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# Indigenous Culture-Based School Mathematics in Action Part II: The Study’s Results: What Support Do Teachers Need?

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**Indigenous Culture-Based School Mathematics in Action**
**Part II: The Study's Results: What Support Do Teachers Need?**

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Abstract: This second part of two related articles reports the answers to the research question: What precise supports must be in place for Grades 5 to 12 teachers to enhance their mathematics classes in a sustainable way with Indigenous mathematizing and Indigenous worldview perspectives? In addition to various logistical supports, two other types of supports were identified: supports for *learning* and *unlearning* ways of perceiving the world generally and perceiving Western mathematics specifically. These needed supports came to light when we mentored the teachers. On the one hand, the co-researching teachers *learned*, or had already learned: (a) the plurality of mathematical systems; (b) the perspective of Western mathematics as a human endeavor along with its values, ideologies, and definitions; (c) the mere inclusion of Indigenous mathematizing in a lesson is not enough; and (d) the goal of two-eyed seeing. On the other hand, the co-researching teachers *unlearned*, or had already unlearned: (a) pure mathematics' claim to be value-free, (b) all students have a predilection to excel at mathematics, and (c) subtle appropriation committed by many mathematics educators as if it were common sense to do it.

*Keywords*: Indigenous, culture-based, school mathematics, reconciliation, teacher supports

## Introduction

Four co-researching mathematics teachers in Carrot River, Saskatchewan, collaborated with the authors in a professional development project described in the article "Indigenous Culture-Based School Mathematics in Action: Part I" (Meyer & Aikenhead, 2021). The teachers produced lesson plans for themselves and other teachers to implement. Naturally, the teachers faced a series of challenges that were identified by answering the research question: "What precise supports must be in place for teachers to enhance their mathematics classes in a sustainable way with Indigenous mathematizing and worldview perspectives?"

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On the one hand, the teachers needed initial support: (a) to learn some authentic features of a local Indigenous culture, (b) to locate examples of Indigenous mathematizing[3], (c) to make connections between the Indigenous and Western mathematical systems, (d) to collaborate with school colleagues and the study's mentors, (e) to find the time to accomplish all of this, and (f) to gain new insights into teaching and student learning.

On the other hand, there was also a need to *unlearn*, or to have already unlearned: (a) certain Euro-Canadian ways of perceiving the world, and (b) certain understandings about Western mathematics; both of which would interfere with the success of Indigenous culture-based school mathematics (ICBSM). The participants in our research fairly quickly unlearned what needed to be unlearned. Unlearning can be as fruitful as learning, because unlearning broadens one's openness to what can be learned. Yet unlearning is often the more challenging process, because at first it is invisible to most people steeped in Canadian mainstream culture.

Ideas to be learned and unlearned were identified and discussed with the project's teachers as the issues arose, which often led to a revision of their original lesson plan. Thus, the teachers had the immediate opportunity to put their new learning/unlearning into practice by making that revision. Other teachers who implement these lessons will benefit from the learning/unlearning of the lesson's author.

## Critical Learning and Unlearning

### The Plurality of Mathematical Systems

A simple historical trajectory of the evolution of mathematics, from prehistoric times to the present-day, clearly illustrates the plurality of mathematical systems. Prior to the agricultural revolution (about 10,000 BCE), Indigenous communities *counted* arrows, *measured* cooking ingredients, *designed* clothing, *located* geographic sites, *played* games, and *explained* things to each other using numbers. As described in more detail below, all six processes constitute a cultural anthropological *definition of mathematics* applicable to any culture's mathematics, including school mathematics today (Bishop, 1988a,b).

The agricultural revolution required Mesopotamians to organize themselves into farming villages and commercial towns. They had to invent new ways to *count*, to *design* the layout of a town with

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[3] Indigenous languages are verb-based, whereas Western languages are noun-based (Lunney Borden, 2013). This fundamental difference in cultural worldviews is respected by the use of the term "mathematizing" (a verb). Indigenous mathematizing is rich in values that deal with living in a good way for the survival of the community. Each of the most important 13 to 15 values are represented by the 13 to 15 poles of a tipi. Beginning with the left entry pole, here is one sequence of values: obedience, respect, humility, happiness, love, faith, kinship, cleanliness, thankfulness, share, strength, good child rearing, hope, ultimate protection, and all my relations. This information comes from an excellent resource for Saskatchewan, Cree Elder Mary Lee's (2012) project *Four Directions Teachings*.

simple geometry, to *measure* out who owned what land, to *predict* when flooding would occur, and to *explain* the night sky. The early Mesopotamians created an administration-oriented mathematics system. It had no abstract formulas, just tables of numbers that served as concrete examples of how to solve different types of arithmetic calculations.

About 600 BCE, ancient Greek scholars invented abstract mathematics, made popular by Pythagoras' mathematical cult, and then formalized by Plato's philosophy of mathematics. It emphasized pure ideal mathematics; a philosophy that powerfully influences how people think of mathematics today. Plato believed the universe was comprised of mathematical abstract objects (Aikenhead, 2017b, p. 86) to be *discovered* and not invented by the human mind.[4]

From about 600 to 900 CE, the Islamic empire had extended eastward to India, and their westward conquests took them across North Africa into Spain. Islamic scholars learned Indian mathematics and then Greek mathematics from books in an old Greek outpost in Egypt. In addition to their own mathematical inventions (e.g., algebra), their scholars amalgamated all the known mathematics into an Islamic-Greco version (Ernest, 2016c).

In Spain, around 1200 CE, Roman Catholic monks began to translate Islamic-Greco mathematics from Arabic into Latin, which Renaissance scholars appropriated into European mathematics (Ernest (2016c). An updated 19th century version of Western mathematics is taught in North American schools today (Aikenhead, 2017b, p. 89).

To conclude, "Every major culture has had, or continues to have, a mathematics knowledge system. Therefore, many different mathematics knowledge systems exist. Ergo, mathematics is culturally pluralist[5]" (Aikenhead, 2017b, p. 88).

## Inclusion Is Not Enough

The physical presence of an Indigenous game, painting, story, or activity, is a good first step in planning an Indigenous culture-based mathematics lesson. But it falls seriously short if students *either*: (a) fail to see it as an authentic window into an Indigenous worldview, *or* (b) fail to understand how it is connected to Western mathematics.

Here are five positive examples that do take students beyond mere inclusion; all found in Duchscherer and colleagues (2019, Appendix E). Serena (Gr. 5 teacher) planned a hand-held drumming lesson, an example of Indigenous mathematizing, in which rhythms and repetitions are not only connected to the concepts of multiplication, but also to the cultural meanings that drumming holds for the Indigenous drummer who helped teach the lesson. These meanings were

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[4] Controversy over this issue abounds today. However, if one understands philosophy as something invented by the mind, then its corollary must have the same epistemic status. Plato's religious explanation for the perfection of the circle hints at his ontology. On the other hand, scientists stimulate beliefs in Plato's position by investigating phenomena amenable to mathematical representation.

[5] As explained in Meyer and Aikenhead (2021, footnote 5), pluralism should not be confused with relativism.

conveyed clearly by the stories he told. Students themselves made connections to the meaning of multiplication and division.

When watching Sharon teach a videotaped geometry lesson based on making a dream catcher, Serena realized that Sharon interspersed her Indigenous knowledge over time, rather than presenting it all at once in the lesson. She envisioned Sharon's multiple explicit connections between Western mathematics and Indigenous mathematizing as braiding the two mathematical systems that teachers would relate to each other from time to time.

Kevin (Grs. 10) introduced an Indigenous game called Picaria, another example of Indigenous mathematizing. From time to time during the two-period lesson, students connected the function of Grandfather Rock with Western mathematical spatial reasoning.

Danielle (Gr. 6) wrote stories and word problems that contained content from Western mathematics (e.g., the number line) and Nehiyaw (Plains Cree) ways of living (e.g., hunting and fishing protocols). Each story led to classroom discussions *throughout* the lessons about transferring aspects of the story to the number line.

Krysta (Gr. 12) showed examples of traditional and contemporary Indigenous looming to her students. Wampum belts are an example of Indigenous mathematizing. Students then loomed a small artifact with plastic beads, described it in personal terms, and then mathematically explained a segment of their bead selection process by learning to construct a probability tree. Looming artifacts and constructing mathematical probability trees were explicitly connected to each other by being different cultural ways of telling a story – the personal meaning within a student's culture and the public meaning of interest to a mathematician, respectively. By both artifacts being conceptualized as a story, a new understanding of mathematics occurred, one which tends to reduce math-shy and math-disinterested students' culture clashes with school mathematics (Meyer & Aikenhead, 2021, Figure 1).

In some lessons, students participated in an Indigenous protocol. For example, they learned the Indigenous value of reciprocity when they offered a pinch of tobacco to Mother Earth for borrowing three stones from a near by park to play the Indigenous game of Picario. Students quickly learned the protocols for this simple Indigenous ceremony. Recall the adage of Confucius: "I hear and I forget. I see and I remember. I do and I understand."

When conducting student assessment, teachers should be explicit about going beyond mere inclusion, for example:

- What is the connection between the Indigenous mathematizing we did (e.g., playing a game or making an artifact) and the school mathematics topic we dealt with?
- What do you now *understand* about Nehiyawak (Plains Cree people) that you didn't know before?
- Describe one way that Nehiyaw math differs from school math?

- Describe the main parts of an Indigenous ceremonial pipe used in the school's pipe ceremony, and explain what each part means to the Indigenous group who uses it.

**The Nature of Western Mathematics**

Occasionally, class discussions occurred that compared Indigenous mathematizing with Western mathematics. This was an opportunity for students to learn about Western mathematics' *human dimensions*; more personally, more meaningfully, and in greater depth (Ernest, Sriraman, & Ernest, 2016; Sriraman, 2017). These ideas *about* mathematics lie beyond the conventional spatial, algebraic, and arithmetic ways of knowing Western mathematics; that is, the content of standardized mathematics tests. But for the math-phobic, math-shy, and math-disinterested students (Meyer & Aikenhead, 2021, Figure 1), their perceptions of school mathematics being a human endeavor sparked their engagement in Western mathematics, as our teachers discovered when Indigenous mathematizing was introduced. Students' culture clashes between their self-identities and school mathematics would seem to have been reduced on those occasions.

Teaching an ICBSM lesson about once every six weeks holds promise for shifting the skewed distribution in Meyer and Aikenhead (2021, Figure 1) toward the math-interested and the math-curious part of the spectrum of students' degrees of culture clash.

Specific concrete examples of the nature of mathematics emerged from teachers *critically* exploring two topics: (a) similarities and differences between Indigenous and Western mathematics systems, and (b) cultural aspects of Western mathematics itself.

*Similarities and Differences*

A fundamental concept shared by both Indigenous and Western mathematical systems happens to be one of Saskatchewan's four curriculum goals[6]: understanding "mathematics as a *human endeavour*" (Saskatchewan Curriculum, 2007, website quote, emphasis added). Indigenous mathematizing and Western mathematics have historically arisen out of human needs and human creativity, as described above.

A humanistic representation of Western mathematics also arises from cultural anthropologists who have characterized the mathematics invented in any culture as comprising six general processes (Bishop, 1988b, pp. 148-150): *counting, measuring, locating, designing, playing, and explaining quantitatively*. Therefore, a major similarity between school mathematics and Indigenous mathematizing can be stated in a way that Grades 5-12 students can understand. Those six processes answer the challenging question, "What is mathematics?" (Lunney Borden, 2019), from an anthropological viewpoint.

Because everyday relevance can easily be associated with each of the six processes, this definition of mathematics offers students a concrete action-oriented perspective on Western mathematics.

[6] The other goals are logical thinking, number sense, and spatial sense.

The teachers in our study noted the following observation (Duchscherer et al., 2019, p. 63). When students were learning Indigenous mathematizing, highly positive engagement ensued, particularly by those students who were generally unmotivated (i.e., many of the math-phobic, math-shy, and math-disinterested students).

An educational sociological definition of mathematics offers a further similarity between Western and Indigenous mathematics: *Mathematics is a symbolic technology for humans to forge relationships between themselves and their social and physical environments* (Bishop, 1988b, p. 146). Relationships are a core value to Indigenous worldviews. Thus, this sociological understanding of Western mathematics fundamentally harmonizes with many Indigenous students. So too, for math-phobic, math-shy, and math-disinterested non-Indigenous students whose academic orientation likely steers them toward the abstractions and intuition found in the humanities (Meyer & Aikenhead, 2021).

Whenever we look for human elements in Western mathematics and Indigenous mathematizing, we have a good chance at finding them. Western mathematics' humanistic essences (Sriraman, 2017) are something to which a large majority of students can relate. Humanistic essences became sources of familiarity and motivation to learn curriculum content in the Carrot River ICBSM classes. School mathematics becomes less a culture clash experience and more of a relevant experience in a deeper rigorous way to these students.

A general difference between Indigenous mathematizing and Western mathematics concerns their focus. On the one hand, Indigenous mathematizing embraces four general components of humanness: the intellectual, emotional, physical, and spiritual. On the other hand, the Plato-based tradition of Western mathematics is officially limited to just the intellectual component. In other words, Indigenous mathematizing focuses on "the wisdom tradition of thinking" while Western mathematics focuses on "the knowledge tradition of thinking" (Aikenhead & Michell, 2011, p. 109). No wonder some Indigenous students think that Western mathematics has little depth to it. The poet T.S. Eliot (1963, p. 16) concurs: "Where is the wisdom we have lost in knowledge."

Another difference between Western thinking and Indigenous thinking that causes degrees of culture clashes for many, but not all, Indigenous and non-Indigenous students, is mathematics' deductive, analytical reductionism versus the students' own holistic intuitive reasoning. Teachers who do not understand this type of epistemic culture clash invariably see the world only through the true-or-false lens of Western culture.

Teachers need to be supported in becoming conversant with pluralistic mathematics, specifically, two-way seeing. This makes room for both deductive, analytical reductionism and holistic intuition. Students' culture clashes are reduced when this Indigenous culture-based teaching occurs. This helps explain why Indigenous students' marks in mathematics were found to increase dramatically (see the section "Literature Review" in Meyer & Aikenhead, 2021).

To summarize, the Carrot River co-researching teachers taught how an Indigenous mathematical system differs from the Western mathematical system, usually during spontaneous teachable moments. One consequence for students is a deeper understanding of the nature of Western mathematics as a human endeavor.

Several other consequences became apparent in Carrot River's classrooms. For instance, in Danielle's lesson "Focusing on Negative and Positive Numbers," the number line was a visual expression – a "symbolic technology" within the Western mathematics lexicon, if you will – which students explored. Danielle's stories contained Indigenous content written in the English language. Students translated back and forth between the two languages (i.e., English stories and the Western mathematics stories told with a number line) thereby "coming to know"[7] (Cajete, 2000, p. 110) the number line rather than memorize facts about it.

All languages contain metaphors. This concept describes a feature of the language of mathematics. The concept can be made explicit for students to learn; for example, the equation ($y = ax + b$) is a metaphor for a straight line on a graph; and vice versa. The equation is a symbolic technology. Some students feel more at ease with mathematics when they see it as a language; for the reasons that some students enjoy Social Studies and Language Arts classes the most.

*Cultural Aspects of Western Mathematics Itself*

It was foundational to Indigenous culture-based school mathematics (ICBSM) that the Carrot River teachers were supported in (a) conceptualizing Western mathematics as an important subculture within Canadian mainstream culture, and (b) identifying some cultural features of the Plato-based pure Western mathematics.

The ancient Greeks believed in the superiority of pure abstract thought (Plato's "world of ideas;" Kawasaki, 2002, p. 25), consistent with the idea that mathematics content is discovered as abstract objects that constitute the universe. Plato eschewed worldly practical knowledge (Plato's "phenomenal world;" Kawasaki, 2002, p. 25) connected with human activity. These two views, pure and practical, reflect ancient Greek, hierarchical, class-based society: the elite aristocracy, versus the military, artisans, women, and slaves.

Ernest (2016a) documents fundamental values or types of values harbored by Plato's pure ideal mathematics, including: truth, rationalism, universalism, objectivism, beauty, ethics, and purity. "All are shared cultural values attributed to mathematics knowledge" (p. 211). "Overall my claim is that far from being value-free, mathematics is imbued with a broad range of different types of values drawn from epistemology, ontology, aesthetics and ethics" (p. 212).

Consider, for instance, the Greek value of *purity*; very much alive today as in "pure mathematics." If there is a category named "pure mathematics," then by deductive logic there must be a category

[7] The phrase "coming to know" is a back-translation from a Pueblo phrase that means "to understand in a deep personal way" (Cajete, 2000, p. 110). It is the opposite to memorizing without reflection.

that means "impure mathematics." There is, and it is usually called "applied mathematics," "statistics," or "everyday mathematics;" all pertaining to a context. Pure mathematics is proudly context-free, dictated by its value of universalism. Mathematicians, however, tend to value each other's work according to its purity.[8] Thus, purity is on Ernest's (2016a) list of values just above.

Purism becomes an ideology when used as a doctrine that determines how people or institutions treat others. (Aikenhead, 2017b, p. 89; Ernest, 2016b; Larvor, 2016).

When Plato's pure mathematics is enacted in the real world, only critical analysis can determine its credibility. Sometimes it is credible (e.g., for most scientific paradigms), but sometimes it is not. For instance, students are well aware of the latter case when it comes to their grades in mathematics. What does 52 percent really mean in terms of a student's understanding quadradic equations? Its meaning may have more to do with whether or not the student can borrow the family truck for a date. Quantifying grades determines how students are treated. Thus, quantification is an ideology of pure mathematics (Ernest 2016b). It treats people mainly in terms of numbers. A case in point is test-based accountability in schools, examined in Koretz's (2017) book *The Testing Charade: Pretending to Make Schools Better*.

Of course, people must use quantification. But when they equate it with another pure mathematics value, such as objectivity or truth, as test-based accountability tends to do, then problems can arise.

Consider the case of comparing non-Indigenous and Indigenous students' graduation rates from high school. The 2017-18 Saskatchewan figures for finishing Grades 10-12 in three years is 86 percent for non-Indigenous students, and 44 percent for Indigenous students (Canadian Press, 2019). The decontextualized, pure mathematics, subtraction equation (86 – 44 = 42) is given a context in mainstream North American culture by naming "42" as "a gap," which conveys a sense of deficiency in Indigenous students. As a consequence, the expression "a gap of 42 percent" is not an objective conclusion. As it turns out, pure mathematics itself has very powerfully obliterated the context that explains why there is a difference of 42 (Duchscherer et al., 2019):

> The gap is actually *an educational debt* accumulated by Canada's past and present governments, and approved by a large portion of Canadians who continually looked the other way: when racism occurred, when brutal [cultural] genocide was enacted, and when residential schools tried to kill the Indian in every child. In many ways, Indigenous peoples were officially denied a place in Canada's economic growth. (p. 10, original emphasis)

This debt can be estimated by calculating the cost per Indigenous student per year to create equity in the graduation rates between Indigenous and non-Indigenous students.

The pure mathematics strategy of decontextualizing (e.g., 86 – 44 = 42) can be a social strategy to control others. It privileges ideal abstract thought over real-world action. Plato-based pure mathematics can make this social strategy happen by masking its own social power with its

[8] Many readers will recognize this mathematics purity value as the tension between Sheldon Cooper and Howard Wolowitz in the television series *The Big Bang Theory*.

claimed innocence of being value-free, ideology-free, free from cultural features, and hence, objective.

Armed with the values and ideologies of pure mathematics (Ernest, 2016a), Western mathematics is “one of the most powerful weapons in the imposition of Western culture” (Bishop, 1990, p. 1). When European scholars appropriated Islamic-Greco mathematics, they replaced its Islamic cultural context with a Eurocentric cultural context. That is the reason there is no reference to Mohammad in our Western mathematics.

An unconscious ideology of Western superiority and dominance strongly and systemically contributes to many Indigenous students’ culture clashes with school mathematics. Mukhopadhyay and Greer (2012) explain:

> The development of a multicultural and humanist view of mathematics [e.g., ICBSM] challenges the supremacist position maintained by many mathematician educators who regard abstract mathematics as *the crowning achievement of the human intellect*, and school mathematics as the transmission of its products. (p. 860, emphasis added)

High dropout rates lead directly to the cycle of socio-economic poverty, and to that cycle’s concomitant devastating consequences for the wellbeing of students and their communities.

Anthropologist Hall (1976, p. 192) asserted that Plato’s concept “purity of mind” and Plato’s assumption that the universe is made up of abstract objects, amounted to an intellectual mirage: “*What has been thought of as the mind is actually internalized culture*” (original emphasis); and that was the culture of ancient Greece. Perhaps this mirage could be Plato’s experience with “divine rationality” as Sriraman (2016, p. 2) suggested.

## Avoiding Subtle Appropriation

Many teaching modules have been, and continue to be, developed for Polynesian and Yup′ik students in Hawai′i and Alaska, respectively (ESTEMI, 2016; Furuto, 2014; Lipka, Webster, & Yanez, 2005; Lipka, Wong, & Andrew-Irhke, 2013; MCC, 2016). See Aikenhead (2017b, pp. 104-118) for a review of this literature.

These teaching materials unfortunately have a habit of consistently and subtly appropriating Indigenous knowledge, due to the authors’ implicit Eurocentric ideology that holds European accomplishments (e.g., Western mathematics) superior to other culture’s accomplishments, thus conferring an inferiority onto Indigenous mathematizing. As described just below, the rightful legitimacy and authenticity of Indigenous mathematizing is ignored, which causes its *legitimacy* to be appropriated by Western mathematics educators. In Canada’s era of reconciliation, this is a notable flaw in those teaching materials.

The problem of subtle appropriation can arise when Indigenous patterns or ideas are translated into Western geometry and other mathematical Western ideas. For example, suppose a contemporary Indigenous artist creates a patterned painting of birds. Suppose she tells us that it signifies respect for our winged relations. Suppose, too, a mathematics teacher introduces the Indigenous artifact to their class as an Indigenous artist's accomplishment of creating a tessellation. Obviously, both people hold two very different meanings of what the same painting means. But the mathematics teacher has just appropriated its meaning.

Teachers need to learn exactly how that mathematics teacher's mind perceived the Indigenous pattern as a tessellation. This will help us avoid colonizing Indigenous students further.

In 1930, Einstein shared his fundamental insight into the process of perceiving (quoted in Director, 2006):

> It seems that the human mind has first to construct forms independently, before we can find them in things. Kepler's marvelous achievement is a particularly fine example of the truth that knowledge cannot spring from experience alone, but only from the comparison of the inventions of the intellect with observed fact. (p. 113)

The pre-observation form independently constructed in one's mind plays a pivotal role in perception. There seems to be four consecutive processes at work:

1. When viewing the artifact that celebrates the artist's winged relations, one's mind *recalls* an image of a Western mathematics pattern, and then
2. One's mind *superimposes* that image onto the Indigenous artifact.
3. If there is a potential fit, one's mind *deconstructs* the artifact by:
   a. Focusing only on features that best fit a tessellation image, and
   b. Ignoring other features present in the artifact.
4. By ignoring those other features, one's mind has reconstructed a Western meaning (in this case a tessellation pattern) in place of the Indigenous meaning of the artifact (in this case a spiritual celebration).

Moreover, when one's mind deconstructs the Indigenous pattern and reconstructs a tessellation pattern in its place, the two processes strip the artifact of its original Indigenous meaning, thereby replacing it with a Western mathematics meaning. This causes the original Indigenous meaning to literally disappear. The cultural significance of the original meaning has been ignored, taken from its rightful place, and not even acknowledged. This we call "*subtle appropriation*."

To recap: this appropriation process is: image recall, superimposition, deconstruction, and reconstruction. Its effect is to denigrate Indigenous students in a mathematics class. Expect some Indigenous students to react negatively (Duchscherer et al, 2019, pp. 53-54).

How do teachers avoid subtle appropriation? Here are two examples.

Serena consistently avoided subtle appropriation by teaching her Grade 5 students that the regalia patterns they picked out of a Pow Wow video had a "different purpose" for the dancer than for a geometry lesson. This idea was reinforced by two questions in an assignment given after the students had made their own beading artifact related to quadrilaterals: "What does your beaded object mean to you in a personal way?" and "What does your beaded object mean to a mathematician?" (Duchscherer et al., 2019, Appendix E, Lesson E-D.2, p. 5)

In Krysta's lesson, she avoided appropriation because it was her students who created their own freestyle looming designs. No Indigenous mathematics was translated into Western mathematics. The looming bead activity served as a clever and successful segue into the topic of mathematical probability, and then onto an insight into the literacy nature of mathematical systems – its symbolic technologies.

A further example of *committing* subtle appropriation comes from Mohawk mathematics professor Doolittle (2006). Some mathematics textbooks state, "A tipi is a cone" (p. 20). Doolittle objected to this statement:

> I have heard that countless times. But that is surely wrong; the tipi is not a cone. …There is a body of tradition and ceremony attached to the tipi which is completely different from and rivals that of the cone. My feeling is that Indigenous students who are presented with such oversimplification feel that their culture has been appropriated by a powerful force for the purpose of leading them away from the culture. (p. 20)

In summary, the statement "a tipi is a cone" ignores or strips away the Indigenous meaning of a tipi, and reconstructs in its place a Western geometric meaning.

Our research project paid careful attention to avoiding subtle appropriation. Accordingly, our research differs in this regard from similar projects found in the mathematics education literature reviewed in Aikenhead (2017b, pp. 122-124). Rather than replace an Indigenous idea with a Western idea, the co-researching teachers added the Indigenous idea to a student's fund of Indigenous knowledge, or at least acknowledged they did not know the Indigenous meaning. They always kept the Western idea associated with Western mathematics. Simply put, both systems coexist, and each system belongs to a separate coherent knowledge system (Garroutte, 1999).

If a tipi is not a cone, and a cone is not a tipi, then what is the relationship between the two words? The answer solves the potential problem of subtly appropriating from Indigenous cultures.

The terms "tipi" and "cone" can be understood as analogues (or analogies) located in two different cultures. In the culture of Western mathematics, a cone is analogous to a tipi, but it is certainly not equivalent or the same as a tipi. By not making this distinction perfectly clear to students, and by not informing students of an Indigenous meaning of a tipi, a mathematics teacher is appropriating an Indigenous understanding of a tipi.

## Two-Eyed Seeing Taught to Students

By clearly making the distinction between an Indigenous meaning and a Western mathematics meaning of a painting or tipi, a teacher is engaging in two-eyed seeing (Hatcher, Bartlett, Marshall, & Marshall, 2009). Two-eyed seeing is a crucial state of mind that teachers need support to achieve and maintain. It ensures that reconciliation is alive in a mathematics classroom. "We have come to understand that Western mathematics and Indigenous mathematizing can be viewed as having complementary strengths. Recognizing the strengths of each view will maximize mathematical learning for all students" (Sterenberg & O'Conner, 2018, p. 185). This was precisely what Carrot River students were learning:

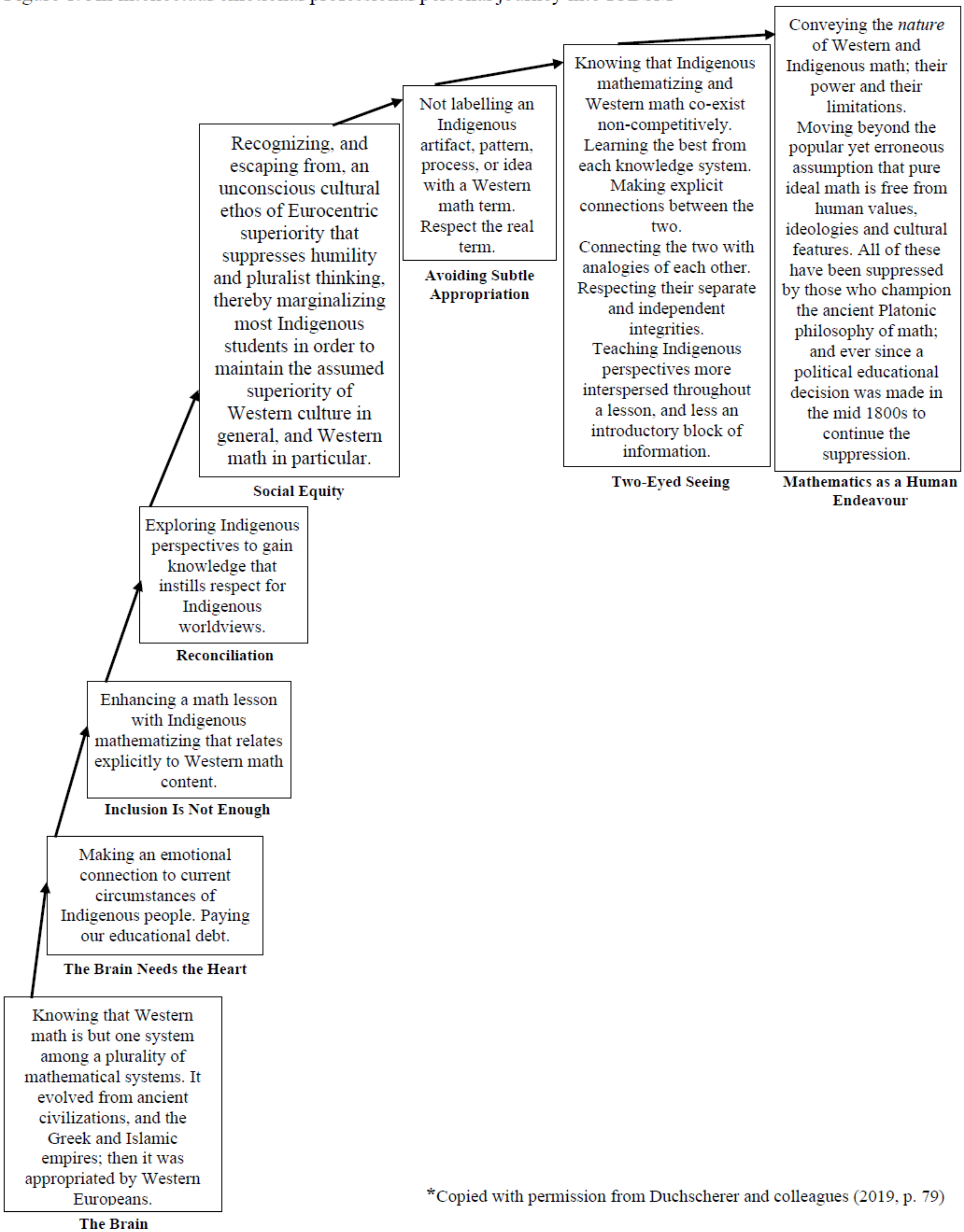
- From Danielle, when they went back and forth between Indigenous stories and the Western mathematics' stories about the number line;
- From Krysta, when they explicitly compared possible stories associated with a wampum belt and stories associated with Western mathematics' probability tree;
- From Serena, when they recognized that patterns seen on regalia have a different meaning for the Pow Wow dancer than for mathematicians;
- From Kevin, when the mathematical strengths of Western statistics revealed gross social inequities between privileged non-Indigenous communities and socially subjugated Indigenous communities. In this case, the two-eyed seeing corresponded to two different "*normal*" living conditions in Canadian society.
- From Sharon, when she taught a dream-catcher geometry lesson. Photos show students explicitly engaged in two-eyed seeing, interacting between their personal Indigenous dream-catcher patterns and some analogous Western geometry shapes (Duchscherer et al., 2019, Appendix F).

The four participant teachers demonstrated that a monocular understanding of the nature of mathematics is quickly expanded into a two-eyed seeing state of mind by the experience of developing or teaching just one or two Indigenous culture-based lessons with the support of an initial mentorship. Some ideas can only be learned or unlearned through personal experience – in this case having one's lesson plan discussed by a Knowledge Holder and an educator experienced in Indigenous perspectives.

## Conclusions

These conclusions are expressed in two contexts: the independent conclusions the teachers made at the end of the study, and those we have made both in collaboration with the teachers and from our observing their journey into ICBSM. A synopsis of the teachers' journey of learning and unlearning is found in Figure 1 (next page).

Figure 1. An intellectual/emotional/professional/personal journey into ICBSM*




*Copied with permission from Duchscherer and colleagues (2019, p. 79)

**Teachers' Conclusions**

At the completion of the research project, two Team Members, Indigenous consultants from two other school divisions, together interviewed Kevin, Danielle, and Serena individually to learn their ideas relevant to the project's research question. (Krysta was on maternity leave.) Hour-long interviews were conducted independently of Sharon (Team Leader) and Glen (Team Contact Person). The Team Members took notes and each reported orally to the Team Contact Person, guided by their notes. These oral reports were audio recorded, then summarized along with specific quotations. Finally, the summary's accuracy was verified by the interviewers.

All three teachers adamantly and independently emphasized the following five points:

1. Indigenous culture-based mathematics teachers must first and foremost be learners; including learning from, or with, their students when students get stuck with a problem unfamiliar to their teacher. Indigenous mathematizing invariably involves, to some degree, student-centred problem-posing and problem-solving. It is remarkable how the classroom atmosphere changes when students discover their teacher is open to learning from/with them. Teacher-student relationships are strengthened. A teacher's flexibility to take the occasional extra time to become a co-learner with students is crucial to ICBSM. It is not a luxury.
2. Indigenous culture-based teachers first require an emotion-evoking cultural immersion experience. It is a necessary but insufficient key to success.
3. A half-day mentoring by a school division Indigenous consultant, or an Indigenous Knowledge Holder, is a necessary but insufficient key to success.
4. The depth of engagement for *both* non-Indigenous and Indigenous students determines the degree of their success at learning Western mathematics. That depth was enhanced because students learned Indigenous mathematizing and related it to Western mathematics content.
5. A major roadblock to ICBSM is the highly restrictive, over-crowded, outdated curriculum, which cuts into flexible productive time to be an innovator and a learner.

Kevin clarified the curriculum issue when he spoke about open-ended classes in which students pose a relevant problem/question and then solve it by drawing upon some aspect of mathematics (Duchscherer et al., 2019, p. 50): "When I've been given the time and freedom to teach like this, students learn much better. There are some curriculum stumbling blocks to overcome in order to acquire the time to conduct a student-centred class, like the Indigenous culture-based lessons we've developed for this research project." Louie (2017, p. 488) identified such stumbling blocks as the curriculum's framing "mathematics as a fixed body of knowledge to be received, and… [thus] unintentionally excluding many students from rich learning opportunities."

If a curriculum requires all students to see their world the same way as mathematicians do, then most non-Indigenous students in the math-phobic, math-shy and math-disinterested portion of the spectrum of students' culture clashes (Meyer & Aikenhead, 2021, Figure 1) would tend to experience school mathematics as an attempt at indoctrination. They would resist by memorizing their way to a passing grade, and may likely end up hating mathematics. Indigenous students in the same portion of the spectrum would experience school mathematics as a continuation of Canada's colonization. Some would resist by dropping out of school.

Many math-phobic, math-shy and math-disinterested students likely have self-identities that excel in the humanities or commerce. In Carrot River, they became particularly engaged in the Indigenous mathematizing activities, however.

Serena, Danielle, and Kevin have already independently continued their ICBSM achievements into the next school year (2019-2020). Moreover, they recommended expanding the culture-based teaching to all curriculum subjects within the school.

**Our Conclusions**

Because many of our conclusions have already been discussed, they are only summarized in this subsection.

The TRC's (2016) calls to action include: "developing culturally appropriate curricula" (p. 165) and "Building student capacity for intercultural understanding, empathy, and mutual respect" (p. 180). Achieving these two calls to action would go a long way to increase the high school graduation rate for Indigenous youth. Other major results could follow:

1. Reconciliation would be a greater part of all students' school experience.
2. The systemic race-related marginalization of Indigenous students in school mathematics would be reduced, if not eliminated.
3. Many more Indigenous youth would be better qualified for entering Saskatchewan's job market, thereby providing a major advantage to Saskatchewan's economy (Cooper, 2012; Saskatchewan Chamber of Commerce, 2017; Sharpe & Arsenault, 2009).
4. A major barrier to teachers' innovative mathematics teaching would be removed, in order to accomplish consequences 1-3.
5. The revised curriculum would make a significant initial payment toward reducing Saskatchewan's educational debt to its Indigenous citizens.

Mathematics, more than any other school subject, is responsible for Indigenous students not graduating from high school (Abrams, Taylor & Guo, 2013; Aikenhead, 2017a, pp. 83-85; Anderson & Richards, 2016; Perso, 2012). Unfortunately, that pervasive situation suggests an accusation of systemic racism.

Oesterle (2018, p. 161; quoted in Meyer & Aikenhead, 2021) was correct: "[W]hat we have been doing is not 'working'." Furthermore, mathematics education is not working that well for a large majority of non-Indigenous students. Many more high school graduates have learned to hate mathematics than have learned the prerequisite mathematics content for post-secondary STEM programs. Roughly, *the ratio is 40 to 25* respectively (Meyer & Aikenhead, 2021). It would seem that the quest by such groups as the NCTM (Larson 2016), educators, and parents to prepare most students for post-secondary STEM programs, has created collateral damage with the severe consequence of the general public's resistance to using a Grade 8 level of mathematics comfortably and competently in their everyday worlds of commerce, general employment, home life, etc. (Ginsburg, Manly, & Schmitt, 2006). When have most adults ever been confronted with, for instance, a quadratic equation that was *necessarily* relevant to them?

The most succinct answer to our research question ("What precise supports must be in place for teachers to enhance their mathematics classes in a sustainable way with Indigenous mathematizing and worldview perspectives?") is:

I. A revised curriculum in harmony with a humanistic, Indigenous culture-based, school mathematics program, for the large majority of students;
II. Saskatchewan authentic teaching materials to serve a renewed curriculum. Our research project has established a template for school divisions and ministers of education to develop locally relevant ICBSM.
III. Transformative professional development experiences.

Our recommendations are based on these three issues.

## Recommendations

### A Revised Curriculum

We recommend that Saskatchewan's Ministry of Education remove barriers that currently discourage schools from teaching ICBSM. The Ministry could cull obsolete and inappropriately abstract curriculum content taught to the majority of students (i.e., the math-disinterested, math-shy, and math-phobic), many of whom do not learn the mathematics practised in the everyday worlds of most adults.

Given the international academic achievement success of ICBSM, imagine the potential benefits of an additional curriculum emphasis on *Western* culture-based school mathematics (WCBSM) – contextualized in the typical adult's everyday world (Aikenhead, 2017b, pp. 128-130, 132-133). Students would witness, experience, and learn how Western mathematics works in *their everyday world*; rather than in a mathematician's abstract everyday world. Simply put, students would generally learn Western mathematics from how it is used in mainstream culture.

At the same time, the Ministry of Education needs to provide a refocussed attention to the minority math-interested, math-curious, and math-oriented students; especially to Indigenous students who show potential for a Western mathematics self-identity.

## Developing Authentic Teaching Materials

Our research study provides a strategy for producing teaching materials that would match a revised curriculum. Scaling up our project to a province-wide effort requires more personnel and greater efficiency, of course, for over the next 5 years. We recommend that the Ministry of Education establish cadres of developers of teaching materials. The cadres would be comprised of the following groups of people: (a) mathematics teachers already familiar with, or highly interested in learning about, a Saskatchewan Indigenous culture; (b) Indigenous Elders and Knowledge Holders who would ensure authentic local content and protocols are used, and who would promote the local language to some reasonable degree in the teaching materials; and (c) writers for polishing the products of the collaboration between groups (a) and (b) into publishable teaching materials. Inexpensive modules could be printed for distribution (Duchscherer et al., 2019, pp. 71-72).

## Professional Development

Transformative professional development experiences are not only for classroom teachers. They are required for curriculum developers, teaching material developers, and school administrators; along with representatives from the Ministry of Education, school divisions, and school board associations. A cultural immersion, planned and led by local Indigenous Elders and/or Knowledge Holders, is the only effective way to begin the journey into ICBSM.

Learning to teach Saskatchewan Indigenous mathematizing and Indigenous perspectives was identified by the collaborating teachers as a journey. Lesson planning, accompanied initially with mentors' collaborative feedback, is a particularly rich context for advancing a person's journey into school mathematics for reconciliation, and for increased student academic achievement. According to the teachers, their experience was not so much a superb professional development exercise as it is a personal life journey with far reaching rewards. It represents reaching the goal of "coming to know" (Cajete, 2000, p. 110) Indigenous culture-based school mathematics (ICBSM).

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