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Short Communication

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Toward Health Equity in Neuroscience: Current Resources and Considerations for Culturally Broadening Educational Curricula

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Abstract

Background: Health literacy is essential for health equity and past metrics show that literacy is best supported by early exposure to the wide range of topics that constitute physical and mental health. Many outstanding educational resources from around the world are available specifically for the neurosciences, but the wealth of knowledge offered from the peer-reviewed literature has not been centrally organized. Absent from such a resource as well are explicit methods for customizing teaching that maximizes meaningfulness to students and teachers with different backgrounds and enriches inclusivity of the field.

Methods: We reviewed and summarized neuroscience curriculum resources published in the academic literature with elaboration about their type, target audiences, formats, and reported outcomes. We similarly summarized peer-reviewed articles drawn from Canadian-based publications on Indigenous teachings about mind and brain as a lens for adapting and augmenting neuroscience and discourse on brain and mind.

Results: We deliver a consolidated resource of conventional tools for teaching neuroscience based on 13 peer-reviewed publications in neuroscience. We discuss and expand on them with methods from 18 Indigenous academic writings on science, and brain and mind.

Conclusions: To meet the goals of global access to health equity and realize a diverse workforce in the basic and clinical neurosciences that is representative of the population, educational approaches must be both strategic and culturally sensitive. The task starts with reaching youth at the earliest stages and nurturing their curiosity and providing culturally meaningful tools to their teachers to advance their passion for neuroscience.

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Introduction

Neuroscience has had a massive impact in both basic and clinical spheres over the past decades, but equity and access concerns remain. The proliferation and progress of research and translation has not gone unnoticed, with organizations such as the International Brain Initiative, the Canadian Brain Research Strategy, the US BRAIN Initiative, and the Human Brain Project representing the widespread support and interest in investing in and further developing the field on a global landscape. With psychologists, molecular biologists, computer scientists, chemists, engineers, and many others all encompassed under the broad scope of neuroscience, this highly interdisciplinary field is in need of an equally wide range of trainees with varied cultural backgrounds. Students may be inspired to pursue higher education in these areas, but there is no standard expectation that they be introduced to neuroscience prior to university. Science, technology, engineering and math (STEM) outreach is a priority today [1-3]; discourse on the importance of broadening educational perspectives to promote health equity *writ large* is limited [4-6].

Many organizations such as the Society for Neuroscience (SfN) [7], the Association for Psychological Science [8], and the National Institutes of Health [9] have responded to fulfill this need. SfN's Brainfacts.org has its own editorial board, and the US-based National Science Teachers Association has published lesson plans for elementary, middle, high school and post-secondary education (https://www.nsta.org/lesson-plans), as has the National Biology Teachers Association (https://nabt.org/Resources-American-Biology-Teacher). University neuroscience departments, such as the one housed by the University of Minnesota (BrainU.org) have also implemented independent youth outreach programs to introduce neuroscience concepts to school-aged youth [8, 10-13]. With an ever-increasing focus on preparing the youth of today for the neurological sciences of tomorrow, guidance for customizing curricula that speaks to the diversity of perspectives and values are still needed. Indeed, as Rogers-Chapman highlighted in 2014, interest in pursuing STEM education from historically marginalized populations and people from low-income households rises steeply when their views and backgrounds are explicitly considered [14]. And, as Hahn et al [5] (2015) have argued, health equities are similarly improved when outreach is tailored for a community.

To encourage a similar trend in neuroscience outreach, the overarching objective of the present work, broadening the perspective through which curricula are designed and offered is one answer. Such adjustments will not only promote curiosity for the neurological sciences, but also instill confidence, capacity, and a sense of equitable belonging along the trajectory of training to professional choice and placement in a majority dominated field [15-17].

Materials and Methods

Institutional review board approval was not applicable. This study was conducted in compliance with the ethical standards of the responsible institution on human subjects as well as with the Helsinki Declaration.

Data collection

We conducted two independent sets of searches to yield resources broadly for neuroscience based on the peer-reviewed literature, and resources specifically from the Canadian literature on Indigenous approaches to teaching about science, with a focus on brain and mind to complement it. Both searches, drawing upon methods described for example by Tricco et al [18] (2018) and Harding et al [19, 17] (2021), were conducted in May 2021.

Neuroscience resources

We searched Google Scholar, Education Resources Information Center (ERIC), Web of Science, EBSCO Academic Search Premier, Education Source, Teacher Reference Center, and APA PsycInfo using the following search strings and related variants: “youth”, “neuroscience”, “brain”, “mental health, “curriculum”, “workshops” and “education” and their combinations to identify published neuroscience outreach programs and curricula. The databases were chosen based on their focus on education and resource development. Inclusion criteria were English-language full text, related to the design, implementation, and evaluation of a program with neuroscience content, targeted at youth in high school and younger, and involved workshop activities and curricula.

Test strings included terms in three categories for maximum capture: population (e.g., youth, adolescents, urban, rural), intervention (e.g., curriculum, teaching, outreach, early intervention, programming, ethical design), and topic (e.g., science, neuroscience, brain, mind, mental health, wellness, mental health literacy). Search terms were refined for a final capture of papers most relevant to our objectives. Returns were manually curated to exclude irrelevant articles that remained, and duplicates. We also cross-referenced returns with searches of the first 10 pages of Google Scholar and sites of SfN, Canadian Association for Neuroscience, International Brain Research Organization, and Human Brain Project for relevant material on youth education to ensure a closed set of papers.

Canadian Indigenous resources

We focused on Canadian Indigenous content for approaches to cultural adaptation of curricula given the geographic location of the author group, the commitment of this country to Truth and Reconciliation [20], and priorities for neuroscience recently articulated by the Canadian Brain Research Strategy [15]. In this regard, we conducted a search for papers on Indigenizing science curricula and outreach to youth in Canada as the specific lens for this aspect of the project. To achieve a complementary goal to the first search, we mined eight databases (Informit Indigenous Collection, Education Source, Education Resources Information Center (ERIC): Free, LearnTechLib, PsycINFO, Teacher Reference Center, and Web of Science) using key words and strings, and their variants and combinations, for “Canada”, “Indigenous”, “science”, “brain”, and “mind”.

Analyses

To meet the resource delivery objectives of this work, the final set of eligible papers reporting on neuroscience curricula were organized according to year of publication, format and length of the program, range of neuroscience topics covered, populations targeted (e.g., age group), methods to assess the program, and overall impact of the outreach. Analysis and summary of the final set of articles on Indigenous approaches were adapted for details and variables most relevant to them by year of publication, population, intervention, topic, methods of assessment, and reported impact. Articles were read and reviewed by the authors for content relevant to resource delivery objectives of the work. Consolidated notes were organized in table format.

Results

Neuroscience curricula

Thirteen papers reporting on neuroscience curricula met inclusion criteria (Fig. 1). Fifteen were excluded as they did not contain workshop-specific content. Full text was inaccessible for three. All papers were published between 2006 and 2020. Table 1 [21-33] summarizes the 13 articles analyzed in detail. The number of students reached by each of the programs ranged from 18 to 9,000.

Training formats and duration

Seven studies utilized pre-existing curricula or learning goals such as the BrainLink curriculum or the SfN core concepts and

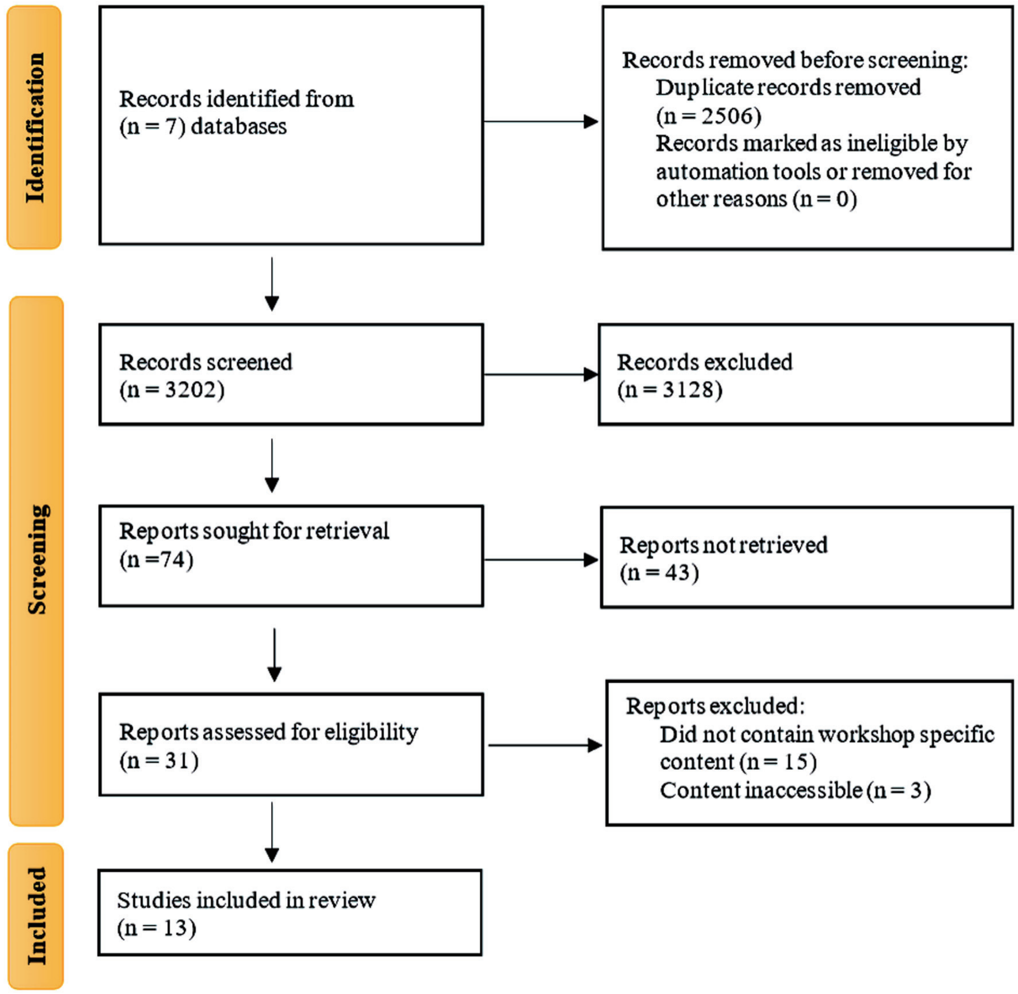

Figure 1. Search process, returns, and curation for youth neuroscience outreach literature.

resources; five studies designed their own lesson plans and activities. Twelve of 13 articles reported on curricula based on workshops; one reported on a series of neuroscience workshops included into a school term [23]. The majority of these articles targeted the K-12 population, (10/13 articles) with the exception of one study that focused specifically on preschoolers [26] and two studies that targeted high schoolers [30, 32]. The majority of workshops included a combination of mini-lecture style presentations and hands-on activities (11/13 articles), which varied depending on the age range of the students, from building pipe cleaner neurons (2/13 articles) to sheep brain dissections (3/13 articles). One article provided in-depth guidelines for activities based on age range and student capability with varying activities within different categories such as neuroanatomy, drugs, neurologic and mental health disorders, and brain function [24]. Workshop duration varied from sessions of 45 - 60 min (5/13 workshops) to 8-h sessions (1/13 workshops). Program length ranged from 3 days [21] to 20 weeks [30]. The majority of the programs were designed and hosted by undergraduate students (10/13 articles). Six of 13 articles described curricula targeting underserved youth specifically.

Content and knowledge objectives

All workshops taught basic neuroscience concepts. Four workshops included neurodegenerative diseases and disorders in their curriculum [23, 29, 32, 33]; three included drug and drug effects [27, 29, 33]. Across workshops, similar activities as described in the section above were used to teach structure and function of the brain and nervous system. Some workshops expanded beyond basic neuroscience to include skills such as understanding neuroscience in journal articles [28], sleep and dreaming [29], brain plasticity and learning [21, 26]), and genetics and behavior [21].

Assessments and impact

Results suggest that workshops are particularly effective in improving science communication skills (11/13 articles) and understanding of neuroscience concepts (12/13 articles) among youth. Eight articles described pre and post quizzes; two types of surveys were used by two workshops to assess impact both

Table 1. Studies on Youth Neuroscience Outreach

Publication	Population (used for analysis)	Training format	Duration	Content	Assessment format	Reported outcomes
MacNabb et al, 2006 [21]	Grade 5-8 students from Minnesota (n = 9,023) Grade 5-8 teachers from Minnesota (n = 56) University of Minnesota	Teacher training Presentations Exhibit stations Class activities/ experiments Various resources loaned to classrooms	2-week BrainU sessions 3-day workshop	Nervous system anatomy Neuronal communication Movement Genetics and behavior Visual influence on motor learning and neural pathways Neural pathways Learning and memory	Short multiple-choice survey Open-ended feedback survey for students	↑ in understanding of neuroscience concepts by teachers and students ↑ in teacher confidence in teaching neuroscience ↑ in students' interest in neuroscience ↓ in the number of inappropriate or negative peer interactions
Saravanapandian et al., 2019 [22] (same workshop as Romero-Calderon et al, 2012 [29])	Grade K-12 students across the Los Angeles area (n = 298) University of California, Los Angeles Undergraduate students (n = 29)	Student training (2 weeks) Practice presentation to peers (1 week) Practice presentation to peers and faculty (1 week) Visiting K-12 classrooms (5 weeks)	10-week program 4/10 weeks used for preparation	Training in the 5E (engage, explore, explain, elaborate and evaluate) instructional model	Pre-workshop surveys Post-workshop surveys 1 week after completion 3 - 6 multiple choice questions on key learning objectives	↑ in teaching from undergraduate students ↑ confidence in communicating science and ↑ in interest in pursuing teaching careers ↑ in K-12 students' STEM interest and understanding of neuroscience concepts
de Lacalle et al, 2012 [23]	Grade K-12 students in California	Kids Judge! science fair Mentoring program "Medicine in Movies" film series	Autumn 2006 - Spring 2011	Biomedical sciences (including predominantly the neurosciences), with a focus on scientific discovery	Teacher surveys Focus groups Science communication survey Attendee surveys Interviews with program staff Performance data on the California Standards Tests (CST)	↑ in proficiency rates over the project period ↑ in community engagement Small ↑ in attitudes towards public speaking Undergraduate confidence in their ability to present science to children did not change much due to prior experiences Classroom teachers and mentors reported that the mentoring program was valuable to students

Table 1. Studies on Youth Neuroscience Outreach - *(continued)*

Publication	Population (used for analysis)	Training format	Duration	Content	Assessment format	Reported outcomes
Deal et al, 2014 [24]	Local K-12 students (n = 3,500) from Biddeford, ME Undergraduate (n = 45) and graduate/professional students (n = 33) from the University of New England's Center for Excellence in the Neurosciences	Modules focused on different topics with age-appropriate activities 8 - 10 students per group	60-min time-adjustable modules	Brain safety Neuroanatomy Drugs, abuse, and addiction Neurological and psychiatric disorders Cognitive function	Student survey using "My Attitudes Towards Science" (MATS) survey Feedback survey for undergraduate student volunteers	↑ connections between undergraduate volunteers with university faculty ↑ in confidence presenting scientific information ↑ in interest for careers in the scientific field
Vollbrecht et al, 2019 [25]	Grade 6-8 students from underrepresented groups in the Holland, Michigan area (n = 174) Hope College undergraduate students (n = 22)	Discussion Short introductory presentation Demonstrations Activities	5-slide PowerPoint presentation followed by post-test 2 - 7 days after classroom visit	Content modified from BrainLink curriculum [21]	10-question multiple choice quiz (pre and post workshop) to assess student understanding Survey on the impact of the outreach event for undergraduate students	↑ in understanding of neuroscience concepts ↑ in excitement and ↑ in confidence in science communication in undergraduate students No significant change was observed for questions 2, 4, 8, or 10
Brown et al, 2019 [26]	Preschool students from Northwestern PA ages 5 - 6 (n = 18) Undergraduates studying neuroscience or education	Lessons were designed and taught by two undergraduates Introductory neuroscience lesson Individual check-ins 5 lessons with activities	3-h sessions 3 days a week for 6 weeks	Anatomy and function Sensory and motor systems Brain plasticity and learning	Baseline assessment Post-workshop assessment	↑ in percentage of correct quiz answers ↑ in performance on post-assessment test questions in students who received neuroscience outreach lessons compared to control students
Toledo et al, 2020 [27]	Low-income grade 6 students in Riverside County (n = 77)	Tiered curriculum Interactive lessons	1-h weekly workshops for 5 weeks	Neurons Brain anatomy Autonomic nervous system function Drug effects	15-min pre and post workshop survey Demographics Attitudes towards science and learning Understanding of neuroscience concepts	Significant ↑ in attitudes towards science and learning ↑ in knowledge post-intervention in 7 out of 8 content areas No changes in excitement about learning science material and school learning opportunities No changes in knowledge of neurons, which was unexpectedly high at pre-test No statistically significant gender differences were found

Table 1. Studies on Youth Neuroscience Outreach - *(continued)*

Publication	Population (used for analysis)	Training format	Duration	Content	Assessment format	Reported outcomes
Bravo-Rivera et al, 2018 [28]	K-12 schools (n = 20) and universities (n = 17) in Puerto Rico	Series of individual outreach workshops Hands-on activities	Not specified	Understanding neuroscience in journal articles Basic neuroscience concepts (e.g., anatomy, neurons, function) Use of "Backyard Brains" laboratory equipment	None	None
Romero-Calderon et al, 2012 [29]	Grade K-5 (ages 5 - 10) (n = 958) Grade 6-8 (ages 11 - 13) (n = 415) Grade 9-12 (ages 14 - 18) (479) Multi-level schools grade K-8 (ages 5 - 13) (n = 61) University of California Los Angeles	Introductory presentation Age-appropriate in-depth presentations Hands-on activities guided by undergraduate students	45-min workshops during the 2006 - 2011 school years	Basic neuroscience concepts Senses, memory and learning, motor systems and reflexes, and brain injury (ages 5 - 9) Sleep and dreaming, handedness, and pain (ages 10 - 13) Drugs, nerve impulse conduction, gender differences, circadian rhythms, stroke, and neurodegenerative diseases (ages 14 - 18)	None	None
Pollock et al, 2017 [30]	Underserved high school students in the Bay area Local high school and a local youth center	Combination of game-making and neuroscience education	Weekly, 2-h after-school sessions over the course of 2 academic quarters	Modified curriculum using the California State University East Bay (CSUEB) Game Jam and Brain Bee Engineering and science portion based on the California Next Generation Science and Engineering Standards	Event maps and analysis of activities and guidance format Video data (23 sessions) Observation and field notes (15 sessions)	↑ in engagement in neuroscience when integrated fully into game design The experience affords students rich, engaging opportunities

Table 1. Studies on Youth Neuroscience Outreach - *(continued)*

Publication	Population (used for analysis)	Training format	Duration	Content	Assessment format	Reported outcomes
Fitzakerley et al, 2013 [31]	Grade 4-6 students in Minnesota	Short introduction Interactive demonstrations Real human brain activities	45 - 60-min interactive presentations	Structure and function Electrical and chemical communication Learning and plasticity Neuron anatomy	Teacher survey on value of presentations and teaching experience Student survey on attitudes towards science, views of scientists, and their own ability to learn	↑ in attitudes towards science ↑ in understanding and memory of neuroscience content
Colon-Rodriguez et al, 2019 [32]	Puerto Rican minority high school students (n = 200) Undergraduate students (n = 424)	4 workshop sessions Discussions and activities designed by University of Michigan graduate students (n = 9) Spanish/English workbook	8-h sessions	Central nervous system Sensory, motor, and autonomic systems Common neurodegenerative diseases Anatomy	15-min pre- and post-workshop evaluations (11 questions both multiple choice and short answer) Written feedback form	↑ in understanding of neuroscience and enthusiasm towards science in both high school and undergraduate students Workshop topics and hands-on experiments most well received
Chudler et al, 2018 [33]	Grade 6-8 students at Washington State or Oregon schools (n = 1,240) Middle school science teachers at Washington State or Oregon schools (n = 23)	Professional development workshops in either Seattle (5 shorter days) or Yakima (3 days) 5E model (engagement, exploration, explanation, elaboration, and evaluation) Individual lessons on different topics	8 lessons + resources given to teachers to administer over the course of 12 weeks	Neuroanatomy and neurophysiology Effects of plants on treating illness and altering brain function Movement and motor functioning Neurodegenerative diseases and neurological disorders Exploration of bacteria and its relationship to neurological diseases Stem cells and regeneration Stimulants and depressants Nervous system	Pre- and post-tests 15 content-related questions Attitudes about science were measured using a subset of questions from the Simpson-Troost Attitude Questionnaire (STAQ)	↑ in percentage of correctly answered content questions for all grades (54.1% average correct answers compared to 69.3%) Number of correct science content answers did not vary significantly based on gender Differences between average pretest score and posttest score varied by grade level No statistically significant change in the Self-Directed Effort scale or the Science is Fun for Me scale Motivating Science Class scores were higher at post-test but not statistically significant

Studies are presented in the order described in the text. Arrows indicate statistically significant effects reported by authors. STEM: science, technology, engineering and math.

on neuroscience and STEM; five used one method or the other.

Undergraduate partnership programs provided an opportunity for undergraduates to utilize their knowledge of neuroscience topics and improve their science communication skills (6/13 workshops). Undergraduates themselves demonstrated an increase in skills related to science communication, leadership, teaching, organizational skills, self-confidence, and time management. For example, survey results from the Hope College Brain Awareness Week demonstrate that these events provided valuable skills and lessons for undergraduate students [25]. The average assessment of the impact of outreach (-5 = a significant negative impact on life or skills, 0 = no impact, 5 = a significant positive impact on life or skills) consistently fell above 2.24 with the highest impact being excitement about science communication (4.12 average), teaching skills (3.82 average), and communication skills (3.76 average).

Indigenizing curricula

Eighteen articles were included for Indigenizing teaching of western materials of 39 total. Sixteen were excluded from the total return of 31 as they did not contain methods on Indigenizing curricula; five were inaccessible. All papers were published between 2005 and 2020. The reports were a mix of primary research articles reporting on workshops, literature reviews, and case studies (Table 2) [34-51].

Various tools were used to assess the workshops: interviews [34, 36, 38, 47, 50], self-assessments or self-reflections [36, 40, 46], and talking circles, group discussions, or storytelling [34, 39, 42-44]. Other assessment methods included the "what + how = value" equation [41]. Five articles reported that incorporating various features of Aboriginal pedagogy into teachings have significant impacts on student engagement, motivation, and general understanding [35, 38, 41, 50, 51].

Overall, the papers focused on approaches such as the medicine wheel of learning pedagogy, incorporating Indigenous protocol, and place-based education.

Medicine wheel learning philosophy

Seven of 18 articles described how the medicine wheel of learning pedagogy (MWLP) ensures that students "learn in a whole and balanced manner" and that all four dimensions of an individual are actively engaged and committed in the educational process [36]. These four dimensions are given varying names in the literature but overall tend to represent mental, spiritual, emotional, and physical elements. The MWLP encompasses the ideas of incorporating culture, promoting a good environment, and utilizing appropriate learning styles.

Indigenous protocol

Twelve papers described how incorporating Indigenous culture requires including Indigenous protocols and educating children through traditional Indigenous approaches to learning and growing. The protocols included the use of talking circles (3/12), healing circles (3/12), prayers (3/12), storytelling (5/12), traditional medicine (2/12), two-eyed seeing (4/12), and involvement of Elders (6/12).

Place-based education

Six papers touched on the impact of place when conducting teaching. Two of these promoted delivering curricula on the appropriate land by hosting cultural events in the community, or by visiting local facilities to better connect the students to the material and highlight the interconnectedness of learning. The remaining four underscored the importance of directly participating with the natural world and incorporating hands-on learning to offer context and understanding.

Discussion

Neuroscience teaching: from today to tomorrow in research and practice

The material available online on teaching neuroscience specifically and science more broadly to youth today represents an exciting array of conventional and novel approaches, and includes ways to assess their efficacy for nimble updating and refinement. Search engines have their limitations, and in this respect, we recognize that some programs may have been missed. In addition, we only focused on Canadian-based Indigenous methods towards broadening and acculturating curricula here. Some methods may be generalizable or transferable, but we recognize and respect the heterogeneity of all cultural groups. Other relevant resources that may be accessed to even further broaden teachings than those captured here are available from writings, for example, from self-healing communities [52, 53], addressing native culture within science curricula [54] and science standards in the USA [55, 56], and books such as No Snow Day for the Brain [57].

The resource here consolidates peer-reviewed reports on neuroscience curricula available at the time of this writing, as well as approaches that center on Canadian Indigenous epistemologies. The marriage of the two has not been previously attempted in the neurological sciences, and it applies to teaching students from all backgrounds beginning at the earliest stages of intervention. We do not attempt to directly compare the results from each phase of work or differentially value or evaluate the strengths or weaknesses of the different programs presented here. They are complementary and each has much to offer. Their attributes can be integrated and adapted in many ways in the evolution and delivery of future neuroscience curricula. The benefits conferred by such interventions are further reaching than simply increasing students' interest in neuroscience. Indeed, early and acculturated education has been shown to improve health equity in underserved populations in three specific domains: increasing professional diversity, creating more accessible and relevant education, and boosting health literacy [4-6].

Table 2. Studies on Indigenizing Science Curricula

Publication	Population	Indigenization approaches	Assessment	Reported observations and outcomes
Cheeptham et al, 2020 [34]	13 - 15 years old Indigenous youths that attended the Thompson Rivers University (TRU)_ Aboriginal Youth Summer Camp in Science and Health Science (n = 149)	Exposing campers to science and health science through academic, recreational, and culturally-relevant camp activities Place-based education (PBE) via guided tours of local facilities (water treatment plant, rural First Nations health center) Interactions with professionals in healthcare to explore potential career paths Partnerships with local community	Exit surveys, wrap-up evaluation and debriefs with staff Informal conversations with campers and other participants	↑ in attendance rates ↑ in levels of stated interest and growth over time
Thomas et al, 2006 [35]	Literature review, interviews (n = 15) Participants in research (n = 6)	Combined healing properties of Aboriginal healing circles and self-awareness and empowerment practices of the psychotherapy technique known as “focusing”	45-min interview to discuss purpose of research Self-reporting mental health assessment	Reported themes from participants’ first-hand experiences were experience, relationships, spirituality and connectedness, empowerment, and self-awareness ↑ in student interest when content acknowledges existing frameworks of healing and knowledge within Aboriginal communities Further efforts are needed to equip First Nation practitioners with knowledge, values, and skills required to promote holistic wellness within their families and communities
Ragoonaden et al, 2017 [36]	Students taking EDUC 104, a new collaborative Indigenous perspectives course at the University of British Columbia-Okanagan 11 women and 6 men between ages of 18 and 56 (n = 17)	Holistic approach from Indigenous epistemology Medicine wheel with four dimensions of learning: wisdom and logic (mental), illumination and enlightenment (spiritual), trust and innocence (emotional), and introspection and insight (physical)	Interviews conducted at the conclusion of the course Longitudinal, mixed-methods study	Interviews yielded three major themes: circles of learning, peer mentoring, and relationship with the instructor The interconnectedness of the self in relationship to society and education is important to ↑ student learning

Table 2. Studies on Indigenizing Science Curricula - *(continued)*

Publication	Population	Indigenization approaches	Assessment	Reported observations and outcomes
Higgins et al, 2019 [37]	Opinion text	Indigenous ways-of-knowing-and-being Place-based education (PBE) Collaboration with Indigenous scholars, Elders, and Knowledge Keepers	Not applicable	Marginalization results from the attempt to fit Indigenous knowledge into Western scientific knowledge frameworks Indigenous ways-of-knowing-and-being are often included as tokenistic means to an end Fairclough's three-tiered model is effective in allowing conceptualization of different relationships involved in curriculum document production
Mack et al, 2012 [38]	Individuals from Native communities across the USA Individuals running informal programs to engage Native American youth in science and environmental education (n = 21)	Indigenous ways of knowing Evaluating progress in spiritual and ethical terms Integrating Native science (e.g., medical plant uses, cosmology, and star knowledge) Two-eyed seeing	Interviews	Confirming and validating traditional knowledge using contemporary science is a way of conducting culturally sensitive science education programs Tailoring educational programs to a community's specific local culture and needs leads to an ↑ in effectiveness Native ways of knowing can add value and ↑ academic success for Indigenous youth Effective practices include creating hands-on, inquiry-based lessons that are reflective of the culture; utilizing the community as an integral resource in the development of curriculum; using local Native language.
Fellner, 2018 [39]	Author reflection and opinion text	Implementing Indigenous protocols and ethics, talking circles, storytelling, and land-based pedagogies as integral parts of the learning process Delivering curriculum using oral teachings and storytelling Inviting Elders to deliver curriculum Delivering curriculum on the land and/or in the context of community ceremonies and events Using traditional medicines	Talking circles	Incorporating Indigenous knowledge, and introducing students to how to bring Indigenous ethics, standards, and practices into their work is essential for decolonizing curricula Students learned how to prioritize community and ceremonial protocols and ways of knowing, being, and doing in their work. Learning Indigenous knowledges in relation to community wellness is critical for students in community psychology and allied disciplines, as "our communities know what we need to heal".

Table 2. Studies on Indigenizing Science Curricula - *(continued)*

Publication	Population	Indigenization approaches	Assessment	Reported observations and outcomes
Root et al, 2019 [40]	Students enrolled in MIKM 2701 at Cape Breton University	Course led by local Elders and Knowledge Keepers with facilitation support from university faculty Provided culturally relevant education by introducing Mi'kmaw-centered teaching and learning processes grounded in the locally specific contexts of Unama'ki (Cape Breton) and Mi'kma'ki Two-eyed seeing Course began and ended with traditional ceremonial prayer	Assessment in the form of self-reflection analyses by students at week 13 of taking the course	Analysis yielded five themes: identifying cultural self (situating); *msit no'kmaq* or relating to others and the natural environment; feeling or experiencing and acknowledging the emotions raised through learning; responding through shifting; and/or, sticking in personal position Both Indigenous and non-Indigenous students expressed satisfaction about information shared during the course ↑ in knowledge of Indigenous storytelling, spiritual ceremonies, and accounts of residential school experiences from personal, Indigenous perspectives for non-Indigenous students Indigenous students indicated that they had never learned about their culture, language, and history in their school experiences.
Farrell et al, 2020 [41]	Teachers along the Fraser Canyon corridor, in the Nlaka'pamux and Sto:lo Nations (n = 35)	Adapting Place-Based Education (PBE) and decolonizing education for the instructor and researchers	Used a "what + how = value" basic equation	PBE is necessitated by active, living relationships in place and provides opportunities for critical pedagogy grounded in Indigeneity. ↑ in ability of pre-service teachers to apply historical and geographic thinking competencies and build principled practical knowledge of PBE Walking the land gave context and ↑ in understanding to students' learning.

Table 2. Studies on Indigenizing Science Curricula - *(continued)*

Publication	Population	Indigenization approaches	Assessment	Reported observations and outcomes
Pearce et al, 2005 [42]	Students at Mother Earths Children's Charter School in Canada (MECCS) Over 300 students, teachers, parents, community Elders, and researchers	Approach is delivered in a cultural context and framed around respect for Mother Earth, respect for all living things, and respect for oneself (PBE) Medicine wheel informs the school philosophy Interactive learning activities that focus on a holistic, visual, and team approach to education Daily routines incorporate fundamental Indigenous practices such as prayer, sweetgrass ceremonies, sharing circles, and healing circles Involvement of Elders	Visual narrative inquiry to directly evaluate the experiences of students, parents/guardians, teachers, admin, and Elders Focus on the individual and how life might be understood through a telling and re-telling of the visual narrative story	↑ in focus on respect in the school rather than authoritarian discipline ↑ in harmony, cooperation, and group work due to the cohesive, community-oriented environment ↑ in school year with longer school days allows for seasonal ceremonies that occur at times outside of regular school days
Brown et al, 2020 [43]	Unspecified	Talking circles	Literature review Case study using talking circles to assess community engagement	Talking circles are useful to build/nurture/reinforce/heal relationships, and connect spiritually/intellectually/emotionally with other people Talking circles can be used as an evaluation practice for evaluators looking to build relationships, share power, and solve problems
Bartlett et al, 2012 [44]	Mi'kmaw community of Eskasoni First Nation Unspecified adults (those attending post-secondary)	Two-eyed seeing	Discussion on Integrative Science undergraduate program created to include Indigenous knowledges and ways of knowing into an established science university program	Mainstream and Indigenous knowledges and ways of knowing must engage in a co-learning journey Two-eyed seeing is central to co-learning Development of an advisory council of willing, knowledgeable stakeholders is needed to implement such changes
LaFever, 2017 [45]	Unspecified	Medicine wheel Talking circles	Literature review	Using all four quadrants of the medicine wheel is a step all educators can take to Indigenize pedagogy
Baydala et al, 2009 [46]	Indigenous children (K-8) from North Central Alberta (Cree, Nakota Sioux, Blood, Blackfoot, Ojibway, Dene, Inuit, Metis)	Medicine wheel	Longitudinal evaluation of change in measures of behavior, academic achievement, self-perception, and health of children in the form of questionnaires	All measures significantly declined or showed no significant change Higher performing students transferred out of the school and ↑ in enrolment of special-needs students.

Table 2. Studies on Indigenizing Science Curricula - *(continued)*

Publication	Population	Indigenization approaches	Assessment	Reported observations and outcomes
Neeganagwegin, 2020 [47]	Indigenous Elders and Knowledge Keepers Indigenous youth in school	Indigenous educational models PBE Use of the native language Focus on relationships	Interviews	Incorporating Indigenous educational models into Canadian schooling is beneficial for Indigenous populations and for educators and governments who work with Indigenous communities.
Future Skills Centre (FSC-CCF), 2020 [48]	Elementary and secondary students, Indigenous learners in post-secondary education STEM graduates	Indigenous science approach Emphasis on relationship to space and time Structural authority Two-eyed seeing	Literature review	Bridging Indigenous ways of knowing with Western science leads to an ↑ in engagement and performance for Indigenous students. ↑ in motivation and enrolment in STEM when specialized programs targeted to Indigenous students is used Other strategies include curriculum reform for K-12, increase in STEM outreach to Indigenous students, and creation of associations for Indigenous professionals in STEM occupations.
Science First Peoples, 2019 (teacher resource guide) [49]	Elementary and high school Indigenous students	Incorporation of Indigenous knowledge and Indigenous Science PBE Interconnectedness	Teacher resource guide on how to structure curriculum	Resource guide promotes the inclusion of Indigenous perspectives in science courses.
Preston et al, 2013 [50]	Aboriginal high school students in Saskatchewan	Inclusion of Aboriginal worldview Medicine wheel teachings on focusing on mind/body/emotion/spirit	Semi-structured individual interviews	↑ in motivation for educational success stemmed from 4 quadrants of learning: awareness (east, physical, fire); knowledge (south, mental, earth); continuous improvement (west, emotional, water); and perseverance (north, spiritual, air) Incorporating features of Aboriginal pedagogy when teaching can ↑ student engagement
Rebeiz et al, 2017 [51]	Aboriginal youth (First Nations and Metis)	Land-based learning (PBE) Incorporation of spirituality Medicine wheel	Case study of the H’a H’a Tumxulaux Outdoor Education Program	↑ in student engagement and learning when land-based learning focused on hands-on experiences, guided by traditional spiritual values and built upon the medicine wheel is used

Studies are presented in the order described in the text. Arrows indicate statistically significant effects reported by authors. STEM: science, technology, engineering and math. PBE: Place-based education.

Increasing professional diversity for health equity

Health equity is improved when practitioners and researchers represent the various cultures and social backgrounds of the communities they serve. A representative clinical workforce engenders trust among patients, and better communication through common language. Trust is also enhanced in research when representation is proportionate to target populations, as is the opportunity for inclusive study designs and meaningfully generalizable results [4].

Making education accessible and relevant

Achieving a diverse workforce in brain health is a direct result of the dedicated goal of capacity building, and capacity building is made possible when education is accessible and contextually relevant. As reported above, when curricula are adapted to specific populations, student interest and engagement increase [34, 35, 48, 50, 51], as do subsequent pathways to future educational attainment. The net result of accessible education is expanded and culturally diverse peer-to-peer and professional pools that have the on-the-ground capabilities and knowledge to directly impact health inequities.

Boosting health literacy

Education is a social determinant of health, and educational interventions have been shown to enhance health literacy and improve health-related outcomes [5, 6]. Culturally adapted curricula embrace the nuances and distinctiveness of different populations, and recognize, respect, and uphold their autonomy and right to delf-determination.

Conclusions

The neurological sciences must embrace the need for an expanded educational dynamic. In doing so, the goals of enriched inclusivity of the field, capacity building, and global investment in health equity in both the present and future will be met. This commentary brings together curricula from the peer-reviewed literature for teaching neuroscience to youth alongside published methods that can broaden their reach and cultural meaningfulness. It provides a resource for engaging youth in neuroscience and is a move towards closing gaps in brain and health equity through outreach and capacity-building for diverse groups.

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Conflict of Interest

None to declare.

Informed Consent

Not applicable.

Author Contributions

AL and JI developed the concept for this report. CL and AL conducted the literature searches and analyzed the results. AL, JI, and CL interpreted the articles and wrote the manuscript. All authors discussed the report and reviewed the manuscript at all stages.

Data Availability

The authors declare that data supporting the findings of this study are available within the article.

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