data. However, the preliminary findings are promising and suggest the need for more work.

I turn now to the students' reflections on the non-Western elements of the course. Students' portfolios, submitted at the end of the semester, offered two opportunities for such reflection. One opportunity was in response to an explicit request for this reflection as a standalone component of the portfolio:

> Your portfolio should include a brief reflection (orally or in writing) on your engagement with ideas outside of the "Western" mathematical tradition which we've explored together this term. You could reflect on a specific tradition outside of this one, you could reflect on the ways these traditions overlap, collide, or integrate with one another; you could simply reflect on how our explorations have impacted you.

The second opportunity was in the students' reflection on the portfolio as a whole, in response to the following prompt: "Finally, your portfolio should include a personal reflection (in writing or in an audio or video recording) that serves as a "guide" of sorts to the rest of the portfolio, explaining why you've chosen to include the work that you have."

Several portfolio responses suggest that the course was effective in helping students appreciate the cultural underpinnings of mathematical ideas. For example, one (white female) student noted, "after this class I understand that [math] doesn't come without a significant narrative attached. I never really focused on the fact that all of the math I've learned in my lifetime comes from an almost exclusively European tradition." Another student, who identified as a Hispanic female, shared a decidedly different perspective: "It's fairly easy to detect the euro-centricity in our education system growing up in two different cultures. Even if my parents haven't gotten much education, I immediately recognize that education is strongly directed toward the major groups in this country." This dichotomy mirrors one of the phenomena already suggested by the survey data: white students showed significant gains in understanding of the role culture plays in mathematical sensemaking while non-white students showed no such gain. Students in the latter group do not need explicit instruction to know that Western mathematics education is a fundamentally white-centered enterprise.

Another common theme in students' reflections was the development of a nuanced understanding of the Western mathematical tradition, absent specific reference to non-Western ways of knowing. "I once thought that traditional, Western mathematics was a universal bastion of truth, that these mathematical ideas were so pure that they were discovered facets of the universe itself," one (white male) student notes, concluding, "I now realize that math is completely a human invention." Another (also white male) student's comments are similar:

> The authors [Lakoff and Núñez] write about mathematics being built on "conceptual metaphors" and being closely related to our minds rather than separate from them. Although at first I was a little discouraged by this seeming restraint put upon mathematics in the minds of the authors, I have come to appreciate their perspective.

This student was not the only one to admit to initial struggles with a positive outcome. One of his peers (a white female) remarks that

> [b]efore this class, I thought of mathematics as something that just is. Math is math is math. I thought of it as something that was black and white, as something that could be right or wrong…This course, especially with the time we spent on non-traditional mathematics, has truly helped to me see the creativeness and beauty that I had overlooked within mathematics.

Perhaps most important for instructors who might want to incorporate non-Western ways of knowing into their math classes, several students reported enjoying the non-Western content of the course, ascribing it a high value. "I really wish other mathematics classes would incorporate non-Western perspectives of mathematics," one (white female) student offered. The same student, who plans to become a middle school mathematics teacher, elaborated on the role such perspectives could play in the classes she will soon be teaching:

> I feel that using some of these non-Western perspectives that I was introduced to in this class and in this reading in particular, I will be able to give my students a whole new perspective and help them gain a better appreciation for mathematics…This could help show students that mathematics is not just an irrelevant subject that does not relate to anything and something they should not care about. Students would be able to see mathematics in a different light and see how relevant it is to their lives and other disciplines in general.

Another (white female) student admitted that "[o]ur journey exploring mathematics outside of the traditional Western Approach has had quite an impact on my understanding of mathematics as a whole and has also been honestly one of my favorite pieces of the class." One of her peers (another white female) agrees: "Overall, I really enjoyed how this class was able to tie in some non-traditional mathematics or mathematics that were based outside of the European perspective." Yet another student (a Hispanic male) was very blunt in his assessment: "to be honest, I felt as it was a disservice to me and my fellow UNCA mathematicians to not have had a math classroom of this importance earlier."

Indications for pedagogical practice and future study

Even these meager preliminary results suggest that modest changes to a college mathematics course's curriculum (taking three or four hours of class time out of an entire semester) can lead to gains in students' appreciation for the role that culture plays in mathematics. These results also indicate a need for both more widespread adoption of intentional pedagogical practices related to non-Western ways of knowing and further exploration of the role such practices can play in helping students appreciate scientific perspectives outside of the traditions centered in most Western scientific curricula.

I close by offering one more case for incorporating Indigenous perspectives into traditional college mathematics classes: doing so is rejuvenating, enlightening, and fun, as much for the instructor as for their students. Learning to see our subjects through lenses other than our own can bring us all joy, even as it brings us closer together.

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Appendix

Contents of the post- survey

[**Note:** each of the ten items on the survey below asked students to respond with one of "Strongly disagree," "Slightly disagree," "Neither agree nor disagree," "Slightly agree," or "Strongly agree." Responses were coded with values from 1 ("Strongly disagree") to 5 ("Strongly agree") to permit quantitative analysis.]

Thank you for taking a few moments to complete the following survey on some of the social, cultural, philosophical, etc. aspects of mathematics. This survey, and a similar one I asked you to complete at the semester's start, will help me to better understand if and how our class impacted your perception of these aspects. Please contact me (pbahls@unca.edu) if you have any questions, comments, or concerns with this survey!

1. Mathematical ideas are discovered, not invented.
2. Mathematical ideas vary from culture to culture.
3. Mathematical ideas are built into the universe.
4. Mathematics is socially constructed.
5. Understanding culture helps us understand science and math.
6. Mathematics helps me understand the world around me.
7. I enjoy doing mathematics.
8. I like learning about mathematics.
9. I understand mathematics most easily when I work on it with others.
10. I feel like my contributions to the body of mathematical knowledge are valued.

If you have any other comments about the topics treated by this survey, please feel free to include them here: [space provided]

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"We must recognize that [students] are complex beings made up of interacting minds, bodies, spirits, emotions and so on. On some level, we need to design universities that recognize, value, and account for these complexities" (p. 1).

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