Out-of-School, Applied, In-School, and Indigenous Mathematics

Glen Aikenhead

Introduction

High school mathematics teacher Mr. Hazelton was lying in his hospital bed, waiting for his nurse to calculate his dose of medication. Feeling apprehensive, he Googled "mathematics proficiencies of nurses" and found several articles of interest. Perlstein and colleagues (1979), for example, discovered that the mean score on standardized test items for 95 practising pediatric nurses was 77% with a range from 45% to 95%. More recently, Brown (2002) reported a mean score of 75% on a standardized mathematics test among 850 nursing students across Canada and the U.S., and Özyazıcıoğlu and colleagues (2018) found that the third-year nursing students in their study scored 79% on ratio and proportion questions. Should Mr. Hazelton be worried, faced with these somewhat discouraging results?

His mathematical mindset made him worry. "This lack of mathematical literacy [by nurses] has often been included as part of the widespread debates regarding the instances of nurse prescription errors, sometimes resulting in serious patient injury or even death" (Jarvis et al., 2015, p. 1). Despite his apprehension, when Mr. Hazelton's medication arrived, he nervously swallowed it. And, to his great relief, everything turned out well. Was he just lucky? It turns out that Mr. Hazelton had no reason to worry. His positive result with the medication was, in fact, the outcome with the highest probability, for reasons that will soon become clear.

> Typically, mathematicians' mindsets are biased towards the Platonist system of an ideal, hypothetical and abstract world.

What led to Mr. Hazelton's worries? His narrow mathematical mindset did not take out-of-school mathematics into account. Typically, mathematicians' mindsets are biased towards the pure mathematics system dictated by our curriculum—the Platonist system of an ideal, hypothetical and abstract world. Perhaps Mr. Hazelton, our fictional representative mathematics teacher, needs to learn about out-of-school mathematics, retool his mindset, and consider the positive implications for his classroom teaching. Before doing so, however, we need to better understand Mr. Hazelton's point of view.

In-School Pure Mathematics

Today, Plato's ideas about mathematics directly and indirectly exert enormous influence throughout Western cultures in general, and over mathematics education in particular (Ernest, 2019; Linnebo, 2018). In essence, Plato's philosophy celebrates the purity of the mind while holding worldly matters in contempt. It contends that mathematical ideas existed before humanity existed, and that therefore, these ideas have been *discovered* by mathematicians. This shields mathematics from any doubts expressed about the truth of its conclusions, the ethics of its influence, and the ethics of mathematicians (Ernest, 2018).

From Plato's philosophical axioms, he and his followers logically deduced "truths," which include the beliefs that mathematics is value-free, culture-free, non-ideological, purely objective in its use, generalizable, and universalist—in other words, the only acceptable mathematics system (Ernest, 2016a,b). Notice that the above list of fundamental features has nothing to do with the role of people in mathematics, conveying a message implied in most mathematics textbooks: mathematics is separate from the human condition. These features express "the antithesis of human activity—mechanical, detached, emotionless, value-free, and morally neutral" (Fyhn, Sara Eira, & Sriraman, 2011, p. 186). No wonder learners who have a humanistic outlook on life assess school mathematics as uninteresting or even objectionable.

Plato's ideas have stiff competition from mathematicians and mathematics educators who contend that humans are the source of mathematics. They oppose the narrowness of the age-old (24-century-old, to be exact) Platonist view conventional in school mathematics (e.g., Ernest, 2016a,b; Ernest, Sriraman, & Ernest, 2016; Sriraman, 2017). Take, for instance, the Platonist claim that mathematics is culture-free. Anthropologist Hall (1976) asserted that Plato's concept "purity of mind" (p. 192) and his philosophical assumption that the universe is made up of abstract mathematical objects that mathematicians discover amounts to an intellectual mirage: *"What has been thought of as the mind is actually internalized culture"* (p. 192, original emphasis). In other words, mathematics can be described as a *cultural* enterprise, a position that contradicts the messages conveyed by most mathematics curricula that indirectly promote Plato's philosophy.

> Plato's ideal of pure mathematics is not only cultural, it is value-laden, ideological, and with degrees of subjectivity in its use.

It turns out that Plato's ideal of pure mathematics is not only cultural, it is value-laden, ideological, and with degrees of subjectivity in its use (Ernest et al., 2016; Larvor, 2017). More specifically, Western mathematics is guided by such ideologies as superiority, purism and quantification, and embraces values such as truth, rationalism, universalism, objectivism, and beauty. While we may speak of the *culture of Western mathematics*, Platonists insist that their mathematics is the *only* true mathematics, and that it is culture-free. Consequently, they strongly object to it being called "Western."

Out-of-School Mathematics

A well-known research study by Hoyles, Noss and Pozzi (2001) illustrates out-of-school contextualized mathematics located in the real world, and not in Plato's purity of the mind. Setting aside the ideology[1] of quantification (e.g., the doctrine of letting test scores and their means control humans and their society), they decided to spend a total of 80 hours on the ward with 12 pediatric clinical nurses to observe nurses as they prepared dosages for their patients, watching carefully to see how many mistakes they make. During their visits, the researchers observed 30 instances of drug administration that involved 26 different types of ratio calculations. Their conclusion? Zero mistakes. Mr. Hazelton's positive outcome in the hospital really *was* predictable. Hoyles and colleagues concluded, "Most nursing literature on drug calculation…in mathematics education focused on individual performance on '*decontextualized*' written tests" (p. 11, emphasis added). These pediatric nurses' 30 calculations, however, were all *contextualized* in the reality of a hospital ward.

Obviously, these results (75% to 79% versus 100%) suggest that abstract, decontextualized mathematics (mostly in-school mathematics) must be significantly different from concrete, contextualized mathematics (mostly out-of-school mathematics). The two types of knowledge have also been referred to as "declarative" and "procedural" (Chin et al., 2004).

[1] In general, an ideology is a doctrine that tells people or institutions how to treat others.

Mr. Hazelton's worry, then, suggests that he had a blind spot in his mathematical mindset: While he paid attention to the declarative research results, he did not consider the nurses' procedural mathematics proficiency and therefore underestimated their mathematical ability.

What kind of contextualized proportional reasoning did the clinical nurses actually use? Their professional training provided them with specific procedures to be used in the workplace. Here is one such algorithm (Hoyles et al., 2001):

The actions that a nurse would perform in identifying and handling three quantities when preparing a drug: Look at the drug dose prescribed on the patient's chart ("what you want"); next note the mass of the packaged drug on hand ("what you've got") and then the volume of solution ("what it comes in"). (p. 13)

Selden and Selden (n.d., website quote) translated this on the Mathematical Association of America website as:

$$\frac{Drug\ prescribed}{Dose\ per\ 'measure'} \times Number\ of\ measures$$

Mathematicians' mathematical mindsets may lead them to see the nurses' procedural proportional reasoning from a purely algebraic perspective as:

$$Dosage = \frac{w \cdot v}{g},$$

where w is *w*hat you need, v is *v*olume of solution, and g is what you've *g*ot.

Notice that while the three algorithms (i.e., the nurses', Selden and Selden's, and the algebraic one) are expressed in three different languages, they share a similar meaning. However, they are not the same. Similar to their research with nurses, Hoyles and colleagues (2001) investigated the practices of investment-bank employees and commercial pilots. They discovered a similar disconnect between these employees doing decontextualized (declarative) mathematics and performing contextualized (procedural) mathematics. According to the behaviour of these people who do out-of-school mathematics, they use a different type of knowledge than in-school mathematics people do (i.e., procedural vs declarative, respectively).

Further insight comes from Devlin's (2005) research into the "street mathematics" of school-aged children who work as street market vendors in a third-world country. With permission, the researchers unobtrusively listened to the vendors as they interacted with their customers. The purpose was to assess the accuracy of the children's out-of-school, contextualized, street mathematics. It was found to be consistently accurate more than 98% of the time. Next, the researchers had each street vendor do some typical in-school decontextualized mathematics. The results were as follows:

They averaged only 74% when presented with [textbook-like] market-stall word problems requiring the same arithmetic, and a mere 37% when *virtually the same problems* were presented to them in the form of a straightforward arithmetic test. (website quote, emphasis added)

Context matters! In-school mathematics (i.e., abstract Platonist mathematics devoid of context) is a different kind of knowledge than out-of-school mathematics (i.e., reality-based mathematics immersed in context), for most, but not necessarily all learners.

Did you notice that mathematician Devlin belies a strong Platonist bias in judging the two situations as "virtually the same problems"? From the young market vendor's perspective, however, they are obviously *not* the same. In my view, we have found a blind spot in Devlin's mathematical mindset, similar to Mr. Hazelton's blind spot. Devlin does not seem to understand the vendors' mathematical perspective: in other words, the concept of out-of-school procedural mathematics. Perhaps that is due to the Platonists' insistence that their mathematics is the only true mathematics.

Most elementary teachers do not have such blind spots, moving back and forth from out-of-school to in-school mathematics daily. This is a matter of common sense to the teachers. This is because most elementary teachers know that most of their learners *must* be taught mathematics in context (Hill et al., 2008), where "mathematics becomes best understood by how it is used" (Barta et al., 2014, p. 3). Otherwise, learning rarely occurs. They therefore relate their learners' world (out-of-school mathematics) to the curriculum content, the latter being written in a vocabulary of abstract in-school mathematics, (e.g., quantity, patterns, sorting, shape and space). This learning is aided by visuals, manipulatives, and through play for the youngest learners (Brokofsky, 2017).

> Most learners must be taught mathematics in context, where mathematics becomes best understood by how it is used.

Out-of-school mathematics is typically encountered in three cultural venues: home, community, and employment in most workplaces *not* requiring mathematics specialists highly proficient in algebra, geometry, and calculus. For instance, Martin (2014) and Tencer (2016) identified the following as the highest-paying jobs for people who hate mathematics: business managers, bank clerks, financial advisors, office workers, sales people, many health care workers, therapists, most trade workers, university professors of humanity subjects, lawyers, police officers, many entrepreneurs, and power plant operators, to name a few.

Applied Mathematics

Mathematics teachers often talk about *applying* the curriculum's in-school pure mathematics to out-of-school contexts. But how much does this make sense, now knowing that nurses, financial advisors, commercial pilots, and street vendors, for instance, master concrete procedural mathematics directly on the job? *Applying* abstract pure mathematics, it turns out, is not necessary for them. In fact, it could be risky. Recall how well nurses and street vendors did on their decontextualized in-school pure mathematics tests.

Who *does* apply pure mathematics, then? And how do they do it, exactly? In general, scientists, engineers, mathematics teachers, architects, medical doctors, and some mathematicians apply pure mathematics on the job. In fact, anyone can do it, as long as their worldview or self-identity happens to harmonize with that of a mathematician to a sufficient degree (Nasir, 2002). However, without being familiar with the research, math-oriented people such as our fabled Mr. Hazelton are likely to *assume* that nurses, financial advisors, and pilots also apply pure mathematics at work. Why do they assume this? Here are several potential reasons:

1. They have a mathematical blind spot. They do not sufficiently understand out-of-school mathematics or humanistic self-identities.
2. They subscribe to a Platonist ideology of purism, which favours purity over practicality, and assigns high status to pure abstract mathematics and low status to applied mathematics. And, after 12 years of reading this message conveyed in textbooks and hearing it from some secondary school teachers, most of the general public accepts the ideology of mathematical purism as part of their mainstream Canadian culture, without critically thinking about the ethics of doing so (Ernest, 2016b, 2019).
3. Their worldview enables them to "see" abstract, pure mathematics in the world around them. To them, this lens is just common sense, and they assume that anyone can do it. They are oblivious to their unconscious mental act of projecting pure mathematics concepts onto the world around them, a process that mathematicians call "applying mathematics."
4. They are unfamiliar with the mechanism for applying mathematics consciously or unconsciously, a process that has four steps: recalling, superimposing, comparing, and judging (or three steps: "superimposing, deconstructing, and reconstructing"; Aikenhead, 2017, p. 101). It proceeds as follows:
    a. Their mind invents *images* of mathematical abstractions they have learned (Einstein, 1930; quoted in Director, 2006), which are *recalled* as a result of seeing features in the real world.
    b. They *superimpose* a recalled image onto that feature.
    c. They *compare* their mind's image and the observed feature.
    d. Their mind *judges* the closeness of fit between the two. When there is a close enough fit, the person identifies that feature in terms of the image superimposed on it, which in turn is associated with the original mathematical abstraction. Voilà: The abstraction is perceived in the real world.

When you are conscious of these steps, you have a realistic in-depth understanding about what "applying math" means. Note that step 4.a above, which involves inventing images of mathematical abstractions, can be very challenging for the majority of Saskatchewan high school graduates (as explained below), and largely irrelevant outside of school. Being conscious of this fact helps you avoid Mr. Hazelton's and Professor Delvin's blind spot. At work, rather than applying an abstraction, a person's mathematical procedural knowledge is most often recalled or further refined in order to get a specific job done. Out-of-school mathematics has meaning in relation to a concrete task and, likely, to many personal and idiosyncratic associations. Abstractions, however, are universal by definition. However, they can sometimes only get in the way of completing a task efficiently.

> The prerequisite to applying pure mathematics is to have understood in depth the abstract concept in the first place.

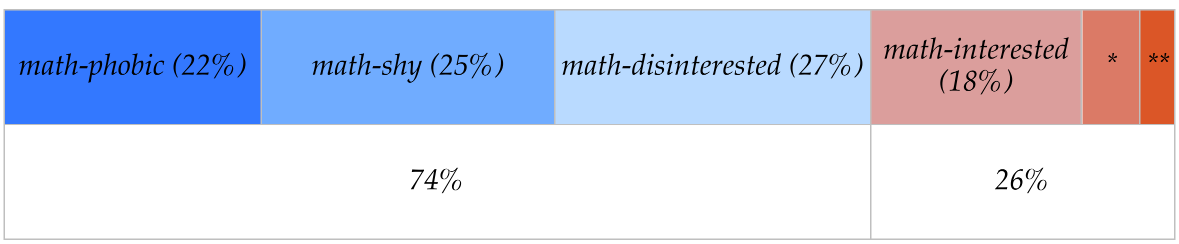
The most important thing to remember about the act of unconsciously applying pure mathematics is that the prerequisite is to have understood in depth the abstract concept in the first place (from which the human mind constructs a representative image; Einstein, 1930). However, this deep understanding is only available to learners to the extent that their worldview or mathematical self-identity harmonizes with a mathematician's (Nasir, 2002).

Mathematical Mindsets: Students *vs* Mathematicians

Learners whose worldviews tend not to harmonize with a mathematician's worldview to various degrees comprise about 70-74% of high school graduates in Saskatchewan, and include future nurses, financial advisors, and pilots (Card & Payne, 2017; Meyer & Aikenhead, 2021a). To varying degrees, these high school graduates tend to be interested in the humanities and tend to have negative predispositions to pure mathematics. Indeed, an AP-AOL News poll conducted by Ipsos (2005) found that about 37% of young adults "hate math" (p. 2). According to the same poll, only 23% of adult respondents stated that mathematics was their favourite subject, while 51% chose a humanities subject as their favourite. On the surface, this polling result does not make secondary school mathematics look good. However, we need to look deeper.

Imagine a spectrum of learner diversity. At one extreme are learners whose worldviews and self-identities (Nasir, 2002) generally harmonize with that of their mathematics teacher (the right-hand side of Figure 1). At the other extreme are learners who often develop serious psychological or physiological anxieties when forced to think mathematically, especially when being assessed (Ernest, 2018; Maloney, Fugelsang & Ansari, 2016). Figure 1 is structured in line with PISA's six student proficiency levels (OECD, 2019) to avoid simplistic dichotomous reasoning.

Figure 1. Distribution of Saskatchewan Grade 12 learners' degrees of harmony between their self-identities and mathematicians' worldviews. Not for streaming learners. The percentage proportions of learners in each category arise mostly from PISA 2018 proficiency data, bounded by other research sources. Source: Meyer and Aikenhead (2021a).



* *math-curious* (5%)
** *math-oriented* (3%)

These six categories must be treated as being very flexible and tentative, because learners' designation to a category depends on many changeable factors (e.g., the teacher, topic, grade level, classroom environment, degree of past success, season, etc.). The categories have been proposed for the purpose of discussing learner diversity, and certainly not for streaming purposes. Fine distinctions between them are not made in this article.

Figure 1 shows the percentage of learners likely to be in each of the six categories, primarily based on PISA 2018 data (OECD, 2019) and modified by Meyer and Aikenhead (2021a) to conform with data published in the research literature (Card & Payne, 2017; Frederick, 1991). The data create a skewed distribution of learners in favour of those who would avoid high school mathematics if they could. This spectrum of learner diversity produces several notable issues to consider.

Even though the math-phobic, math-shy, and math-disinterested learners generally do not perform well on mathematics tests, they can excel at doing a small number of specific kinds of mathematical tasks (Louie, 2017). These could be cultivated by their teacher, of course. In line with Boaler's (2015) "growth mindset" discussions, learners can move towards the right side of Figure 1 (Boaler & Confer, 2017), even if not far enough to "learn math to the highest levels" (youcubed at Stanford University, 2020, p. 1). My experience tells me, however, that many teachers seem to believe this youcubed message on its commercial website. To me, this expectation seems an unfair burden for teachers to bear. Still, teachers should strive to understand and empathize with the math-phobic, math-shy, and math-disinterested learners and learn how to communicate more effectively with these learners so as to help them develop a more positive mathematical mindset.

> Teachers should strive to understand, empathize with, and communicate more effectively with the math-phobic, math-shy, and math-disinterested learners.

One of the goals of the Saskatchewan curriculum is "understanding mathematics as a human endeavour" (Saskatchewan Ministry of Education, 2008, p. 9). This goal opened the gate, so to speak, to include Indigenous ways of knowing in a recently constructed provincial mathematics pedagogical resource for teachers and leaders of mathematics in Saskatchewan entitled *SaskMATH* (Provincial Education Sector, 2021, website quote). It is legitimate, therefore, to treat Indigenous mathematizing as out-of-school mathematics content with which to enhance your mathematics classes and reach even your most math-phobic learners. You will be surprised to discover how many humanistic contexts there are in which students can engage with mathematics in their real world (Aikenhead, 2021a,b).

Indigenous Mathematizing and Perspectives

Out-of-school mathematics is related to Indigenous mathematizing because each is preoccupied with procedural knowledge. In other words, they share a focus on getting a job done. However, they differ in the type of understanding that results: intellectual versus wise, as explained later in this section. The term "mathematizing" is used because Indigenous languages are "verb-based" (Aikenhead, 2017, p. 87), whereas Western languages are noun-based. This cultural difference is respectfully acknowledged and accurately described by the verb "mathematizing," in keeping with an anthropological definition of mathematics for any culture: counting, measuring, locating, designing, playing, or explaining quantitatively (Bishop, 1988, pp. 147-151).

Traditional Indigenous mathematics systems continue today, expressed through actions. A McDowell Foundation research report (Duchscherer et al., 2019) describes Grade 5-12 students at Carrot River engaged in the following mathematizing activities, each associated metaphorically with curricular content (shown in brackets along with the name of the lesson creator):

1. pow-wow dancing and beading (polygons; Serena Palmer);
2. playing games (probability and combinatory logic; Danielle Vankoughnett; and two-dimensional spatial reasoning using problem solving strategies; Kevin Duchscherer);
3. hand drumming (multiplication; Serena Palmer);
4. looming (probability trees; Krysta Shemrock);
5. berry picking (number line; Danielle Vankoughnett);

Project leader and knowledge holder, Sharon Meyer, produced three videos that exemplify Indigenous mathematizing. Two are excerpts from exemplary Indigenous culture-based mathematics lessons she taught, which involve birch-bark biting (angles and symmetries) and dream catcher construction (polygons and two-eyed seeing), respectively.

The project report identifies various kinds of supports that teachers need in order to collaborate to produce high quality, Indigenous mathematizing lessons that connects with specific curriculum entries. The report also identifies what teachers need to learn if they have not already, as well as what they may need to *unlearn* in order to facilitate these lessons in a manner that is faithful to their intent.

Conclusion

Indigenous mathematizing shares some values with Western mathematics (e.g., truth, beauty, and the human desire to make sense of the world). However, the two mathematical systems rely upon completely different ways of knowing. While understanding Western mathematics is accomplished according to the *intellectual* tradition of understanding, which is mainly linear, reductionist, analytical, and resides in the brain, understanding Indigenous mathematizing is accomplished through the *wisdom* tradition of understanding—a holistic balance engaging the intellectual, emotional, physical, and spiritual dimensions of the medicine wheel (i.e., the brain, heart, body, and soul).

A concept of importance to Indigenous culture-based school mathematics is *two-eyed seeing* (Hatcher et al., 2009). It means to learn the best from each system, and then use either one, or a hybrid of both. In doing so, we must take care to maintain the cultural authenticity of each system (Garroutte, 1999), lest the Platonist ideology of superiority infringes on the equity spirit of two-eyed seeing, as witnessed during European colonization (Bishop, 1990). However, the effort is worthwhile, as inviting Indigenous mathematizing into the classroom may help math-phobic and math-shy learners give greater attention to relevant curriculum content (Meyer & Aikenhead, 2021b) and thereby move toward a more positive mathematical mindset.

References

Aikenhead, G. S. (2017). Enhancing school mathematics culturally: A path of reconciliation. *Canadian Journal of Science, Mathematics and Technology Education, 17*(2: Special Monograph Issue), 73-140.

Aikenhead, G. S. (2021a). A 21st century culture-based mathematics for the majority of students. *Philosophy of Mathematics Education Journal*, *37*(in press).

Aikenhead, G. S. (2021b). Resolving conflicting subcultures within school mathematics: Towards a humanistic school mathematics. *Canadian Journal of Science, Mathematics and Technology Education*, *21*. https://doi.org/10.1007/s42330-021-00152-8.

Barta, J., Eglash, R., & Barkley, C. (Eds.) (2014). *Math is a verb: Activities and lessons from cultures around the world*. Reston, VA: National Council of Teachers of Mathematics.

Bishop, A. J. (1988). The interactions of mathematics education with culture. *Cultural Dynamics*, *1*(2). 145-157.

Bishop, A. J. (1990). *Western mathematics: The secret weapon of cultural imperialism*. SAGE.

Boaler, J. (2015). *Mathematical mindsets*. Chappaqua, NY: Jossey-Bass/Wiley.

Boaler, J. & Confer, A. (2017). Assessment for a growth mindset. Stanford University. Retrieved from https://www.youcubed.org/wp-content/uploads/2017/03/1439422682-AssessmentPaper.pdf

Brokofsky, J. (2017). Math education aims to foster mathematical mindset among students. Saskatoon Public School Announcements. Saskatoon Public School Division. Retrieved from https://www.spsd.sk.ca/Pages/newsitem.aspx?ItemID=150&ListID=bd4dadc7-6f25-477b-9a8e-e04294db3fa9&TemplateID=Announcement_Item#/=

Brown, D. (2002). Does 1 + 1 Still Equal 2? A study of the mathematic competencies of associate degree nursing students. *Nurse Educator*, *27*(3), 132-135.

Card, D. & Payne, A. A. (2017, September). High school choices and the gender gap in STEM (Working Paper 23769). Cambridge, MA: National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w23769

Chin, P., Munby, H., Hutchinson, N. et al. (2004). Where's the science? Understanding the form and function of workplace science. In E. Scanlon, P. Murphy, J. Thomas et al. (Eds.), *Reconsidering science learning* (pp. 118-134). London: Routledge Falmer.

Devlin, K. (2005, May). Street mathematics. Center for the Study of Language and Information at Stanford University. Retrieved from https://www.maa.org/external_archive/devlin/devlin_05_05.html

Director, B. (2006). On the 375th anniversary of Kepler's passing. *FIDELIO Magazine*, *15*(1-2), 98-113. Retrieved from http://www.schillerinstitute.org/fid_02-06/2006/061-2_375_Kepler.html

Duchscherer, K., Palmer, S., Shemrock, K. et al. (2019). *Indigenous culture-based school mathematics for reconciliation and professional development*. Saskatoon, Canada: Stirling

Einstein, A. (1930, November 9). Albert Einstein über Kepler. *Frankfurter Zeitung*. Frankfurt, Germany.

Ernest, P. (2016a). Mathematics and values. In B. Larvor (Ed.), *Mathematical cultures* (189-214). Springer International.

Ernest, P. (2016b). Mathematics education ideologies and globalization. In P. Ernest, B.

Ernest, P. (2018). The ethics of math: Is math harmful? In P. Ernest (Ed.), *Philosophy of mathematics education today* (pp. 187-216). Cham, Switzerland: Springer International.

Ernest, P. (2019). Privilege, power and performativity: The ethics of mathematics in society and education. Philosophy of Mathematics Education Journal, *35*(December), 1-19.

Ernest, P., Sriraman, B., & Ernest, N. (Eds.) (2016). *Critical mathematics education: Theory, praxis and reality*. Charlotte, NC: Information Age.

Frederick, W. A. (1991). Science and technology education: An engineer's perspective. In S.K.

Fyhn, A. B., Sara Eira, E. J., & Sriraman, B. (2011). Perspectives on Sami mathematics education. *Interchange*, *42*(2), 185–203.

Garroutte, E. M. (1999). American Indian science education: The second step. *American Indian Culture and Research Journal, 23*(4), 91-114.

Hall, E. T. (1976). *Beyond culture*. Toronto: Doubleday.

Hatcher, A., Bartlett, C., Marshall, A., & Marshall, M. (2009). Two-eyed seeing in the classroom environment: Concepts, approaches, and challenges. *Canadian Journal of Science, Mathematics and Technology Education*, *9*, 141-153.

Hill, H. C., Charalambous, C. Y., Lewis, J. M. et al. (2008). Mathematical knowledge for teaching and the mathematical quality of instruction: An exploratory study. *Cognition and Instruction*, *26*, 430-511.

Hoyles, C., Noss, R., & Pozzi, S. (2001). Proportional reasoning in nursing practice. *Journal of Research in Mathematics Education, 32*(1), 4-27.

Ipsos. (2005). Press release. Retrieved from http://www.ipsos-na.com/news-polls/pressrelease.aspx?id=2756

Jarvis, D.H., Kozuskanich, A., Law, B., & McCullough, K. D. (2015). The techno-numerate nurse: Results of a study exploring nursing student and nurse perceptions of workplace mathematics and technology demands. *Quality Advancement in Nursing Education 1*(2, Article 5).

Larvor, B. (Ed.) (2017). *Mathematical cultures*. Springer International.

Linnebo, Ø. (2018). Platonism in the philosophy of mathematics. In W. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy*. Retrieved from https://plato.stanford.edu/archives/spr2018/entries/platonism-mathematics/

Louie, N. L. (2017). The culture of exclusion in mathematics education and its persistence in equity-oriented teaching. *Journal of Research in Mathematics Education*, *48*, 488-519.

Maloney, E., Fugelsang, J., & Ansari, D. (2017, November 17). Math anxiety: An important component of mathematical success. The Learning Exchange. Retrieved from https://thelearningexchange.ca/math-anxiety/

Martin, E. (2014, November 13). High-paying jobs for people who hate math. *Business Insider.* Retrieved from http://www.businessinsider.com/high-paying-jobs-for-people-who-hate-math-2014-11

Meyer, S. & Aikenhead, G. (2021a). Indigenous culture-based school mathematics in action: Part I: Professional development for creating teaching materials. *The Mathematics Enthusiast, 18*(1&2), 100-118. https://scholarworks.umt.edu/tme/vol18/iss1/9

Meyer, S. & Aikenhead, G. (2021b). Indigenous culture-based school mathematics in action: Part II: The Study's Results: What Support Do Teachers Need? *The Mathematics Enthusiast*, *18*(1&2), 119-138. https://scholarworks.umt.edu/tme/vol18/iss1/10

Nasir, N. S. (2002). Identity, goals and learning: Mathematics in cultural practice. *Mathematical Thinking and Learning*, *4*(2 & 3), 213–247.

OECD (Organization for Economic Cooperation and Development). (2019). *PISA 2018 results*: *What students know and can do* (Vol. 1). Paris, France: OECD Publishing.

Retrieved from https://www.oecd-ilibrary.org/education/pisa-2018-results-volume-i_5f07c754-en;jsessionid=2K5uGllr5qssRvRBzxiYONwK.ip-10-240-5-79

Özyazıcıoğlu, N., Aydın, A. I., Sürenler, S. et al., (2018). Evaluation of students' knowledge about paediatric dosage calculations. *Nurse Education in Practice, 28*(January), 34-39.

Perlstein, P. H., Callison, C., White, M. et al. (1979). Errors in drug computations during newborn intensive care. *American Journal of Diseases of Children*, *133*, 376-379.

Provincial Education Sector. (2020). *SaskMATH: A provincial resource for teachers and leaders of mathematics in Saskatchewan*. Retrieved from https://saskmath.ca/

Saskatchewan Ministry of Education. (2008). *Mathematics 8.* Author.

Selden, A., & Selden, J. (n.d.). Research sampler 6: Examining how mathematics is used in the workplace (website). Mathematical Association of America. Retrieved from file:///C:/Users/Glen%20Aikenhead/Documents/Math%20education/How%20Math%20is%20Used%20in%20the%20Workplace%20-%20Math%20Assoc%20of%20Amer.html

Sriraman, B. (Ed.) (2017). *Humanizing mathematics and its philosophy*. Springer International.

Tencer, D. (2016, March 14). Canada's highest-paying jobs for people who hate math. *The Huffington Post Canada.* Retrieved from https://www.huffingtonpost.ca/2016/03/13/highest-paying-jobs-for-people-who-hate-math_n_9452198.html

youcubed at Stanford University. (2020). https://www.youcubed.org/evidence/anyone-can-learn-high-levels

Glen Aikenhead is Professor Emeritus (2006), University of Saskatchewan, Canada. He earned an Honours BSc (University of Calgary, 1965), Masters of Arts in Teaching (Harvard University, 1966), and a Doctorate in Science Education (Harvard University, 1972). His projects in science and mathematics education over the years have emphasized relevance for learners. Since the early 1990s, Dr. Aikenhead has engaged in cross-cultural school science for both Indigenous and non-Indigenous students. In 2000, he collaboratively developed a community-based series of units entitled Rekindling Traditions. *Since then, he helped edit the Grades 3-9 Saskatchewan science textbook series, which highlights Indigenous knowledge; in 2011, he co-authored* Bridging Cultures, *a resource for teachers implementing science curricula that recognize Indigenous knowledge as a foundational way to understand the physical world; and, in 2014, he published a collaborative, action-research, professional development program for teachers entitled* Enhancing School Science with Indigenous Knowledge. *In 2020, Saskatchewan's science program was recognized by the Conference Board of Canada as leading Canada in reconciliation. Currently, Dr. Aikenhead is involved in a similar innovation for Saskatchewan's mathematics program. He published a monograph,* Enhancing School Mathematics Culturally, *as a 2017 issue in an academic journal. During the 2018-19 school year, Dr. Aikenhead and Plains Cree Knowledge Holder, Sharon Meyer, received a McDowell Foundation grant (Culture-Based School Mathematics for Reconciliation and Professional Development) to collaborate with four Carrot River mathematics teachers to develop Indigenous mathematizing lessons that connected with the curriculum. In 2020, he helped develop the SaskMATH project.*