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School Science and Mathematics Storylines

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Abstract In celebrating the Journal's 20 years of publication, one of its many storylines in science education is identified, and a potential second storyline in mathematics education is introduced. The first looks back 20 years to trace a trajectory of articles about enhancing school science with Indigenous ways of living in Mother Earth. The second looks ahead to what may likely evolve into a trajectory about enhancing school mathematics with Indigenous mathematizing. The article ends by describing a recent research study that gives detailed texture to this emerging trajectory.

Résumé Alors que l'on célèbre les 20 ans de publication du Journal, deux de ses nombreuses trames sont recensées. La première retourne 20 ans en arrière pour tracer une trajectoire d'articles sur le rehaussement de la science scolaire par l'intégration des modes de vie autochtones sur la Terre Mère. Une deuxième trame se penche sur ce qui pourrait probablement devenir une trajectoire de rehaussement des mathématiques scolaires par l'intégration de la mathématisation autochtone. L'article se termine par la description d'une étude récente qui présente moult détails sur cette nouvelle trajectoire.

Keywords Indigenous · Culture-based · School science · School mathematics · Culture clashes

Introduction

Over the past 20 years, the *CJSMTE* has provided the academy with policy- and research-related articles that articulated future fundamental innovations in science, mathematics and technology education. It has been a Canadian home to many stimulating conversations. This article focuses on two such conversations, and it unfolds in three phases. The first phase traces a specific school science theme found in *CJSMTE* articles during the Journal's 20 years. The articles animated the innovation of enhancing Western school science with Indigenous ways of understanding Mother Earth.

The second phase concerns the enhancement of school *mathematics* with Indigenous mathematizing; a topic introduced during a CJSMTE research conversation (Aikenhead, 2017); that is, an evidence-based policy proposal and a likely beginning to a future CJSMTE storyline. The term "mathematizing" respects

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the fact that Indigenous languages are verb-based, whereas Western languages are noun-based (Lunney Borden, 2013). This fundamental difference in cultural worldviews is reflected in the term "mathematizing" (a verb), exemplified by the mathematical activities in which counting, measuring, locating, designing, playing or explaining quantitatively (Bishop, 1988b) occur within all cultures, Indigenous and Western cultures alike. Perhaps the second phase of this article, associated with a new storyline, may lead to fundamental innovations during the next 20 years in Canadian school mathematics.

In its third phase, this article reports on a Research and Development (R&D) study that investigated the support that mathematics teachers in grades 5–12 needed when they began to enhance their math classes in a rural Saskatchewan school with the occasional Indigenous mathematizing lesson connected to our curriculum's Western mathematics content.

A School Science Storyline

Had the *CJSMTE* began publishing *25* years ago, it may likely have published the policy article "Toward a First Nations Cross-Cultural Science and Technology Curriculum" (Aikenhead, 1997). The article treated the field of science as a subculture of Western cultures. I pointed out that to learn Western science, Indigenous students had to move intellectually, emotionally, physically and spiritually from (a) their own culture that sustained their self-identities, to (b) a "foreign" solely intellectual subculture of Western science education. As a result, unrecognized culture clashes caused social inequities. Indigenous students were systemically marginalized by this clash between their self-identities and their perceptions of science, scientists and school science.

A few pioneer science educators had already begun to explore ways to address these barriers to Indigenous students' engagement and achievement in school science (George & Glasgow, 1988; Jegede & Okebukola, 1990; Kawagley, 1995; MacIvor, 1995; McKinley et al., 1992; Snively, 1990). In order to lessen the degrees of culture clash experienced by many Indigenous students, these science educators described or showed how to make Indigenous ways of knowing Mother Earth part of science instruction (Aikenhead, 1997). They encouraged "the validity of students' culturally constructed ways of knowing" (p. 217), thereby recognizing the *coexistence* and *non-competition* between Indigenous and Western ways of knowing Mother Earth and nature, respectively. Indigenous students' achievement improves in science classes when they take on a Western way of knowing nature (i.e., Western science), without suppressing their own Indigenous understandings.

My 1997 policy article was put into action by a R&D project that explicitly provided a meaningful postcolonial context for both Indigenous and non-Indigenous students in grades 6 to 11 (Aikenhead, 2000). The project was written up in the *CJSMTE* as "Cross-Cultural Science Teaching: *Rekindling Traditions* for Aboriginal Students" (Aikenhead, 2002a). Six community-based teaching units were produced in villages across northern Saskatchewan. Today, it would be called "place-based" or "land-based" teaching. The units explicitly taught some of the values held by each knowledge system, Indigenous and Western.

An Indigenous Elder or knowledge holder in each village determined what Indigenous content to include, and they mentored the teachers on this Indigenous content. Elders often participated in a classroom lesson. Relevant Western science knowledge was then added to the unit to *extend* students' understandings of the topic at hand, but it never replaced the Indigenous knowledge. Moreover, Indigenous community perspectives defined the structure of each unit, and each unit always began with some of the Indigenous content.

This *CJSMTE* article (Aikenhead, 2002a) was instrumental in disseminating how to implement my 1997 policy article. A process had finally been established for school divisions to develop locally relevant Indigenous culture-based school science. I also argued against a hegemonic representation of "Aboriginal knowledge" by the concept "traditional ecological knowledge" (TEK). A final ending to this side story (*mise en abyme*) would have to wait 15 years for TEK's demise in a *CJSMTE* article (noted below).

A separate paper within the *Rekindling Traditions* project, "Stories from the Field" (Aikenhead, 2000), detailed salient, idiosyncratic political features of the town's and villages' political environments. This knowledge was shared to sensitize teachers to pay attention to their own political environment—politics matters.

The implementation of policy-based or theory-based research into educational practice can meet political road blocks. Very few science educators go into the profession to engage in such politics. This may explain why policy-to-practice and research-to-practice transitions invariably fail when one assumes the popular academic viewpoint depicted in Fig. 1 (the gears are not connected, only arrows show where connections could be made if only the science educator knew how). My past professional experiences had taught me the function of politics in curriculum innovations. Coincidently, an inspiring *CJSMTE* article by Fensham (2002) introduced the jargon "educo-politics" to the Journal, a term that means political power struggles in education. In my subsequent commentary supporting Fensham (Aikenhead, 2002b), I succinctly summarized his advice by drawing on a Hill Street Blues[1] character, Sgt. Jablonski, for how to get things accomplished: "Do it to them before they do it to you" (p. 55). This advice requires well-timed political action, as represented by a central gear in Fig. 2. It may lead to stronger results than Wagner's (2019) strategy, "to set up panel discussions with the people who are making themselves popular [in the traditional and social media] by complaining about mathematics education" (p. 71).

In the context of science and mathematics education, Sgt. Jablonski's advice refers to dealing with reactionary scientists, mathematicians, teachers, parents and bureaucrats. For example, soon after Australia's Labour Prime Minister's February 2008 apology to Australian Aboriginal and Torres Strait Islander peoples, science educators officially enhanced their national science curriculum with knowledges gifted by Aboriginal families. When a Conservative government came into power, however, it instigated a *Review of the Australian Curriculum* (Australian Government Department of Education, 2014). As a result, the Indigenous-related content was summarily deleted from the curriculum on the advice of a few powerful university physicists. For example:

1. "A submission by Prof. John Ridd also expresses hostility toward the cross-curriculum priorities and recommends that they 'be removed completely'" (Australian Government Department of Education, 2014, p. 174). In the same document, Ridd stated, "The curriculum shaping process has been heavily influenced by modern educational fads" (p. 184).
2. Another influential professor, Egor Bray, concurred. "Science can change society, but society cannot change Science. …There is no room for cultural sensitivity" (p. 182).

The reactionaries had won at educo-politics, for the time being. The social equity conscious Australian science educators had not successfully followed Jablonski's practical advice.

Rekindling Traditions motivated a rational speculative manuscript, "Towards Decolonizing the Pan-Canadian Framework," being published as a Viewpoint in the *CJSMTE* (Aikenhead, 2006). The Pan-Canadian Framework (CMEC, 1997) lacked any mention of Indigenous knowledges. Collaboration "with Aboriginal [E]lders is a key feature of policy development if we want to achieve cultural relevance, sensitivity, and the support of the Aboriginal community" (Aikenhead, 2006, p. 389).

My 2006 article reviewed educational jurisdictions that had enhanced science programs with Indigenous perspectives. A revised Pan-Canadian Framework could support Indigenous communities in their historic move from a colonial past to a *postcolonial*[2] present. In the same article, I critiqued Saskatchewan's grade 10 science curriculum to illustrate the types of changes that needed to be made, an instance of educo-politics

[1] Hill Street Blues was a popular comedy TV series that appeared 1981–1987 and won several awards. It followed the daily work life of a New York precinct.

[2] "Postcolonial" does not mean colonialism has ended, but rather, it means all forms of systemic colonialism are identified, critiqued and changed, with respect to social justice.

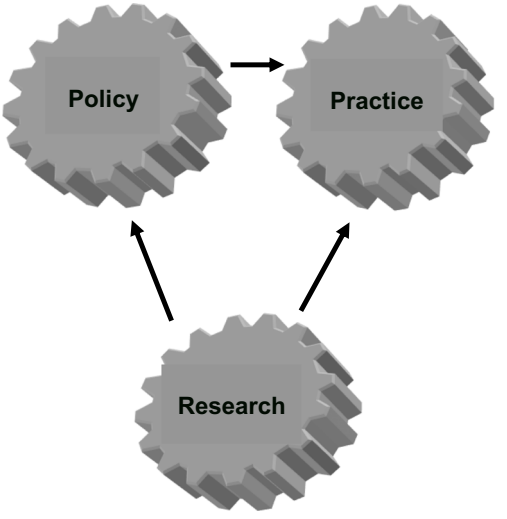

Fig. 1 Popular academic assumptions

to be sure. In response to pressure from several diverse sources, Saskatchewan's Ministry of Education began to seriously work on how all curricula could be improved with the addition of Indigenous perspectives, particularly the K-10 science curricula.

A measure of the maturity of any academic invisible college is the appearance of a book or a special issue of a journal disseminating a range of accomplishments by the college's members. Such was the case for the Indigenous school science invisible college. Herman Michell (2009), a Woodland Cree author and science educator, served as guest editor for the *CJSMTE*'s Volume 9, Issue 3, entitled "Indigenous Science Education from Place: Best Practices on Turtle Island."

Four splendid articles by well-known researchers indicated the breadth and depth of this evolving storyline. Hatcher et al. (2009) discussed how the powerful metaphor of "two-eyed seeing" clarified their analysis of Cape Breton University's program called "Integrative Science." The metaphor continues to be a core concept today. Lewthwaite and Renaud (2009) explored the guiding principles of "Inuit

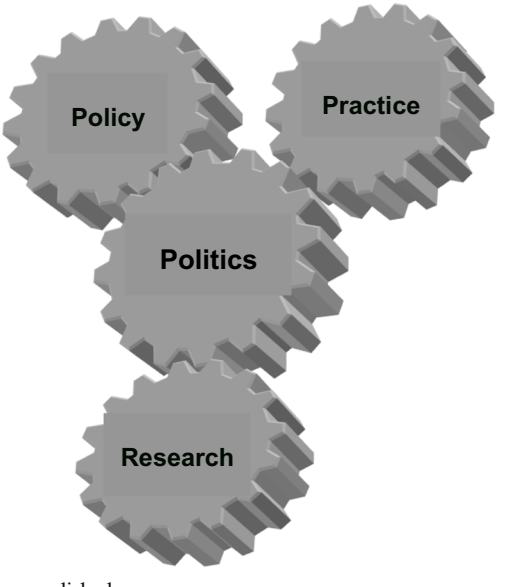

Fig. 2 Reality for getting things accomplished

quajimajatuqangit" and created a quantitative instrument to initiate community discussions. Sutherland and Henning (2009) developed a theoretically and empirically derived, thoughtful, extensive framework useful to those who plan Indigenous-enhanced science programs. And the storyline of decolonizing science education was extended by Belczewski's (2009) personal account of what an individual can accomplish. Her article is very helpful to science educators contemplating decolonizing their teaching.

In 2008, Prime Minister Stephen Harper made a historic apology to former students of Indian Residential Schools on behalf of all Canadians, and he established Canada's Truth and Reconciliation Commission (TRC). *The educo-politics of science education suddenly and radically changed* with Canada's attention to residential schools' injustices. One consequence is described in the *CJSMTE* article "An Emerging Decolonizing Science Education in Canada" (Aikenhead & Elliott, 2010). Saskatchewan's Ministry of Education collaborated with key stakeholders in Saskatchewan to modify the pan-Canadian framework to meet new specifications for a twenty-first century science curriculum framework enhanced with Indigenous knowledges. The framework placed Indigenous knowledges parallel to, but different from, the knowledge of the Western sciences (Aikenhead & Elliott, 2010). Elders chose the Indigenous perspectives that were included in a non-tokenistic way.

The Ministry also initiated a state-of-the-art development of a teacher-authored science textbook series, *Pearson Saskatchewan Science* (grades 3–9). Its development was overseen by an Advisory Council that included Elders who decided what Indigenous ways of knowing Mother Earth would be integrated into each textbook's four Western science units[3] (View, 2016). Furthermore, the Elders had full control over how their Indigenous understandings were written and represented in the textbooks (Aikenhead & Elliott, 2010). The process was fully collaborative, not merely consultative.

The next appearance in the *CJSMTE*'s school science storyline came when Higgins (2014) extended Belczewski's (2009) article on decolonization. He analyzed the science education community's translation from decolonizing theories to espoused pedagogical practices. Then came the final word on TEK by Kim et al. (2017) in their comprehensive argument concluding that the concept TEK amounted to cultural appropriation.

In summary, this *CJSMTE*'s science education storyline began with an evidence-based innovative *policy* article. This was followed by *Rekindling Traditions*, a small-scale *R&D research* project that implemented the policy to demonstrate its credibility. Then came the *politics* of Saskatchewan's scaled-up implementation that produced a textbook series that encouraged widespread *practice* in Saskatchewan and Manitoba schools. This scenario is conveyed by Fig. 2. All four aspects (policy, research, politics and practice) must mesh purposefully over time in order to produce a significant sustainable outcome.

Toward a School Mathematics Storyline: A Policy Document

A future *CJSMTE* school mathematics storyline began in a way similar to the school science storyline: with an evidence-based policy document. In the mathematics case, it was the *CJSMTE* monograph "Enhancing School Mathematics Culturally: A Path of Reconciliation" (Aikenhead, 2017). Its overarching goal was to repeat for school mathematics what had been accomplished with school science in Saskatchewan. This was made possible because *the educo-politics of mathematics education suddenly and radically had changed* because of the TRC and Canada's new era of reconciliation.

The policy document emphasized teaching mathematics in authentic *cultural* contexts; that is, how mathematics is actually used in either (a) non-mainstream Canadian settings (e.g., Indigenous cultural contexts), or (b) mainstream Canadian cultural settings (e.g., in societal, commercial, recreational and

[3] By political necessity, the status quo organization of science textbooks needed to be maintained, rather than follow the Indigenous-oriented organization used in *Rekindling Traditions* (Aikenhead, 2002a). By adding Indigenous content to the textbook was enough of a major change for science teachers, without revamping the organization of science topics as well.

personal domains). Accordingly, we can speak of "*Indigenous* culture-based school mathematics" and "*Western* culture-based school mathematics."

Animating an Emerging School Mathematics Storyline: Policy Put into Action

A future *CJSMTE* school mathematics storyline is strengthened here by summarizing a small-scale R&D project that explored the viability of *Indigenous* culture-based school mathematics in the crucible of mathematics classrooms with non-Indigenous teachers, located in the small rural Saskatchewan town of Carrot River (Meyer & Aikenhead, 2021a, 2021b). The project was co-planned by its principal investigator, Sharon Meyer (Cree knowledge holder, and highly experienced educator) and myself. It turned out to be an educo-political strategy to launch the monograph's education policy into the public domain.

Context

The R&D project focused on reconciliation occurring in mathematics classrooms (grades 5–12) and the prerequisite professional development necessary to make it happen. Canada's TRC (2016) defines "reconciliation" in terms of cross-cultural respect through mutual understanding. Reconciliation is not a destination, but an ongoing process. It matters how we *do* things, such as how we teach mathematics. By learning examples of local Indigenous mathematizing and their concomitant cultural perspectives, teachers and students develop respect by *understanding* their Indigenous neighbours. And therein lies a tangible act of reconciliation—respect through understanding.

Respect necessitated more than an *intellectual* understanding of Indigenous people. The Carrot River teachers found the project "not so much a professional development exercise as it was a personal life journey with far reaching rewards" (Duchscherer et al., 2019, p. 6). To begin with, the teachers' interest had been motivated by Canada's political era of reconciliation.

Four non-Indigenous teachers (Kevin Duchscherer, Serena Palmer, Krysta Shemrock, and Danielle Vankoughnett) and their non-Indigenous principal (Sari Carson)[4] collaborated with Team Leader Sharon Meyer and Team Contact Person Glen Aikenhead (titles designated by the funding agency). Because the five participants produced most of the qualitative data that appears in the Project Report written for the Stirling McDowell Foundation, the participants' contribution warranted their place as first co-authors of that document (Duchscherer et al., 2019), among a total of 10 co-authors.

The R&D project explored how mathematics can be taught in grades 5–12 by including an Indigenous culture-based perspective, thereby enhancing Western mathematics pedagogy with Indigenous mathematizing. These two coexisting cultural systems have similarities and differences that created interest among all Indigenous and most non-Indigenous students. The study exemplifies *Indigenous* culture-based school mathematics.

Literature Review

International studies have shown that, when Indigenous ways of knowing and mathematizing are introduced into school mathematics, two consequences are observed. First, for *Indigenous students*, there is an "increase in the mastery of science and math concepts, deeper levels of student engagement in science and math, and increased student achievement in science and math" (U.S. Congress House of Representatives Subcommittee on Early Childhood, Elementary and Secondary Education, 2008, p. 13). This increase is usually dramatic (Lipka & Adams, 2004; Nicol et al., 2020).

[4] At the end of the R&D project, all participants decided to have their real names used in public documents, rather than be anonymous.

Secondly, *non-Indigenous students* tend to improve their achievement noticeably in those same classrooms (Adams et al., 2005; Beatty & Blair, 2015; Lipka et al., 2005; Lipka et al., 2013; Richards et al., 2008). In short, taking time to teach some Indigenous mathematizing produces a win-win result in the improvement of students' academic mathematics achievement.

As mentioned in the science storyline, one foundational explanation for these empirical results draws on *reducing the degree of culture clash* for the *majority* of all students. In mathematics, this majority comprises about 74 to 70 percent of Saskatchewan (Aikenhead, 2017; Meyer & Aikenhead, 2021a) and Ontario (Card & Payne, 2017) high school graduates, respectively. Meyer and Aikenhead (2021a) characterized the diversity within this majority as "math-phobic, math-shy, or math-disinterested" [5] (p. 104). Due to the predilections and interests of these students for the humanities and social sciences, they tend to have a degree of culture clash between (a) their cultural self-identities, and (b) either their views of the culture of school mathematics, or their views of a person who thinks, talks and believes like a mathematician (Aikenhead, 2017). A poll taken among adults in their 20s and 30s found that about 40 percent declared they "hated" mathematics, while 25 percent stated that mathematics was their favourite school subject (CNN.Com [Education], 2005).

Such culture clashes do not exist for the small minority of high school graduates (approximately 26 and 30 percent, Saskatchewan and Ontario, respectively). Meyer and Aikenhead (2021a) described this latter group as "math-interested, math-curious, or math-oriented" (p. 104). This group, which certainly includes mathematics teachers, tends to have a difficult time understanding such clashes because they personally do not experience them. This of course exacerbates the degree of culture clash experienced by the math-phobic, math-shy and math-disinterested learners.

In addition to decreasing learners' culture clash, a second foundational explanation underlying students' increased achievement with Indigenous culture-based school mathematics concerns the fact that Indigenous mathematizing is always an *action*. When students are active learners, they tend to respond with increased engagement, motivation and interest, which can spill over to when analogous Western mathematics is connected to their Indigenous mathematizing. When school mathematics is perceived by non-mathematics-oriented students as being mainly irrelevant to their everyday worlds, they tend to respond positively when they experience culture-based mathematics with which they can identify, as opposed to experiencing an abstract foreign culture of conventional school mathematics (Duchscherer et al., 2019). Their improved feelings toward a mathematics identity lead to higher achievement. As reported in Aikenhead (2017), the win-win achievements were established in Aotearoa New Zealand, Alaska's extensive and highly influential "Math in a Cultural Context" project, Norway, Sweden, Hawai′i, Nova Scotia, British Columbia, Alberta and Ontario.

The Carrot River R&D project was inspired by the successes of the above research studies. The Swedish study (Jannok Nutti, 2013) was of particular interest because it focused on the role of Sámi teachers as co-researchers, more so than most other research projects (Aikenhead, 2017). Jannok Nutti, of Sámi ancestry, wrote, "The intention of the culture-based mathematics activities was *to reconstruct school mathematics* by creating a learning environment grounded in both school mathematics and Sámi culture-based knowledge" (p. 63, emphasis added). This statement signified the inclusion of Sámi perspectives (i.e., Sámi ontology, epistemology and axiology) in mathematics classes.

Her intention is captured by "Stage 3" in the following category scheme that she borrowed to assess the degree to which her teachers reached this third stage (Jannok Nutti, 2013, p. 66):

Stage 1: Mathematics content and Sámi *general* themes (e.g., reindeer management) would appear almost independently in lessons.

[5] These heuristic flexible categories discourage simplistic dichotomies concerning student achievement. They are not meant to be used in tracking students. Categorization is ephemeral, influenced by many variables, such as mathematics topic, teacher, age, SES and systemic racism.

Stage 2: Content is integrated into a *specific* everyday Sámi activity (e.g., baking or cooking a specific Sámi dish, or fishing for a specific fish species), but not quite in a way that follows traditional Sámi ways; for instance, using Western ways of measuring in a recipe, instead of body measures.

Stage 3: As stated above, teachers "creating a learning environment grounded in both school mathematics and [authentic] Sámi culture-based knowledge."

Jannok Nutti explained why her Sámi teachers did not reach stage 3. "The teachers wished to implement Sámi culture-based mathematics teaching, but felt that they lacked the knowledge and time [away from teaching the required curriculum content] to implement Sámi culture-based teaching" (p. 68). They appeared to get stuck at stages 1 or 2.

In conclusion to this literature review, other than for Jannok Nutti's work, the research literature did not appear to investigate the explicit, concrete, critical supports needed by teachers implementing Indigenous culture-based school mathematics. Supporting teachers' efforts is pivotal for moving from policy to practice.

Our Saskatchewan study was designed to help fill this void in the literature by posing the following research question: "What supports do teachers need to enhance their teaching of Western mathematics in a sustainable way by bringing some examples of local Indigenous mathematizing into their classrooms?" (Duchscherer et al., 2019, p. 1).

The Research Process

We discovered an array of necessary teacher supports that came to our attention explicitly and implicitly during the following events. (See Duchscherer et al., 2019, pp. 14–37, for details.)

1. Conducting a day-long introduction to the research project in late August, 2018, by Nehiyaw (Plains Cree) knowledge holder Sharon Meyer, Nakawē (Saulteaux) Elder Albert Scott, and researcher Glen Aikenhead, a 4th generation settler of British ancestry.
2. Holding a two-day culture immersion in early October, run by Albert and Sharon.
3. Mentoring each teacher individually on the topic of Indigenous mathematizing for a half-day released time during October.
4. Mentoring the development and revision of the teachers' lesson plans that included Indigenous mathematizing, during November 2018 and during March to May 2019.
5. Collaborating with the teachers and principal as co-researchers throughout the project.
6. Engaging in various conversations and structured interviews throughout the school year. Each conversation and interview had a different purpose, and all were audio-recorded. The interviews were not transcribed but were summarized and included some important quotable statements. Each participant edited their summary to ensure its accuracy.
7. Holding a final independent interview with each teacher by two Indigenous consultants from two other school divisions.

These strategies allowed us to discover the teachers' individual viewpoints, feelings, challenges and accomplishments at learning Indigenous perspectives, in the context of engaging their learners in Indigenous mathematizing. By resolving their challenges collaboratively, we identified concrete instances of what they needed to learn or unlearn (or what had been previously learned and unlearned) in order to implement Indigenous culture-based school mathematics effectively.

We listened and watched carefully to how the teachers learned to feel comfortable as they became an Indigenous culture-based mathematics teacher. This non-assessment approach differs from Jannok Nutti's

(2013) use of a predetermined rubric. As a result, we acquired much-needed concrete advice for school divisions and ministries of education when introducing Indigenous culture-based school mathematics. Our central strategy was to engage teachers in developing lesson plans for other teachers to use, a spinoff feature to the R&D project.

Findings

On the one hand, teachers needed initial support: (a) finding authentic Indigenous sources of information, (b) *learning* some features of local Indigenous cultures, (c) locating examples of Indigenous mathematizing and (d) creating a school-based support network (a.k.a. a professional learning community) among the project teachers. On the other hand, we discovered the need for teachers to *unlearn* certain Euro-Canadian ways of understanding Western mathematics and perceiving the world; ways that interfere with cross-cultural understandings found in Indigenous culture-based school mathematics. Of course, this was only if teachers had not already unlearned them. Both the unlearning and learning are summarized here.

Plurality of Mathematical Systems

Teachers need support to unlearn the idea that there is only *one* true mathematics, the one usually taught in school, and to learn that many major cultures worldwide have established mathematical systems (Aikenhead, 2017; Barta et al., 2014; Duchscherer et al., 2019; Nicol et al., 2020). The one taught in school was appropriated from the Islamic-Greco mathematics system during the early Renaissance Period, and evolved into Western mathematics with Plato's ancient Greek philosophy intact (Aikenhead, 2017; Ernest, 2016c). Therefore, Indigenous culture-based school mathematics deals with *both* Western mathematics and Indigenous mathematizing. This occurs in a way that respects their separate authenticities (Garroutte, 1999), represented by the metaphor "two-eyed seeing" (Hatcher et al., 2009).

Inclusion Is Not Enough

This refers to Jannok Nutti's stages 1 and 2 levels of instruction. Just the appearance of Indigenous content in a lesson does not meet the criteria of a proper Indigenous culture-based school mathematics' lesson. The Indigenous mathematizing must offer a clear glimpse into an Indigenous worldview or a set of protocols, *and* into a precise connection to Western mathematics content. Students should be able to explain these connections to a family member at home.

For example, one of Danielle's lesson introductions told a captivating story about an Indigenous family following traditional protocols when berry picking. Her story also introduced her grade 6 students to the number line by the questions she posed. Students translated aspects of the story's quantitative information so it made sense on a number line. There was a clear connection between the Indigenous content and a number line. (For details, see Duchscherer et al., 2019, Appendix E, lesson E-C.1.) The importance of such connections was captured by Serena's "braiding model of instructing culture-based school mathematics" (p. 66).

What Is Mathematics?

Dictionary definitions of mathematics usually succumb to the narrow view that there is only one true mathematics; for example, "a group of related sciences, including: algebra, geometry, and calculus; concerned with the study of number, quantity, shape, and space; and their interrelationships, by using a specialized notation" (Makins, 1994, p. 964). This definition has not changed significantly since the eighteenth century.

Teachers of Indigenous culture-based school mathematics need support to minimize a dictionary definition in order to maximize definitions applicable to any culture's mathematics. Here are two such definitions:

1. From cultural anthropology: mathematics is *counting*, *measuring*, *designing*, *locating*, *playing* and *explaining quantitatively* (Bishop, 1988a, 1988b; Lunney Borden, 2019).

These are all fundamental activities that naturally engage students when Indigenous mathematizing is being learned, or when Western mathematics is being taught in an action manner consistent with an anthropological definition of the subject.

2. From a sociological perspective: mathematics is "a symbolic technology for creating relationships between humans and their social and physical environments" (Bishop, 1988b, p. 146).

Emphasis here is placed on relationships between humans and the world around them (i.e., their culture). This definition harmonizes with an Indigenous worldview in which relationships are paramount, as well as with most students' idea of relevance (Barta et al., 2014).

These last two definitions assert an understanding of *mathematics as a human endeavour*; one of the Saskatchewan mathematics curriculum's four goals; the other three being logical thinking, number sense, and spatial sense. Learning mathematics as a human endeavour sparked Carrot River students' engagement in their mathematics classes, as witnessed by their teachers. (For more details, see Duchscherer et al., 2019, p. 63.) Learner engagement generally leads to greater in-depth understanding.

Unlearning Plato's Philosophy of Mathematics

Plato's deductive axiomatic mathematics logic of theorem building works well, but only because of its internal consistency anchored by agreed upon axioms. Plato's philosophy also posits the axiomatic belief that the universe is comprised of mathematical abstract objects that have been *discovered* rather than being *invented* by the human mind. This belief precipitates a contentious debate on the internet even today. However, I suggest that anthropologist Hall (1976) has successfully discredited the Platonist perspective when he asserted that 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*" (p. 192, original emphasis). Plato's internalized culture was a notable sector of the ancient Greek intelligentsia.

Germane to mathematics education, several other tenets of Plato's philosophy deny mathematics being a human endeavour; for instance: the belief that pure mathematics is *value-free*, *unrelated to culture* and *non-ideological* (Aikenhead, 2017). The origin of this belief dates back to the ancient Greek cult of Pythagoras (about 500 BCE), made popular by Plato (about 400 BCE), only to resurface when elite Renaissance scholars appropriated Islamic-Greco mathematics in a way that valorized Plato. Later in about 1850, Plato's philosophy became ensconced in public education in Canada because the educo-politicking by elite university mathematics departments was more effective than the business community's and humanistic educators' educo-politicking (Aikenhead, 2017).

Because of its powerful pervasive influence on the general public today, Plato's philosophy becomes most important in the educo-politics of Indigenous culture-based school mathematics. For this reason, Plato's pure mathematics is scrutinized here. Challenging Plato's philosophy, Ernest (2016a) explained how pure mathematics is *value-laden*, not value-free. Mathematicians are constantly guided by the values of "truth, rationalism, universalism, objectivism, beauty, 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).

Plato's pure mathematics tends to treat others according to the ideologies of *superiority*, *dominance*, *quantification and purism* (Ernest, 2016b). In general, ideologies are doctrines that determine how people or

institutions treat others. Teachers need support in (a) identifying these four ideologies, and then (b) analyzing each one for how they influence mainstream Canadian culture, as well as for possible negative consequences in their classrooms. For instance, teachers should ask themselves which of these ideologies:

1. encourage the belief there is only one true mathematics?
2. cause the social consequence of Indigenous students feeling marginalized in mathematics classrooms; and thus, restricting them to a greater extent from graduating from high school compared to their non-Indigenous counterparts?
3. assert with social and political power the doctrine that quantified knowledge is the only worthwhile knowledge in Canadian society? and
4. establish a power hierarchy between pure mathematics and impure (applied, everyday) mathematics?

Consider Lakota Elder Deloria's (1992) analysis. "What could be more superstitious than to believe that the world in which we live and where we have our most intimate personal experiences is not really trustworthy, and that another mathematical world exists that represents a true reality?" (p. 40).

A superiority ideology of some mathematics educators was identified by Mukhopadhyay and Greer (2012):

> The development of a multicultural and humanist view of mathematics 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)

An unconscious ethos of embracing the four ideologies (superiority, dominance, quantification and purism) is detrimental to many Indigenous and non-Indigenous students' engagement in school mathematics. Therefore, the policy to implement Indigenous culture-based school mathematics becomes stronger. Moreover, because the cluster of these ideologies mirrors characteristics of cultures, Plato's pure ideal mathematics can be seen as a subculture of mainstream Canadian culture, and thus, it has cultural features. Bang and Medin (2010) offer a pragmatic notion of the term "culture" that fits well with the goal of culture-based school mathematics.

> Although the construct of culture is problematic, people nevertheless "live culturally"…[by way of] a wide repertoire of sense-making practices that people participate in, particularly in everyday contexts. …This understanding of culture implies that there is no cultureless or "neutral" perspective any more than a photograph…could be without perspective. In this sense, *everything is cultured*. (pp. 1014–1015, emphasis added)

One subversive and effective political feature of Plato-based mathematics is *masking* its socio-political power by claiming an innocence of its rationalism, objectivism and purism. Consider, for instance, the difference in graduation rates between Indigenous and non-Indigenous students based on the proportion that completes grades 10–12 in three years. In 2018, the figures for Saskatchewan were 86 and 44 percent, respectively (Canadian Press, 2019). Mathematicians refer to the Plato-based mathematics equation (86 – 44 = 42) as an objective way to describe "the gap" between the two graduation rates. This equation is an example of pure mathematics, but the event does not stop there. The answer "42" was labelled "a gap," which evokes a deficit among Indigenous students. Pure mathematics has masked its power by an assumed purism in (86 – 44 = 42).

A critical analysis of the above leads to a plethora of other reasons lying behind the answer "42;" for instance: colonization, intergenerational trauma from residential schools and ubiquitous racism. Notice how a simple pure mathematics calculation produced both a number and simultaneously exerted the social power of conferring a deficit. Mathematics teachers need support to critically analyze Western mathematics'

invisible subjective power to influence political and social consequences. Learning to be critical thinkers concerning these four ideologies is supported by learning to avoid subtle appropriation and learning to embrace two-eyed seeing; the next two topics.

How to Avoid Subtle Appropriation

Many teaching modules have been developed specifically for Polynesian and Yup′ik students in Hawai′i and Alaska, respectively, to improve students' standardized test scores based on the US's Common Core State Standards. (See Aikenhead, 2017, pp. 104–118, for a review of this literature.) These Polynesian and Yup′ik teaching materials unfortunately have an unintended habit of consistently and subtly appropriating Indigenous knowledge, due to an unconscious Eurocentric ideology that bestows inferiority to Indigenous mathematizing.

The rightful legitimacy of the Indigenous knowledge is thereby ignored by these mathematics educators who describe an Indigenous idea or pattern by using a European word, which can only have a European meaning and not an Indigenous meaning. This eliminates the original meaning of the Indigenous idea or pattern. Thus, its *meaning* and *legitimacy* have been appropriated by these mathematics educators. In Canada's era of reconciliation, this is a notable flaw (Aikenhead, 2017). As a consequence, Indigenous students "may implicitly or explicitly, come to question the motives of teachers who lead them away from the true complexities of their cultures" (Doolittle, 2006, p. 20). (See Duchscherer et al., 2019, pp. 51–56, for many examples of subtle appropriation.)

A more in-depth understanding of subtle appropriation can be achieved from Einstein's (1930) fundamental insight into the process of observing (translated in Director, 2006). It helps explain a mechanism by which subtle appropriation occurs:

> 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 independent pre-observation form constructed in our minds plays a pivotal role in perception.

For example, suppose an Indigenous student came to school with a bracelet she beaded herself. Intending to complement her *and* to introduce today's geometry lesson, the teacher exclaimed to the class, "Helayna has a beautiful bracelet she made all by herself. Look at its colourful right triangles. Today we're going to learn about many kinds of triangles." Helayna would likely feel perplexed. She would think to herself, "Those coloured patterns are four sacred Medicine Wheel colours. The patterns are called "ē-nistwāpiskēk" (Plains Cree) that means: "it goes with three sides." Ē-nistwāpiskēk is found in certain patterns of flower petals, a gift from Mother Earth. Ē-nistwāpiskēk is not a triangle!

Obviously, the teacher and Helayna hold two very different ideas about what the bracelet's patterns mean: triangles versus a spiritual representation connected to the land. More importantly, however, *the mathematics teacher has just unknowingly appropriated the Indigenous meaning of Helayna's bracelet*. The teacher showed a lack of understanding, and thus, a lack of respect shown to Helayna.

Exactly how did the teacher unconsciously do this? There seems to be four consecutive processes at work. (See Aikenhead, 2017, [pp. 122–124] for a linguistic explanation.)

1. When viewing the bracelet, the teacher recalled an image of a Western mathematics right triangle as Einstein explained, and then
2. The teacher's mind superimposed that image onto a section of Helayna's artifact.
3. Because there is a good enough fit, the teacher's mind deconstructed that section of the artifact by:

a. focusing only on features that best fit a right triangle image, and
b. ignoring other features of the bracelet (e.g., the repetitions of only four colours) and its relationship to certain flower petals.

4. By ignoring those other features, the teacher's mind has reconstructed a Western geometric shape (a right triangle) in Helayna's Indigenous artifact.

What we call "subtle appropriation" happens when our minds deconstruct, for example, an Indigenous artifact pattern and reconstruct a geometric shape in its place. The two processes strip the artifact of its original Indigenous meaning and replace that meaning with a Western mathematics meaning (i.e., a right triangle, along with all its Platonist connotations). In short, this appropriation process is image recall, superimposition, deconstruction and reconstruction.

The teacher's subtle appropriation could have been easily avoided by asking Helayna what her artifact means to her. In Carrot River, grade 5 students quickly learned to recognize when they knew or did not know the original Indigenous meaning of Powwow regalia patterns, for instance. They became comfortable acknowledging they did not know, which is a respectful way to handle the situation (Duchscherer et al., 2019).

Two-eyed Seeing

By clearly making an explicit distinction between an Indigenous meaning of a beading pattern and a Western mathematics meaning of a geometric shape, a teacher is engaging in two-eyed seeing (Duchscherer et al., 2019; Hatcher et al., 2009). This entails learning the strengths of both Indigenous mathematizing and Western mathematics, and then idiosyncratically drawing upon either knowledge system. "Culture-based mathematics teachers teach the integrity of both ways of doing mathematics. Students decide which way of knowing (or which combination of ways) they will draw from in any situation that presents itself" (Duchscherer et al., 2019, p. 59). Classroom examples are also found in Duchscherer et al. (2019).

Rather than commit subtle appropriation, the project's co-researching teachers either added one more Indigenous idea to their students' funds of Indigenous knowledges, or alternatively, they acknowledged that they did not know the Indigenous meaning. They always kept the Western idea associated with only Western mathematics (Meyer & Aikenhead, 2021b).

Two-eyed seeing also encourages teachers to unlearn the habit of only reasoning analytically and dichotomously (i.e., either x or y). It opens a person's mind to understand holistic thinking (i.e., some of both x and y) endemic to Indigenous rationality. This creates mutual understanding that leads to intercultural respect; the core to reconciliation according to the TRC's (2016) call to action, "Building student capacity for intercultural understanding, empathy, and mutual respect" (p. 180).

Simply put, both systems coexist, and each system belongs to a separate coherent knowledge system (Garroutte, 1999). Two-eyed seeing is a crucial mindset (Dweck, 2006) that teachers need support to achieve it and to maintain it. This ensures that reconciliation is alive in a mathematics classroom.

Teachers' Conclusions

At the end of the project in June 2019, Serena, Danielle and Kevin were interviewed individually (Krysta was on maternity leave) by two Indigenous consultants employed by two different school divisions (Duchscherer et al., 2019). This provided information independent of the researchers. The following is a succinct synopsis of those interviews:

Adamantly, all three teachers emphasized the following five points:

1. Culture-based teachers must first and foremost be learners; including to learn *with* their students.
2. Culture-based teachers first require a substantial culture immersion experience.

3. Mentoring by school division consultants, Indigenous knowledge holders or Elders is a necessary but insufficient key to success.
4. The depth of a student's personal engagement determines the degree of their success at learning mathematics.
5. A major roadblock to implementing culture-based school mathematics is the highly restrictive, overcrowded, outdated curriculum to be taught (p. 63).

Researchers' Conclusions

The word "reconciliation" is a noun. But in their classrooms, the Carrot River teachers' Indigenous culture-based instruction turned the word into a verb. The most succinct answer to the research question, "What is the needed support for teachers implementing Indigenous culture-based school mathematics?" is four-fold:

1. A revised mathematics curriculum,
2. Saskatchewan authentic teaching materials,
3. A professional development experience for implementing Indigenous culture-based mathematics, and
4. A culture immersion to begin that journey.

The TRC's (2016) calls to action specifically included "developing culturally appropriate curricula" (p. 165). This entails renewing Saskatchewan's mathematics curriculum in two ways: (a) include Indigenous mathematizing from time to time by giving more attention to "mathematics as a human endeavour," a Saskatchewan curriculum goal, and (b) delete obsolete and the least necessary content to free up time for teachers to innovate with Indigenous culture-based instruction.

It became apparent that two occasions of *creating and revising* a lesson plan, in collaboration with mentors, was sufficient experience for teachers to feel competent to continue the project the following year as a professional learning community. Principal Sari specifically noted "the project's sustainability" (Duchscherer et al., 2019, p. 4). Therefore, lesson planning accompanied with feedback is a particularly rich context for advancing a teacher's journey into school mathematics for reconciliation.

The R&D project is also a template for scaling up the process to a province-wide level to produce the much-needed teaching materials authentic to Saskatchewan. Scaling up would require more personnel, greater efficiencies and attention paid to the five Indigenous languages in Saskatchewan (Duchscherer et al., 2019).

To become a successful Indigenous culture-based teacher, the Carrot River teachers *unlearned* the notion that pure mathematics exists independently of humans, and they *learned* several important ways in which it is a human endeavour. For example:

1. Teachers set aside the Eurocentric ideology of superiority to unlearn subtle appropriation, in order to make way for developing a capacity for two-eyed seeing.
2. Teachers unlearned Plato's philosophy of pure mathematics (e.g., the belief that it is value-free) and then learned some of the values and ideologies embraced by Western mathematics.

Epilogue

An educo-political strategy used by Platonist proponents to stifle humanistic innovations in school mathematics includes masking their socio-political power with innocence (McKinley, 2001); an innocence associated with their claiming to be objective, value-free, ideology-free, universal and free from cultural

influences (Aikenhead, 2017). Their allegiance to Plato's philosophy of mathematics arises mostly from 12 years of using textbooks that attempt to indoctrinate a mathematician's mindset, attractive to only the math-interested, math-curious and math-oriented learners. In the past, Platonist proponents have also masked their power by appealing to academic conventions. But these have amounted to "systemic racism" (p. 77), for example, asymmetric graduation statistics between Indigenous and non-Indigenous learners, or more subtly, what British Columbia's Auditor General called "the racism of low expectations [of Indigenous learners]" (Bellringer, 2019, p. 23).

However, the educo-politics in Saskatchewan's school mathematics recently moved in a positive direction toward Indigenous culture-based school mathematics. The Saskatchewan media paid attention to the R&D project summarized in this article (CBC News, 2019; EFN Staff, 2019; Giesbrecht, 2019). This attention coincided with the Provincial Education Sector[6] establishing a twelve-member executive committee to organize and manage a working group of about 45 mathematics teachers (grades 1–12) and school division consultants, all chosen for their expertise. The working group's task was to develop the content for the website called "SaskMATH" (Provincial Education Sector, 2020), comprised of evidence-based best practices for teaching number sense and mathematics as a human endeavour. The Sector associated "human endeavour" with "Indigenous ways of knowing" for the SaskMATH project, and mandated the latter be integrated throughout SaskMATH where ever possible. This mandate represents a humanistic and culturally responsive approach to school mathematics.

Sharon and I were appointed to the executive committee. Our tasks included conducting professional development for the working group, developing material for the website, helping edit the final version and participating in the working group's deliberations held during six-day-long meetings over five months, face-to-face and videoconferencing.

The working group showed an enduring commitment to including Indigenous perspectives in school mathematics. For instance, they quickly learned to spot subtle appropriation in teaching materials on the internet.

As I collaborated with them, two reasons became apparent for why many teachers, province wide, may be discouraged from attempting Indigenous culture-based school mathematics. First, there is a paucity of ready-to-use Saskatchewan teaching materials, either booklets for learners to read in English (e.g., *Akaguagaankaa*, one of many Math in a Cultural Context's booklets—https://www.uaf.edu/mcc/culture-and-math/modules/) or bilingual booklets for rejuvenating Indigenous languages, such as Thigpen and Canul's (2018) Meso Caribbean marine ecology booklets that teach both Western and Indigenous ways of knowing the ocean. Alaska's Math in a Cultural Context project is beginning to develop lesson plans now, similar to the seven sets of lesson plans developed in the Carrot River study, or perhaps similar to the many isolated examples across Canada of individual teachers creating their own lessons enhanced with Indigenous ways of knowing, of which only their community is aware. But as mentioned above, the Saskatchewan project also provides a template for ministries of education to produce appropriate teaching materials. It would be adequate to have two or three lesson plans developed for each semester at each grade level. These could be translated into a province's major Indigenous languages, as currently being accomplished in the Meso Caribbean project.

A second reason that many teachers may be discouraged to take the time to innovate with SaskMATH Indigenous ideas is due to the province's highly overcrowded curriculum that demands much time from teachers.

The chances of establishing a degree of Indigenous mathematizing in the curriculum are greater when credible advocates for enhancing school mathematics with Indigenous perspectives are positioned more favourably than Platonist detractors are, in a Sgt. Jablonski-esque sort of way.

An Indigenous culture-based school mathematics storyline will evolve in CJSMTE over the next 20 years as Saskatchewan and other provinces renew their mathematics curricula to meet Canada's twenty-first

[6] The Provincial Education Sector is a consortium of the Ministry of Education with 28 Boards of Education across Saskatchewan.

century realities for all learners, but mostly for the approximately 70 percent of today's math-phobic, math-shy and math-disinterested learners, especially for those of Indigenous ancestry.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

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