Decolonizing Light: A Project Exploring Ways to Decolonize Physics

by Ingo Salzmann, Louellyn White, Donna Kahérakwas Goodleaf, and Tanja Tajmel

Ingo Salzmann
<ingo.salzmann@concordia.ca>
Department of Physics, Department of Chemistry & Biochemistry
Concordia University, Montreal, Quebec

Louellyn White
<louellyn.white@concordia.ca>
First Peoples Studies, School of Community and Public Affairs
Concordia University, Montreal, Quebec

In 2018, the Government of Canada established *The New Frontiers in Research Fund* (NFRF) to support high-risk, high-reward and interdisciplinary research. In that framework, we, as a group of non-Indigenous and Indigenous scholars working in fields as different as Physics, First Peoples Studies, Decolonizing Curriculum and Pedagogy, as well as Science and Technology Studies, united to find common ground to explore the decolonization of physics. Here, we outline our motivation, our project rationale and concrete plans underlying our NFRF-funded project *Decolonizing Light — Tracing and Countering Colonialism in Contemporary Physics*, which we will pursue during the next three years.

Decolonization — Why physics, why light?

The aim of our project is exploring approaches to decolonize physics, of both its narratives and contemporary research.[1] We decided to focus on physics, as this discipline plays a special role in the field of science due to its unique scientific authority. Physics is commonly regarded as the "most objective" and the "hardest" science [2], it fundamentally defines scientific key concepts such as energy, matter, force, light, space and time, for all the other sciences. It is the narrative of physics as objective and as socially independent [3] that constitutes and stabilizes its knowledge authority in relation to all other knowledge systems.[2] For our purpose, it is important to understand *physics as a social field* rather than as "pure knowledge" independent from social values and decisions. Physics is more than the laws that describe and predict natural phenomena: it is the overarching field of work with its societal dimension, its history, and the circumstances and purposes of physical knowledge production. The opportunity to participate in producing such scientific knowledge as well as the purposes and benefits of this knowledge are framed by social power relations, by politics, and also by colonialism. This perspective is important because by regarding science as disconnected from society and from its colonial history, colonialism is being reproduced. This is the way in which we regard physics as colonial, and it is based on this notion that we explore approaches to *decolonize physics*.[3]

In our project we decided to exemplarily focus on light (rather than on optics, as optics is a physical field and narrows down the concept of light and what can be said about it), because light is ubiquitous in every society, language and culture. In everyday life, light is a key element that defines familiar aspects like color and warmth. In physics, light is exploited as the primary carrier of information about nature (*e.g.*, in astronomy), used as the primary probe for the fundamental properties of matter (*e.g.*, in spectroscopy), or generated in billion-dollar synchrotron radiation centres — prestigious large-scale research facilities at the forefront of contemporary physics research (such as the Canadian Light Source in Saskatchewan located on Treaty 6 Territory and the Traditional Homeland of the Métis). The purpose of our project is not to find new or better explanations of light; we are not seeking to improve scientific 'truth'. Rather, our project initiatives are motivated by the marginalization of women, Black people, and Indigenous peoples [5], particularly in physics, as it is documented by the statistics of the American Institute of Physics [6].[4] We regard marginalization as a key problem for social equity as well as for scientific quality. Furthermore, we regard scientific knowledge that reproduces bias and colonial power relations as non-acceptable, as stated in the Declaration for science education as human right [7]. In line with Canadian efforts to address reconciliation, universities such as Concordia have embarked on a comprehensive plan to decolonize curriculum, research and pedagogy across all academic units; this includes to increase the presence of Indigenous and Black students, faculty and staff on all levels. Our project is situated in this social, political and historical context.

1. In our understanding of *decolonization,* we follow Linda Tuhiwai Smith: "Decolonization is a process which engages with imperialism and colonialism at multiple levels. For researchers, one of those levels is concerned with having a more critical understanding of the underlying assumptions, motivations and values which inform research practices." [1, p. 21]
2. At this point, we understand *knowledge systems* broadly and do not follow one single definition, as "defining parameters of knowledge systems mirror the disciplinary and political agendas that influence scholars' points of view and methods of analysis". [4, p. 17]
3. For a discussion on definitions of *colonialism* see Ref. [1, p. 21f].
4. Note that intersectional effects such as, *e.g.*, gender AND race, are not considered in these statistics.

Possible decolonizing approaches in physics comprise purposefully training university students from marginalized and racialized groups in physics (*e.g.*, by offering well-funded positions to Indigenous and Black graduate students), initiating collaborations with Black (*e.g.*, Montreal's Haitian community) and Indigenous communities in scientific projects, and seeking conversations with Indigenous Knowledge Keepers about their cultural (philosophical as well as practical-empirical) knowledges to include them in the curriculum. In general, scientists and science teachers aim to increase scientific knowledge and scientific literacy of people. In our view, this includes augmenting studying physics by examining ethical frameworks and historical contexts which ask to whose benefits and on whose costs scientific progress has been made. This is the essence of decolonizing physics, a process based on dialogue which we believe to represent a rewarding approach for all.

DECOLONIZING APPROACHES

Our project consists of two complementary parts which inform each other and are mutually connected through the individual expertise in the research team and our own processes of building relationship. The first part (left column in Fig. 1) focuses on Indigenous Knowledge(s) (IK) and education, where we aim to revitalize IK and bring them to academic attention. This includes developing courses together with Indigenous scholars and Knowledge Keepers in which students approach questions from different or culturally diverse perspectives, as well as de-centering Eurocentric Western science through decolonizing curriculum in ways that elevate Indigenous scientific and intellectual contributions and develop new narratives.

The second part (right column in Fig. 1) focuses on physics and Western/Eurocentric science. There, we aim to critically investigate if and how physics itself has contributed and still contributes to colonialism. We investigate its potential colonial history, its values and underlying decision-making processes and aim to identify "blind spots", the non-knowing or lack of knowledge with regards to the role that science played in the context of colonization (see Sec. III). Finally, we investigate strategies of empowering students and Indigenous communities through scientific training and increasing Indigenous scientific literacy for the purpose of self-governance and participation in scientific research and aim to implement these strategies in our project initiatives.

In the following sections (labelled by the respective authors' initials IS, LW, DG, TT), we write about the project from our diverse perspectives and backgrounds, working together on common grounds to contribute to the goal of making academic education acceptable and accessible for all.

I. DECOLONIZING CURRICULA (DG)

Higher education systems in Canada have a history of perpetuating Eurocentric/Western canons of thought as the 'normative discourse' across all academic fields of study and continue to play a key role in promoting the colonization of Indigenous peoples. Canada's Residential schools — and by extension university systems — set the groundwork to perpetuate on-going Eurocentric educational policies and practices designed to diminish and undermine Indigenous epistemologies, languages, histories and cultures while imposing assimilative frameworks and practices on Indigenous students [8-11]. The impacts of these institutional racist policies and practices has led many Indigenous students to drop out of school [12]. The Truth and Reconciliation Commission of Canada released a national report [13] which contains 94 Calls to Action calling upon all Canadian societal institutions inclusive of higher education systems to address the legacy of Canada's historical and on-going assimilative and genocidal policies and practices towards Indigenous Peoples. In response to these Calls to Actions, universities across Canada have embarked on a path of 'decolonizing and Indigenizing' the academy to address on-going institutional racism that is pervasive in university systems across Canada [14,15].

What does *decolonizing the university system* mean? It requires the act of unpacking and examining, through critical discourse and analysis, the history and contemporary lived experiences of colonization and its impacts on Indigenous peoples. It requires a critical examination of patriarchy, racism, and institutional policies and practices that privilege Eurocentric canons of knowledge systems, to the exclusion of Indigenous peoples' diverse

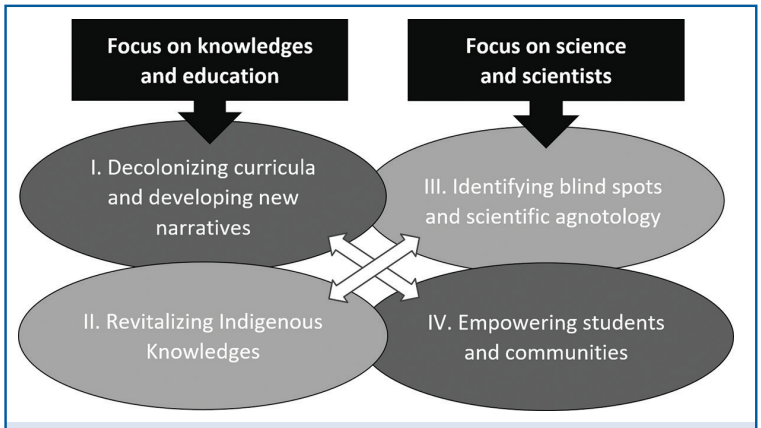
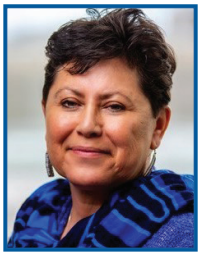


Fig. 1 The two main parts of the project (vertical columns) and the four decolonizing approaches (I … IV) pursued.



Donna Kahérakwas Goodleaf <donna.goodleaf@concordia.ca>
Centre for Teaching and Learning
Concordia University, Montreal, Quebec

Tanja Tajmel <tanja.tajmel@concordia.ca>
Centre for Engineering in Society
Concordia University, Montreal, Quebec

intellectual, agricultural, technological, scientific, cultural, research, and pedagogical knowledge systems, and practices across all academic fields of study [10,16]. It means opening up institutional spaces where Indigenous faculty and settler faculty actively engage as co-constructors in de-centering Eurocentric fields of study and re-centering and validating Indigenous peoples' diverse epistemologies, theories, worldviews, pedagogical practices and research methods across all academic disciplines.

On the faculty level, it requires non-Indigenous settler scholars and scientists to move out of their comfort zone and actively engage in critical self-reflection, analysis and discourse about their role as educators, examining their underlying assumptions, perceptions, biases and belief systems they have about Indigenous peoples. It requires divesting from perpetuating the Eurocentric-'normative discourses' and asking oneself: Whose voices/histories/perspectives are missing in course syllabi? What do I know about the history of the local Indigenous peoples and the territory the university is built on? What pedagogical methods and practices can I use to validate Indigenous students' voices, histories and perspectives in the classroom?

Decolonizing the academy is important because it empowers Indigenous students in their own identities while enriching the educational experiences of all students by providing a better understanding about the history and impacts of colonization, as well as Indigenous peoples' diverse histories, worldviews and contemporary lived experiences. Decolonizing the academia sets a path for all university stakeholders to embark on a path of co-constructing knowledge with Indigenous peoples and communities, while creating a better future for all that values Indigenous ways of knowing.

II. REVITALIZING INDIGENOUS KNOWLEDGE(S) (LW)

As our work aims to center and bring IK to academic attention, we must first understand what it means — which may seem elusive to some, due to the fact that there is no one definition of IK as it reflects the diversity of Indigenous peoples, cultures, and language. IK is also very personal to the individual knowledge holder. Mi'kmaq scholar, Marie Battiste and James Youngblood Henderson state that Indigenous knowledge "cannot be separated from the bearer to be codified into a definition" [17, p. 36]. It is important to understand that IK is, at its core, based on relationality. Battiste and Youngblood define IK as embodying the relations between humans and all living beings and spirits [17]. Tewa scholar, Gregory Cajete elaborates to include relationships to all forces and forms including celestial bodies [18]. These connections form the basis of maintaining social, economic, and diplomatic relationships among human beings. Indigenous worldviews and therefore IK, come from this place of intimate knowledge and understanding of relationality. IK has been and continues to ensure the survival of Indigenous peoples and the world they inhabit and informs decisions about day to day life. UNESCO recognizes the legitimacy and validity of IK as "integral to a cultural complex that also encompasses language, systems of classification, resource use practices, social interactions, ritual and spirituality. These unique ways of knowing are important facets of the world's cultural diversity and provide a foundation for locally-appropriate sustainable development" [19].

However, IK has largely been ignored, disregarded, disrespected, and delegitimized throughout the history of academic institutions and among Western scientists in particular, who often cling to myopic views of the world in which they see themselves as superior [1,17,20]. This serves to "silence, erase, appropriate, dominate, own, and oppress that which it encounters in the world — be it people, knowledge systems, or alternate visions of how the world could be" [21, p. 433]. The divergent worldviews of IK and Western science reflect the ongoing tensions with Indigenous peoples and settlers: "The hegemonic function of academic knowledge production makes individualism, competition, commodification and ownership (and its practices of exclusion in the academic everyday) normal, reifying the colonialist project by forcing the ongoing marginalization of Indigenous knowledge's, ways of knowing and scholarship to the peripheries of what is considered valid" [22, p. 54].

Two-Eyed-Seeing

How do we move forward with a project that brings together such divergent fields of study, backgrounds, worldviews, and ways of knowing? It is all about relationality. That is, our collective relations to each other and relations with time, place, and with all living things. A guiding principle to ground ourselves and our project can be found with what Mi'kmaq elder Albert Marshall calls Etuaptmumk or *Two-Eyed Seeing* [23]. When practicing Two Eyed Seeing a natural phenomenon is viewed through two eyes — two worldviews — one based in Indigenous Knowledge, and the other through Western science. The Two-Eyed Seeing approach allows for intercultural collaboration and multiple perspectives. Marshall writes: "It encourages the realization that beneficial outcomes are much more likely in any given situation when we are willing to bring two or more perspectives into play" [24]. By adhering to the principles of Two-Eyed Seeing, we can reach common ground as we strive for the pursuit of knowledge and understanding. Cree elder and star story expert, Wilfred Buck writes in his book, Tipiskawi Kisik: Night Sky Star Stories, "We arrive at knowledge from many different paths. And the more aware we are of other possibilities, the more sensitive we will be to understanding and difference" [25].

IK, grounded in relationality, is an inherent part of the project in that we commit to supporting IK throughout, recognizing the project as a process, and as an organic co-construction of knowledge. With our diverse backgrounds, we are faced with adhering to principles of IK as we develop our relationships with each other while navigating diverging worldviews and ways of

knowing, and maintaining respect, integrity, and the pursuit of knowledge for all.

III. IDENTIFYING BLIND SPOTS (TT, IS)

One way to reinforce knowledge authority is to erase or subordinate other knowledge systems and to cultivate an ignorance with regards to other knowledges and knowledge systems. For this kind of cultivation of ignorance and oblivion in the context of colonialism, Londa Schiebinger used the term *agnotology* [26], which we find appropriate to use in the context of our project. Figure 2 illustrates the embeddedness of physics in the academic field and the blind spots, the holes of knowledge, which are part of this field and even contribute with *cultivated not-knowing* to the stability of the sciences. The not-knowing, the ignorance, the agnotology makes the dominant narrative function. For example, in the context of the current global environmental crisis, science is seen as the solution. However, science not only plays a major role in finding solutions to the existential threats of our times such as climate change, migration, and the distribution of the global wealth, but also plays a significant role in causing these problems. Practices and decisions in scientific research therefore determine whether scientific and technological innovation is of benefit not only to the present but also to future generations, not only to a few but to most people. This approach requires a critical attitude and the willingness to critically question the scientific field. Frameworks and methodologies for this purpose are, for example, feminist theory [27], critical race theory [28], and Indigenous science and technology studies [29]. As illustrated in Figure 2,[5] we regard what has been referred to as the "core of knowledge in physics" [30, p. 113] as an inherent part of the *social field of physics*, highlighting that physics knowledge is not independent from the actors, their values and the historical context in which it was generated. Let's elaborate this further for the example of the Planck–Einstein relation $E = h \cdot \upsilon$ describing the energy E of a light quantum, a single wave-particle of light emitted or absorbed; υ is the frequency which determines the color of light, h is the Planck number named after the German physicist Max Planck who lived around 1900 in Berlin. This formula has been found valid and enabled the development of solar panels (absorption) and lasers (emission). Every STEM student is expected to know this relation. In our project, we will not question $E = h \cdot \upsilon$.[6] But we ask: What person was Max Planck? What circumstances enabled him (and others) to discover this relation? How was his work related to colonialism, by whom was he funded? What happened in this time around the world? Why were essentially only white men doing physics research? What knowledge about light was disrupted by colonialism? We consider questions of this kind as part of physics in a holistic sense.

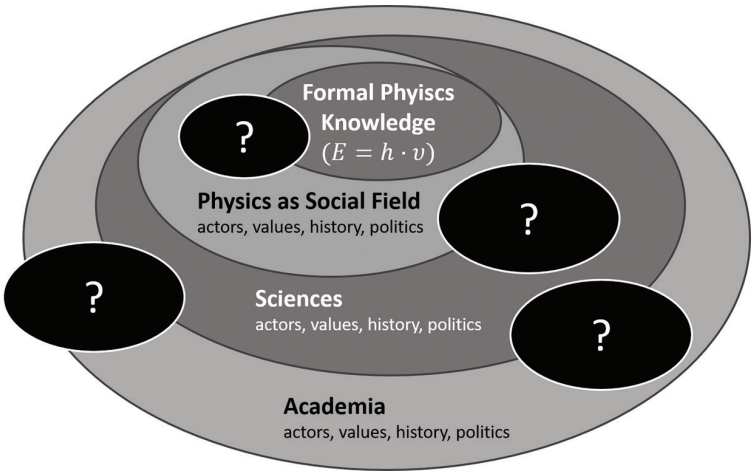


Fig. 2 Physics as a social field embedded in the social fields of the sciences and academia. Black areas illustrate blind spots also contributing to the field.

Decolonizing scientific 'common knowledge'

We as teachers follow curricula which define and decide what students should know, what is considered as 'important' knowledge, as 'common' knowledge and what is expected from a well-educated person, such as a physics graduate, to know. There is consensus that what we (as teachers, as academia) expect is far more than knowing applicable formulae and physical laws. We teach historical physical knowledge even if it does not meet contemporary scientific requirements of 'truth' and correctness. How scientific paradigms (and their changes) are influencing scientific 'truth' is well known from the work of Kuhn and his analysis of science as social institution [31]. We are used to scientific paradigms and their changes. For example, most would agree that every physics student should have heard about Bohr's atomic model, it can be found in logos and as a pin-up in physics departments, it has become the pictogram for the atom and even for physics. We all know that this model is not only wrong but also conceptionally misleading [32]. However, Niels Bohr is still a respected scientist and occupies a key role in physics history (and certainly deserves this role). Another example is Democritus and the atomists. They had the idea that the natural world consists of

5. Like all figures which try to illustrate complex interdependencies, they also bear the risk to oversimplify and even transmit a misunderstanding. However, let us take this figure as an attempt.
6. However, also laws and relations would be interesting to study. As Sandra Harding states, "formal statements require interpretation in order to be meaningful. The results of scientific inquiry can count as results only if scientists can understand what they refer to and mean. Without decisions about their referents and meanings, they cannot be used to make predictions, for example, or to stimulate future research" [27, p. 84].

two different kinds of realities: atoms and void. Atoms are solid with tiny hooks and barbs on their surfaces which enable them to be entangled [33]. Although long since proven to be physically wrong, most physicists would still agree that knowing about the Greek philosophers and their thoughts does not harm physics students and that such knowledge does have its place in academia. *Then, why not knowing and teaching about Indigenous Knowledge systems and philosophies?* They are spatially much nearer to any Canadian student than the Greek philosophers who are distant both physically and temporally (7000 km and 2400 years away) whereas Canadian universities and schools are built on Indigenous territory. With our project we aim to expand the understanding of 'common scientific knowledge' and of 'being educated' by teaching these knowledges, simply because we want our students to be comprehensively educated.

A current example to be examined through a decolonizing lens is the Thirty Meter Telescope (TMT) on Mauna Kea mountain [34]. Apart from its spiritual significance — in Hawaiian cosmology, Mauna Kea is the origin place of the Hawaiian people — the mountain is ecologically fragile [35]. Let us ask, what are the decision processes behind such projects? How are such projects impacting Indigenous realities? What are the values behind these decisions? Whose values are privileged? Decolonizing physics means to train and educate students to ask these questions and to examine them from diverse perspectives. This approach includes research of our own world views, as scientists. To identify "cultivated ignorance", we will study scientists' knowledge of and experiences with colonialism, and investigate textbooks and physics curricula, with which we hope to identify relevant blind spots and fill them with critical knowledge.[7]

IV. EMPOWERMENT (IS, TT)

As a further decolonizing approach, we will pursue training of community members and students to use science for their purposes and to follow research questions that are important for them. We regard situatedness as an important aspect in decolonizing the sciences: for our project, which is situated in the Canadian academic context, this means to elevate knowledges of the cultures and lands where our research and teaching is taking place and which have been erased or ignored by colonialism. Further, we strive to address issues Indigenous communities are confronted with and to exploit physics and science for empowerment and self-governance. So far, we have started a collaboration with the Kahnawá:ke Environmental Protection Office and are currently planning a citizen science project (led by Dr. Gregor Kos, Concordia University) for air quality measurement in Kahnawá:ke, one of the eight communities that make up the Mohawk (Kanien:keha'ka) Nation, in the neighborhood of Tiohtiá:ke/Montreal. The small portable measurement devices employ laser scattering controlled by Raspberry Pi minicomputers. The distribution of these devices, the training of citizens and the collection of data will be maintained by community members.

In another subproject, students from racialized groups get the opportunity to apply for a research project which addresses science and colonialism. For example, one student is currently working on unfolding the different layers of colonialism in Haitian STEM education. In yet another subproject, students are developing a mobile *Decolonizing Light App*, an interactive educational tool for smartphones which augments physical knowledge of light phenomena with Indigenous perspectives, all of which are embedded in their political and historical contexts. Finally, we offer well-funded positions for graduate students to conduct current physics research, which are explicitly advertised in Indigenous networks.

With the variety of activities outlined above we hope to contribute to a science for all and to improve the accessibility and inclusivity of physics.

7. See the contribution by Zanon et al. in the present issue covering one of our activities regarding textbook analysis.

ACKNOWLEDGEMENTS

We acknowledge the support of the Government of Canada's New Frontiers in Research Fund (NFRF), [NFRFE-2018-00725] and by Concordia University.

REFERENCES

1. Smith, L.T. *Decolonizing Methodologies: Research and Indigenous Peoples*. Zed Books, 2012.
2. Fanelli, D., and Glänzel, W. "Bibliometric Evidence for a Hierarchy of the Sciences", *PLoS One,* **8**, e66938 (2013).
3. Garvey, C., and Chard, D.S. *In*: Science for the People. Documents from America's Movement of Radical Scientists, *Edited by*: Schmalzer, S. Chard, D.S., and Botelho A. University of Massachusetts Press, Boston, MA, 2018, pp. 37-62.
4. Baker, K., MA Thesis, University of Waterloo, 2011.
5. Kamai, B., Cid, X., Quichocho, X.R., Little, A., Daniel, K., Gray, C., Neilson, H., and Blue Bird, J. "Indigenous Peoples Exist Within Physics", *American Physical Society (APS) Gazette,* **39**, 4-9 (2020).
6. American Physical Society Statistical Research Center, "Minority Physics Statistics", 2020 [Online]. Available: https://www.aps.org/programs/minorities/resources/statistics.cfm.

7. 1st International Symposium for Human Rights and STEM Education, "Declaration on the right to science education", 2018 [Online]. Available: http://didaktik.physik.hu-berlin.de/lise-mentoring-netzwerk/tl_files/clubLise/theme/images/tagung_2018/Berlin_Declaration_Right_to_Science_Education_2018.pdf [Accessed 08/21/2020].
8. Battiste, M. "Enabling the Autumn Seed: Toward a Decolonized Approach to Aboriginal Knowledge, Language, and Education", *Canadian Journal of Native Education,* **22**, 16-27 (1998).
9. Battiste, M. *Decolonizing education: Nourishing the learning spirit.* Purich Publishing Ltd., Saskatoon, SK, 2013.
10. Battiste, M., Bell, L., Findlay, I.M., Findlay, L., and Henderson, J. "Thinking Place: Animating the Indigenous Humanities in Education", *The Australian journal of Indigenous education,* **34**, 7-19 (2005).
11. Pidgeon, M. "More than a checklist: Meaningful Indigenous inclusion in higher education", *Social Inclusion,* **4**, 77-91 (2016).
12. Louie, D.W., Pratt, Y.P., Hanson, A.J., and Ottmann, J. "Applying Indigenizing Principles of Decolonizing Methodologies in University Classrooms", *Canadian Journal of Higher Education,* **47**, 16-33 (2017).
13. Truth and Reconciliation Commission of Canada, "Calls to Action", Winnipeg, Manitoba, 2015 [Online]. Available: http://trc.ca/assets/pdf/Calls_to_Action_English2.pdf.
14. Indigenous education initiatives at Ontario Institute for Studies in Education (OISE), "Advancing leadership in Indigenous Knowledge and education", 2015 [Online]. Available: https://www.oise.utoronto.ca/oise/UserFiles/File/IndigenousInitiaties2015.pdf.
15. Concordia University, "Indigenous Directions Action Plan: Concordia's Path Towards Decolonizing and Indigenizing the University", Montreal, 2019 [Online]. Available: https://www.concordia.ca/about/indigenous/action-plan.html.
16. Battiste, M., Bell, L., and Findlay, L.M. "Decolonizing Education in Canadian Universities: An Interdisciplinary, International, Indigenous Research Project", *Canadian Journal in Native Education,* **26**, 82-95 (2002).
17. Battiste M., and Youngblood, J., (Sa'ke'j) Henderson, *Protecting Indigenous Knowledge and Heritage: A Global Challenge*. Purich's Aboriginal Issues Series. UBC Press, Purich Publishing, Saskatoon, 2000.
18. Cajete, G. *Native Science: Natural Laws of Interdependence*. Clear Light Publishers, Santa Fe, NM, 2000.
19. UNESCO, 2017 [Online]. Available: http://www.unesco.org/new/en/natural-sciences/priority-areas/links/related-information/what-is-local-and-indigenous-knowledge/ [Accessed 08/21/2020].
20. Mihesuah, D.A., and Wilson, A.C. (Eds.) *Indigenizing the Academy: Transforming Scholarship and Empowering Communities*. University of Nebraska Press, 2004.
21. Brayboy, B.M.J., Gough, H.R., Leonard, B., Roehl, R.F.I., and Solyom, J.A. *In*: Qualitative research: An introduction to methods and designs. Jossey-Bass, San Francisco, CA, US, 2012, pp. 423-450.
22. Gala, C.K., and Holmes, A. *In*: Decolonizing and Indigenizing Education in Canada, *Edited by*: Cote-Meek, S. and T. Moeke-Pickering Canadian Scholars' Press, Toronto, 2020, pp. 51-72.
23. Martin, D.H. "Two-Eyed Seeing: A Framework for Understanding Indigenous and Non-Indigenous Approaches to Indigenous Health Research", *Canadian Journal of Nursing Research Archive,* **44**, 20-42 (2012).
24. Marshall, A. "Learning Together by Learning to Listen to Each Other", EdCan Network, 2018 [Online]. Available: https://www.edcan.ca/articles/learning-together-learning-listen/ [Accessed 08/21/2020].
25. Buck, W. *Tipiskawi Kisik: Night Sky Star Stories*. Manitoba First Nations Education Resource Centre Inc., Winnipeg, MB, 2018.
26. Schiebinger, L. *Plants and Empire: Colonial Bioprospecting in the Atlantic World*. Harvard University Press, Cambridge (Mass.), 2004.
27. Harding, S. *Whose Science? Whose Knowledge? Thinking from Women's Lives*. Cornell University Press, Ithaca, New York, 1991.
28. Delgado, R. *Critical Race Theory: An Introduction*. New York University Press, New York, 2012.
29. TallBear, K. *In*: Critical Indigenous Studies: Engagements in First World Locations, *Edited by*: A. Moreton-Robinson University of Arizona Press, Tuscon, 2016, pp. 69-82.
30. Cole, S. "The Hierarchy of the Sciences?", *American Journal of Sociology,* **89**, 111-139 (1983).
31. Kuhn, T.S. *The Structure of Scientific Revolutions*. Univiversity of Chicago Press, Chicago, 1970.
32. Kiray, S.A. "The Pre-service Science Teachers' Mental Models for Concept of Atoms and Learning Difficulties", *International Journal of Education in Mathematics, Science and Technology,* **4**, 147-162 (2016).
33. https://plato.stanford.edu/entries/democritus/#2 [Accessed 08/21/2020].
34. Neilson, H."Astronomy must respect rights of Indigenous peoples", *Nature,* **572**, 312 (2019).
35. Sanchez, N. "Mauna Kea, what it is, why it is happening, and why we all should be paying attention", 2019 [Online]. Available: https://intercontinentalcry.org/mauna-kea-what-it-is-why-its-happening-and-why-we-should-all-be-paying-attention/ [Accessed 08/21/2020].