Visual Analytics Lab (VAL)

2019

Addressing the imagination gap through STEAMM+D and indigenous knowledge

Diamond, Sara

Addressing the imagination gap through STEAMM+D and indigenous knowledge

Sara Diamond[a,1]

[a]Visual Analytics Laboratory, OCAD University, Toronto, ON M5T 1W1, Canada

Edited by Ben Shneiderman, University of Maryland, College Park, MD, and accepted by Editorial Board Member Eva Tardos November 5, 2018 (received for review May 21, 2018)

Alex Manu describes an "imagination gap," that is, "the gap between current capability and future possibility" [Manu A (2006) *The Imagination Challenge: Strategic Foresight and Innovation in the Global Economy*]. Merriam-Webster defines imagination as "the act of forming a mental image of something not present to the senses or never before wholly perceived in reality"; imagination combines "creative ability" and "resourcefulness" [Merriam-Webster (2018) Imagination. *Merriam-Webster Dictionary Online*. Available at https://www.merriam-webster.com/dictionary/imagination]. This paper considers two interdisciplinary fields in which distinct approaches have sought a solution to the "imagination gap" and have resulted in new research questions, methods, outcomes, and even philosophies. These are science, technology, engineering, arts, math, medicine, and design (STEAMM+D) and Indigenous research that establishes questions and methods from an integrated interdisciplinary worldview and the individual's responsibilities toward community and land. By intertwining these approaches, it is possible for science and society to apply creative problem solving in addressing complex challenges, thereby fostering sustainable innovation.

indigenous | STEAMM+D | new media | interdisciplinary | art and design

Alex Manu (1), in *The Imagination Challenge: Strategic Foresight and Innovation in the Global Economy*, describes an "imagination gap," that is, "the gap between current capability and future possibility." Merriam-Webster defines imagination as "the act of forming a mental image of something not present to the senses or never before wholly perceived in reality"; imagination combines "creative ability" and "resourcefulness" (2). Alex Manu describes the inability to throw off previous forms of hierarchy as a barrier to innovation; hence, researchers need the courage to paint the future from multiple, diverse perspectives that can challenge extant culture and practice. Imagination bears a close relationship to empathy, "the experience of understanding another person's thoughts, feelings, and condition from their point of view, rather than from your own" (3). Methods of and approaches to investigation shape the extent to which challenging, difficult, or unexpected questions emerge in research, and to which difference and empathy are mobilized to help to understand impacts. Codesign, in which all stakeholders participate in the creative process, is particularly critical when collaborating across cultural differences (4). This paper makes an argument for the cultivation of an interdisciplinary, culturally diverse, and empathic imagination. It builds on studies of interdisciplinary creativity such as The National Academies' *Beyond Productivity: Information Technology, Innovation, and Creativity* (5); Frank Moss's historical overview of the MIT Media Lab, *The Sorcerers and Their Apprentices* (6); the record of achievements of Crucible Studio at the Aalto University School of Arts, Design and Architecture (7); and the archives and analysis of the Banff New Media Institute (8). These studies provide rich examples of inventions that could only occur because of collaboration between artists, scientists, designers, and engineers, and they argue for the long game. Seeding multiple, adaptive forms of collaboration in a variety of institutional settings will pay off in societal and economic benefits.

Methods

This paper begins with a discussion of science, technology, engineering, arts, math, medicine, and design (STEAMM+D) themes and provides case studies and lessons drawn from several decades of work. A discussion of Indigenous knowledge embedded in an integrated approach to the arts and sciences follows. I write this paper from the perspective of a non-Indigenous person and draw on referenced sources by Indigenous thinkers, researchers, and makers. I appreciate the advice of Julie Nagam, Chair of Indigenous Art in North America, University of Winnipeg (Winnipeg, MB, Canada), who acted as a critical reader of this paper (9). STEAMM+D and Indigenous knowledge are potentially complementary approaches, yet the divergences in thinking are also challenges. The paper briefly shares the ways that OCAD University is adapting its curriculum and research to better incorporate STEAMM+D and Indigenous knowledge, working closely with Indigenous researchers and communities, and STEAMM+D specialists. This paper does not pretend to suggest a systematic approach to solving the "imagination gap." However, it does draw lessons (see *SI Appendix*, Table S1 for summary) that can support imaginative and inclusive approaches to invention. Many of the examples derive from Canada but are actionable beyond its borders.

STEAMM+D. STEAMM+D collaborations can serve as a source of innovative methods and approaches. Design innovator John Maeda has advocated for the inclusion of the arts and design within science, technology, engineering, and mathematics (STEM) education and research as a source of "breathtaking innovation" (10). Researchers can find new questions to ask or provide new perspectives on existing challenges. New forms of artistic expression, design, or science result from intersections that inspire and advance creative practice, bridging the "imagination gap."

1. Scientific breakthroughs. Collaborations between artists and scientists can result in genuine scientific breakthroughs because of the tools and insights that artists or designers contribute. Leaders of the Human–Computer Interaction community Bill Buxton and Saul Greenberg place value on how the working processes of artists and designers privilege ingenuity over incremental improvement. Artists' methods combine embodied and rational knowledge and often include observation, experimentation, sketching, abstraction, repetition, and critique. Buxton and Greenberg (11) value these tools for how they break the incremental research model. Furthermore, designers can position technical research within a larger system of effects. Hence, Bjögvinsson et al. (12) indicate a changed role for design, "a move from designing 'things' (objects) to designing Things (socio-material assemblies)." These assemblies are processes, methods, and the resulting relationships. In other words, such collaborative research can influence the organization of society, or, in the case study below, our fundamental understanding of the human body. Paola Antonelli is the curator of design at the Museum of Modern Art in New York City and creator of the *Design and*

This paper results from the Arthur M. Sackler Colloquium of the National Academy of Sciences, "Creativity and Collaboration: Revisiting Cybernetic Serendipity," held March 13–14, 2018, at the National Academy of Sciences in Washington, DC. The complete program and video recordings of most presentations are available on the NAS website at www.nasonline.org/Cybernetic_Serendipity.

Author contributions: S.D. wrote the paper.

The author declares no conflict of interest.

This article is a PNAS Direct Submission. B.S. is a guest editor invited by the Editorial Board.

[1]Email: sdiamond@ocadu.ca.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1808679115/-/DCSupplemental.

Published online February 4, 2019.

the Elastic Mind exhibition. She observes that new fields and related technologies such as biotechnology, green and clean technology, and nanotechnologies offer scientists the freedom to use their imaginations and more readily collaborate with artists and designers precisely because the subject matter of these new fields is invisible or malleable (13).

Case study 1: Scientific breakthroughs. In 2003, UK artist Jane Prophet created *Cell*, a project that she initiated with mathematician Mark d'Inverno, geneticist Neil Theise (a world leader in adult stem cell research and liver pathology), computer scientist William Saunders, and curator Peter Ride. Driven by Artificial Life algorithms, the software they created was visually arresting for its time. Using collaborative methods drawn from participatory design, the project proceeded through a series of workshops, intensive residencies, and presentations. It led to Theise's breakthrough discovery of stem cell plasticity and served Prophet's interest in Artificial Life, complexity theory, and aesthetics, effectively demonstrating relationships between previously invisible phenomena (14). Theise's (15) collaboration with Prophet ignited his now-enduring focus on "complexity theory applications to cell biology, formulations of a post-modern biology, and mind-body medicine." This is an example of a useful collaboration that mobilized art and design to further scientific research without subsuming the artist's interests. Prophet continued working on new projects with the same individuals from this impactful collaboration.

Lessons 1: Scientific breakthroughs.

i) *Cell* deployed a rigorous and self-reflective collaboration method. Explicit goals, clear processes, and opportunities to disseminate research are important, as is relative autonomy for each party in applying research results. Project leaders/facilitators should encourage researchers to declare their own research interests and emphasize the importance of crossing comfort lines and disciplinary boundaries.

ii) The best successes occur in integrated teams that are located in close proximity and communicate consistently, combining techniques such as scrums, rapid prototyping, agile engineering, and studio critiques.

iii) Artists encourage the exhibition of results. Public presentations require collaborators to refine the work.

iv) Collaboration requires adequate time to build curiosity, rapport, and working methods.

v) Education can build the tools needed for future success. Art education can emphasize the benefits for artists of such collaborations. These include the satisfaction of solving significant medical or science challenges by applying imagination and one's artistic and technical skills, as well as the possibilities opened by translating scientific methods and materials into one's artistic practice. In reverse, science education can suggest the ways that artistic techniques and collaborations open new ways of seeing data, understanding the body, or creating empathy with a research subject.

2. Art, design, and technology innovations. Meaningful technological innovations can occur through collaborations that involve overlapping the fields of art, design, and science. Artists' efforts to invent and redirect technologies have enriched the flexibility and creative capacity of tools. Canada has been the birthplace of powerful graphics computing, vision research, and 3D screen and camera capacities. These emerged through collaborations between artists, institutions such as the National Film Board and The Banff Centre, and nascent companies. Softimage, Alias/Wavefront, and IMAX are examples.

Case study 2: Art, design, and technology innovations. The Banff Centre for Arts and Creativity in Alberta, Canada, was home to the first Virtual Seminar and Residency on the Bioapparatus and then to the Art and Virtual Environments project in 1994–1995 (16). The latter included a partnership with Interval Research, Softimage, Alias/Wavefront, supercomputer company Silicon Graphics International, and the University of Alberta's computer science faculty. The program stressed, stretched, and repurposed graphics tools, early CAVE technologies, and data scanning systems in what were the most productive and long-lived impacts of this program. For example, Blackfoot artist Lawrence Paul Yuxweluptun, who is both a masked and Sxqyxwey dancer and a Coast Salish painter, participated in both residencies. Yuxweluptun, author of *Inherent Rights, Vision Rights*, described virtual reality (VR) as "very primitive technology" yet hoped to find "a way to bring others closer to my heart so they can understand my belief system… What it is like to be in a possessed state feeling rhythmic sounds of a longhouse, feeling sounds go through oneself, feeling a spirit inside you" (17). Yuxweluptun's designs required challenging algorithms that could build circular movements and manage the proximity of the immersed user in the graphic pathways. This project bears testimony to the power of culturally diverse imagination to fill the gaps created by unconscious bias in technology design (18). Also notable was *Placeholder*, a multiuser virtual environment led by Brenda Laurel and Rachel Strickland of Interval Research, in which interactors adopted the movement of creatures within the world to fly, swim, or crawl through the graphics environment, thereby promoting human empathy with organic life. The installation enabled inventions in early stereo vision, binaural sound and headsets, gloves, and networked VR (19). Brenda Laurel moved on to Sun Microsystems in part because of this kind of research.

The Art and Virtual Environments project is instructive for collaborations between artists, designers, scientists, and technologists at the early stage of a scientific field. Only a few of the artworks produced left prototype phase or were mature enough in aesthetic expression or technical stability to go on to future exhibitions, and few arts institutions had access to supercomputers or technical staff to support such projects. Projects used far more time for programming and rendering than was possible for artistic creation, yet graphics and related VR technologies benefited substantively. Looking back over two decades, both the prototypes and related critical evaluation were remarkably prescient with regard to contemporary mixed reality and VR practices.

Lessons 2: Art, design, and technology innovations.

i) Collaborations between scientists, artists, designers, and industries can result in significant inventions, but it is important to have a patient long-term approach to outcomes. A 2-year project window was too short to realize these objectives. Multiyear funding that builds on successes is a better approach to fundamental research.

ii) Residencies for diverse artists and designers in science laboratories in emerging fields such as nanotechnology, biotechnology, or artificial intelligence, accompanied by adequate funding, will in turn support technology development and maturation.

iii) Artists must enter these opportunities knowing that the resulting art works will be prototypes. At the same time, there should be incentives for artists to engage in these collaborations, including the exhibition of prototypes, credit for technological breakthrough, and potential ongoing work in emerging industries.

iv) Documentation and publication are invaluable to extracting future value and validating participating collaborators. One significant book, *Immersed in Technology*, retains relevance decades later (20).

3. Arts training: Empathy and inclusion. In his article "STEAM not STEM: Why Scientists Need Arts Training," Richard Lachman suggests that the arts can help determine the questions that researchers tackle, bring an ethical context to science, and teach empathy. Lachman (21) argues that the arts require both self-reflection and communication with others. Similarly, in codesign, all stakeholders engage in the design process from the beginning, together defining research questions and imagining technologies and systems (22). James Charlton and the disability rights movement were the first to formulate the concept of "Nothing about us without us," or, by extension, "Everything about us, with us" (23). Many groups that perceive themselves to be on the margins of society (yet are the object of research and policy) have endorsed this idea (24). These approaches offer opportunities for scientists to learn from knowledge embedded within communities that can enlighten new discoveries.

Case study 3: Arts training: Empathy and inclusion. Jutta Treviranus (25) leads OCAD University's Inclusive Design Research Centre (IDRC), composed of computer scientists, health researchers, designers, policy analysts, and disabled stakeholders and makers. IDRC frames disability as a mismatch between the needs of the individual and the design of the product, system, or service [rather than a personal characteristic or a binary state (disabled vs. nondisabled)]. IDRC toolkits are open-source combinations of online resources, websites, web code, exemplars, hubs, and tools that remove barriers to participation for users. IDRC uses machine learning (to indicate different ways of segmenting datasets to better support social inclusion) and blockchain (to underpin cooperative systems among the socially marginalized). The IDRC develops all of its projects in close collaboration with people with disabilities and other marginalized communities. They lead social practice initiatives [for example, the Our Doors Are Open project (26), which supports religious organizations in planning and adopting inclusive physical and virtual architecture]. An associated online Masters of Inclusive Design supports the education of students with disabilities and able-bodied students, creating a new generation of researchers with the lived experience of disability. These efforts create an infinite test bed in which an inclusive future can be imagined, prototyped, and implemented.

Lessons 3: Arts training: Empathy and inclusion.

i) Collaborative research methods, codesign, and inclusive design become critical factors in ensuring that project members respect all participants and that there is empathy between researchers and their subjects. Institutions and laboratories can create criteria for inclusion to ensure that those potentially impacted by research are at the codesign table.

ii) Laboratories benefit by applying the technologies that they have invented to enable diverse researchers' full participation. Microsoft, a collaborator of the IDRC, has prioritized inclusive design and consequently adopted this model.

iii) The IDRC chooses to make its entire roster of inventions open source to promote adoption, improvement, and dissemination.

4. Demystifying science and technology. Some works by artists deconstruct and disclose the working of science and technology. Bruno Latour raised the concern that scientific and technical inventions are "black-boxed"—that is, represented as finished, whole products whose inner workings or modes of development cannot be seen. Science appears as a free-floating enterprise, operating as an engine outside of society, "without people as carriers" (27). The results are resigned acceptance of technologies or fear, rather than participation, in defining the course of technological change. Many artists have undertaken projects either independently or with scientific collaborators that translate technology into forms that are understandable to nonspecialist audiences or that disrupt assumptions about these technologies.

Case study 4: Demystifying science and technology. Rafael Lozano-Hemmer combines creative ability and resourcefulness as an artist, designer, and technology inventor who produces installations and public art works. He creates powerful, metaphorical art works that advance technical, scientific, and data literacy (28). Lozano-Hemmer's *Population Theater* is a scalable data-visualization theater consisting of 7.5 billion individual computer-controlled points of light, offering a one-to-one relationship between the world's population and its data in which a single point of light represents every person. *Population Theater* creates "data-dramatizations" by running data from political economy, cultural studies, sociology, anthropology, psychology, history, communications, and other fields through the population data to help the public visualize and analyze the impacts of these data relative to their population (29). As he describes these interactions, "People may stand on the stage and watch presentations, but they are also encouraged to walk along the corridors amongst the 'rows' of monitors, physically 'zooming-in' to see individual persons" (29).

Lessons 4: Demystifying science and technology.

i) Science translation is challenging, so explorations beyond literal or didactic strategies could lead to breakthroughs that are immersive, affective, and at times humorous.

ii) The promotion of data and science literacy is an ongoing concern. Opportunities for collaboration between science centers, data analytics laboratories, and artists can make big science and big data more legible and accessible (30).

5. New philosophy. Philosophy frames the questions that we ask and the methods that we use. In the 20th and 21st centuries, art and science have often followed different currents, in part because of the separation of these disciplines. However, there are many points of convergence between the arts and sciences, and the persistence of skepticism in science converges with the critical temperament of much of experimental art. For example, the works of Yayoi Kusama, such as *Infinity Mirrors*, have long explored the scientific and philosophical concept of infinity (31). Practitioners of actor–network–theory contend that science is itself a product of its practices and relationships (27, 32), like any other field, including the arts. Linguistics, psychology, philosophy, mathematics, and politics have influenced artistic practice as much as technique. Twentieth-century artistic movements retreated from realistic representations, familiar to science, into abstraction, social and institutional critique, and explorations of the psyche. The 20th-century Dada movement, in which artists appropriated objects, contemporary ideas, and beliefs, repositioning them into new and ironic contexts, remains influential. Walter Benjamin (33), a member of the Frankfurt school, demonstrates that the circulation of images as commodities mediates their meaning. Attention to language, context, and power relations means that artists and cultural theorists believe that reality is contingent, mediated, and made meaningful only through its representation and interpretation. Psychoanalyst Jacques Lacan and philosophers such as Michel Foucault, Gilles Deleuze, and Felix Guattari, and feminists such as Luce Irigaray, Judith Butler, and Donna Haraway inspire postmodern artists such as Mary Kelly, who explores feminine identity (34, 35). These views come into conflict with thinkers who place value on artistic collaboration less for its ability to construct meaning and more for its ability to capture reality. These ideas, however, coincide with recent scientific theory, which recognizes that the observer's presence in experimental processes disrupts objectivity and influences the experiment (36).

In this century, art criticism has expanded to incorporate scientific studies of perception, cognition, and the philosophy of phenomenology (37). Mark B. N. Hansen (38, 39), in *New Philosophy for New Media*, notes that artists' digital works "compel us to confront the rich temporal depth, or affective bodily spacing, that underlies our complex experience of time." Char Davies's (40) immersive VR installations, in which interactors swim through vibrant natural landscapes, have this effect, as does Jon Rafman's *Illusive Sculpture Garden (Hedge Maze)* (41), in which participants explore magical pictorial spaces.

Philosophers of science such as physicist and ethicist Karen Barad (42) assert that researchers need to imagine the world from the point of view of nonhuman living agents, or apply "agential realism," to embed empathy into science. Artist Lisa Jevbratt elaborates on this with her *Interspecies Collaboration*, art made with nonhuman animals, and *Zoomorph*, a software that simulates how animals see (43). Such thinking is important when scientists are designing new life forms or addressing the Anthropocene; it has proven valuable for artists Jennifer Willet and Kira O'Reilly, who explore the ethical parameters of the use of biological materials in *Trust Me I'm An Artist*, and for Anna Dumitriu, who uses CRISPR programming for her *Make Do and Mend* suit (44). A play on the British World War II pamphlet of that name, Dumitriu's work references the 75th anniversary of the first use of penicillin in a human patient (45). Artists and designers increasingly find common ground with science to include perspectives outside of human consciousness, to "place the human in the loop," or to represent ambiguity.

Lessons 5: New philosophy.

i) Philosophers have long drawn from art-making and scientific discovery. Art and science both adopt and interpret concepts from philosophy. Much of this activity is isolated into disciplinary silos and does not "progress" in the linear sense; there are gaps between how artists' practices affect philosophy and how artists adopt new ideas and experiment with them in practice.

ii) Collaborations between artists, scientists, and philosophers that combine empirical practice and new ways of thinking require structured exposure and dialogue, and these could influence the direction of scientific and creative research more directly. University programs, public forums, and funded research can bring these fields together.

The impacts of STEAMM+D collaboration addressed above include scientific breakthroughs; meaningful technological innovation; empathy; deconstruction of the workings of science and technology to promote awareness and responsibility; powerful aesthetic expressions and effective design; and new philosophies with which to understand and shape the world.

Indigenous Knowledge. The discussion thus far draws primarily on Western philosophy to underscore the value of STEAMM+D collaboration. Indigenous scholars, knowledge bearers, and communities offer reflexive, place-based, and relational methods from science and culture that can add a significant dimension to transdisciplinary research. While they are distinct from one another, many Indigenous communities espouse a holistic and integrated view of science, technology, and culture, with cultural expressions operating as a means to uncover and represent scientific discovery. Network theories are compatible with Indigenous philosophy, which views technologies as part of natural systems and humans as relational actors. The discussion that follows proposes that STEAMM+D research can reach a new threshold in collaboration with Indigenous researchers who are grounded in a specific understanding of responsibility, future impact, and temporality. Powerful work that provides models for these practices and ideas is currently underway.

6. Relational and reflexive approaches. Margaret Elizabeth Kovach (46), who is Nêhiýaw and Saulteaux, argues for the adoption of Indigenous methods within the larger framework of qualitative research and the simultaneous decolonization of the academy so that researchers will not appropriate or misuse these methods as they grow in application. Thoughtful challenges to previous hierarchies can enable sustainable innovation and address the profoundly destructive impacts of centuries of genocidal policies and practices. Indigenous researchers must be at the table as these new methods are integrated. Kovach demonstrates that Indigenous approaches to research differ from Western qualitative methodologies in that they rely on tribal knowledge and languages that are more fluid and consistently reflexive (positioning self and context). "Place" positions Indigenous people within their relationship to others, to the environment, and to language (46). Researchers make use of narratives in both their methods and presentation of results. Shawn Wilson, a Cree writer from Northern Manitoba, emphasizes "relationality" as a core principle: (*i*) The shared aspect of an Indigenous ontology and epistemology is relationality (relationships do not merely shape reality, they are reality). (*ii*) The shared aspect of an Indigenous axiology and methodology is accountability to relationships. (*iii*) The shared aspects of relationality and relational accountability can be put into practice through choice of research topic, methods of data collection, form of analysis, and presentation of information (47).

Case study 6: Relational and reflexive approaches. The Native American-led Indigenous Art and Science (IAS) project is committed to developing the science, technology, and creative skills of Indigenous youth and return Indigenous knowledge "back to science." IAS grounds its activities in the values of "respect, relationship, reciprocity, and responsibility" (48), working to train Indigenous scientists. This initiative collaborates with universities, public schools, and tribal communities to promote and practice "restoration-based education." Restoration carries multiple meanings, addressing land, culture, and people. Active learning runs through all IAS activities, with youth engaged in citizen science to bring water systems such as the Kinnickinnic River in Milwaukee back to life (48). Cultural expression, including legends and stories, is a central tenet of the program, which considers digital storytelling to be "a powerful way for youth to learn more about the environment, identify issues of concern and advocate for awareness and solutions" (49).

Lessons 6: Relational and reflexive approaches.

i) Storytelling is a critical scientific method that serves and reinforces both culture and science. Researchers can benefit from listening to stories and translating their discoveries into narratives and metaphors.
ii) Partnerships with institutions that draw from Indigenous pedagogy and build pathways for Indigenous youth to become scientists are likely to bring benefits to those youth and to the science that they pursue.

7. Protocol. Bagele Chilisa explains "protocol" as the means through which reflexivity, as described by Kovach, and relationality, as described by Wilson, is enacted: "Overall, protocol is about respect. From that perspective, it applies to all aspects of the research process, and the researcher needs to be aware of protocol for the particular context and/or tribal epistemology being used" (50). Greg Cajete, in *Native Science: Natural Laws of Interdependence*, maintains that science is a living philosophy, not only a mathematical search for truth. Ceremony, planting cycles, knowledge of plants and environment, creation and place stories, and the nuance of Indigenous languages shape a new view of science that uses culture as a resource (51). Researchers are more likely to be effective when they employ methods that engage the imagination and stem from within communities' existing practices. Lynn F. Lavallée (52), an Anishinaabe and Métis social work researcher and Vice Provost of Indigenous Engagement at the University of Manitoba, has discovered that research within and with Indigenous communities is more effective when "the method includes sharing circles…and symbols such as paintings, drawings, sculptures, crafts, songs, teachings, and stories." Contemporary and historical knowledge across many fields emerges through cultural expression.

Case study 7: Protocol. OCAD University's Professor Bonnie Devine, a member of the Serpent River First Nation, led the recent Uncover/Recover project. Student's of the Indigenous Visual Culture Program explored the vaults of the Royal Ontario Museum to bring history and the affective impacts of fragile artifacts to life using digital media, abstract representation, and storytelling. Students worked closely with Indigenous knowledge keepers and archaeologists, visited originating communities, and undertook personal research that situated the meaning of the objects within their own stories of identity and place while respecting the history of the object (53, 54). Theirs was a deeply challenging experience that confronted museum protocol with Indigenous process, elicited the power of cultural memory, reminded participants of past trauma, and raised questions about where artifacts should reside.

Lessons 7: Protocol.

i) Collaborations between Indigenous researchers and scientific institutions (including museums) require protocol, attention, and time to include room for process and respect for community and place.
ii) The understanding that scientific materials and objects bear life requires recognition and protocol.
iii) Exhibition and presentation deadlines provide powerful means to move projects forward.

8. The animate and inanimate. Indigenous philosophers are devoted to preserving the unity of the animate and the inanimate world; the present, past, and future; and the visible and the invisible. They draw from place, story, and protocol, thereby respecting the value of context. Ahasiw Maskegon-Iskwew was a leader in Indigenous new media art, theory, and philosophy, as well as a proponent of "zoomorphism," or respectful engagement with the nonhuman world (55). He wrote of the ways that Nêhiýawewin, the Cree language, expresses this philosophy:

> Saying something is like something else, or saying that something is something else, is an act of magic. Cree language, Nêhiýawewin, works on the borders between animate and inanimate, those things that have body and meaning and those that do not…. In Cree the representational acts of metaphor and metonymy carry with them a weight of responsibility that is anchored in a vast network in which the human is only a small and sometimes questionable part. In Nêhiýawewin, when you say something is like something else you are representing an awareness, a gift that was given to you to visualize another mesh in the web, to see and to hear the transforming (56).

Glen Aikenhead, professor emeritus at the University of Saskatchewan, and Herman Mitchell, a Woodlands Cree (Nêhiýawak), point out that the Cree view of nature differs fundamentally from traditional Western ideas about holding power over nature or perceiving nature as a series of forces that must be dominated and controlled (57). As an alternative, they propose a set of "Indigenous ways of living in nature" (IWLN), which are place-based, monist, holistic, rational, mysterious, dynamic, systematically empirical, based on cyclical time, and both rational and spiritual. Aikenhead and Mitchell (57) point out that IWLN has "ensured Indigenous people's survival for tens of thousands of years, often under adverse circumstances." The authors argue for an integration of Indigenous and Western science. They state "sustainability is inherent to Indigenous knowledge, a concept not usually integral to Eurocentric science" (58). Like many artists, they contest realism, or a universal truth that transcends culture, and instead suggest that "multiple legitimate ways of understanding nature" exist (59).

Case study 8: The animate and inanimate. "Indigenous futurism" philosophy proposes that we must look ahead seven generations to imagine and take responsibility for the consequences of contemporary decisions. Jason Edward Lewis, a digital media artist, poet, software designer, and founder of Obx Laboratory for Experimental Media, is the director of the Initiative for Indigenous Futures, a 7-year Social Sciences and Humanities Research Council of Canada-funded partnership focused on how Indigenous communities imagine themselves seven generations hence. It is a means to "consciously imagine ourselves in and into the far future" (60). The multiple award-winning digital media artist Skawennati, who was born in Kahnawake Mohawk Territory, has produced a series of works on the games design platform machinama, the emerging technique of filmmaking in a digital environment, expressing Indigenous futures while drawing on the past. Her 2017 work, *She Falls for Ages*, is a science fiction "retelling of the Haudenosaunee (Iroquois) creation story [that] reimagines Sky World as a futuristic, utopic space and Sky Woman as a brave astronaut and world builder" (61). See *SI Appendix*, Fig. S1 for illustration.

Together, Lewis and Skawennati founded the Aboriginal Territories in Cyberspace (AbTeC) research-creation network to "ensure Indigenous presence in the web pages, online environments, video games, and virtual worlds that comprise cyberspace" (62). AbTeC trains youth in video game design, machinima creation, and coding to give them the tools to create speculative fictions about their future and that of the world, addressing the gap between current capability and future possibility.

Lessons 8: The animate and inanimate.

i) A holistic and cyclical approach to science and technology creates agency, allowing individuals and communities to address the "imagination gap" by redressing the past while creating the future.
ii) "Seven generations" thinking requires that all research consider the impact of decisions made now for seven generations into the future. Adopting this stance would create a new philosophical value set for STEAMM+D.

9. Technology and culture. Indigenous people have been producing technologies for close to a million years, including remedies and tools (63). Artist and cultural theorist Jackson 2bears writes that Indigenous people "often understand technology, as something alive and filled with spirit, something with which we are interconnected" (refs. 63 and 64, p. 14). This living network is composed of "obviously living things like animals and plants, but equally to seemingly inanimate things like mountains, rivers, and human-made artifacts" (64). 2bears (64) believes that the responsibilities of artists, scientists, and technologists are significant. They can conjure or remix powerful spirits with unexpected "spectral" impacts in the world through their inventions. Maori curator, artist, and researcher Maree Mills (65) offers the view that technology is a tool of Indigenous resilience, cultural continuity, and a conduit for storytelling that draws from "place-based methods." Mills notes that technological research occurs through creative practice and must place the "ontological and epistemological assumptions of the artist/researcher in context" (65).

Case study 9: Technology and culture. A new wave of Indigenous digital artists is building on the work of previous generations to underscore the power of art and technology to empower Indigenous communities and provide an Indigenous worldview (66). Their research investigates creative forms, tools, the scope of life, and the embodied experience of technologies as read through cultural specificity (67). Scott Benesiinaabandan's media and VR work, such as *Blood Memories* (2013), "seeks to address a continuing development and creation of a deeper personal cosmology; the impact of relationships and familial/communal ties, non-conventional ways of knowing (i.e. dreaming, intuition, blood memory), underlying threats and danger inherent in searching for truth and how these impacts radiate out into wider communities" (68, 69, 70). Indigenous artists working with science and technology are building new tools as well as new forms of expression. Incorporating these technologies and methods will create distinct capabilities that will benefit a broad spectrum of users.

Lessons 9: Technology and culture.

i) Interdisciplinary residency opportunities for Indigenous artists and designers within science laboratories and technology centers would strengthen emerging discoveries. Institutions and industry can create pathways to generalize these discoveries and credit the inventors.
ii) New technical discoveries need to return to communities to ensure that they share benefits.

These ideas and case studies underscore the need to remove technologies from "black boxes" and align them with concepts of relationality. Working from Julie Nagam's research of Indigenous methodologies of collaboration with makerspace and digital laboratories, graduate student Jasmine Winter and educator Justine Boudreau (71) propose "connecting contemporary Indigenous innovations to makerspace theories, and back to traditional Indigenous knowledge in a circular way that finds the common thread of community wellbeing." In an age of increasing globalization and cultural homogeneity, these methods emphasize the importance of place; appropriate protocol for each nation and territory; and respect for the land and all of its life forms, as well as its people. These three values of place, protocol, and respect, coupled with reflexivity and relationality, also form a path to empathy. Winter and Boudreau's practice suggests that addressing the "imagination gap" does not always require a rupture with the past, but rather its reevaluation, leading to creative invention. The edited volumes *Indigenous Art: New Media and the Digital* and *Coded Territories: Tracing New Pathways in Indigenous Art* provide a wealth of other examples of Indigenous STEAMM+D put into practice (72, 73).

Converging STEAMM+D and Indigenous Knowledge. OCAD University is a 143-y-old specialized art and design teaching and research university that prides itself on curricular innovation and research creation (74). In December 2016, after months of facilitated strategic foresight exercises, OCAD University adopted a new vision and mission and, in 2018, renewed strategic directions (75–77). The banner of the new vision statement proposes, "*Transformed by Imaginations:* OCAD University challenges you to audaciously and responsibly pursue the questions of our time through the powerful interplay of art, design, the social sciences, humanities, and the sciences" (75). The university's mission statement further encourages community building and emphasizes diversity, resilience, sustainability, and respect for Indigenous cultures. In response to student demand, a new academic plan will ensure that 75% of students study STEM curriculum within the next 4 years and that all students enroll in one course with Indigenous content (78). Faculties are restructuring programs to support interdisciplinary exchange, and a new building will break down disciplinary barriers.

A cluster hire of five Indigenous faculty (joining six current Indigenous faculty), as well as the increased inclusion of scientists, engineers, and health researchers in the university's faculty ranks, has made these aspirations material. Partnerships with a regional technology university will accelerate STEAMM+D curriculum, programs, and research. A new collective agreement simplifies cross-appointments of faculty and collaborative programs. Many years of testing and improving interdisciplinary programs such as Digital Futures, Design for Health, and Inclusive Design (among others), as well as a recent survey and brand analysis regarding students' needs and expectations, have created confidence in this direction. This confidence is strengthened by over a decade of success in achieving significant funding for STEAMM+D research projects. The true challenge ahead will be the respectful integration of Indigenous methodologies and systems with art, design, and STEM, as well as our curriculum, research, administrative, and governance practices.

Conclusions

The current moment presents us with the opportunity—and the necessity—to utilize diverse methods from two cross-pollinating practices. The core challenges of the "imagination gap" are the need to bridge between current capability and future possibility, to form an image not present to the senses, to imagine from diverse perspectives, to draw upon creative ability and resourcefulness, to challenge extant culture, to draw upon empathy, to ask new and unexpected questions, to find new methods, and to undertake adaptive collaborations. The table in *SI Appendix* summarizes solutions provided throughout the chapter. Creative collaborations, when funded and well managed, demonstrate that social, economic, and cultural applications of STEAMM+D that take into account environmental and human challenges can be imagined and realized, resulting in new technologies, questions, and methods. STEAMM+D combined with holistic, historically grounded, seventh-generation–focused, respectful, and relational methods of Indigenous knowledge in arts, science, and technology will manifest an inclusive, environmentally responsible future.

1. Manu A (2006) *The Imagination Challenge*: Strategic Foresight and Innovation in the Global Economy (Pearson Education, Chicago).
2. Merriam-Webster (2018) Imagination. *Merriam-Webster Dictionary Online*. Available at https://www.merriam-webster.com/dictionary/imagination. Accessed October 20, 2018.
3. Sussex Publishers (2018) Empathy. *Psychology Today*. Available at https://www.psychologytoday.com/us/basics/empathy. Accessed October 20, 2018.
4. Halskov K, Christensen BT (2018) Designing across cultures. *CoDesign* 14:75–78.
5. National Research Council Division on Engineering and Physical Sciences, Computer Science and Telecommunications Board, Committee on Information Technology and Creativity (2003) *Beyond Productivity: Information Technology, Innovation, and Creativity* (National Academies Press, Washington, DC).
6. Moss F (2011) *The Sorcerers and Their Apprentices: How the Digital Magicians of the MIT Media Lab Are Creating the Innovative Technologies That Will Transform Our Lives* (Crown Business, New York).
7. Crucible (2018) Research productions. Available at crucible.mlog.taik.fi/productions/. Accessed October 21, 2018.
8. Cook S, Diamond S (2012) *Euphoria and Dystopia: The Banff New Media Dialogues* (Banff Centre Press, Banff, AB, Canada; University of Waterloo, Riverside Architectural Press, Waterloo, ON, Canada).
9. University of Winnipeg (2018) Julie Nagam. Available at https://www.uwinnipeg.ca/art-history/faculty-staff/julie-nagam.html. Accessed October 28, 2018.
10. Stem to Steam (2018) What is STEAM? Available at stemtosteam.org/. Accessed October 21, 2018.
11. Greenberg S, Buxton B (2008) Usability evaluation considered harmful (some of the time). *CHI 2008 Proceedings, April 5–10; Florence*, eds Czerwinski M, Lund A (ACM, Florence, Italy), pp 111–120.
12. Bjögvinsson E, Ehn P, Hillgren P-A (2012) Design things and design thinking: Contemporary participatory design challenges. *Des Issues* 28:101–116.
13. Antonelli P (2008) *Design and the Elastic Mind* (Museum of Modern Art, New York).
14. Prophet J, Pritchard H (2015) Performative apparatus and diffractive practices: An account of artificial life art. *Artif Life* 21:332–343.
15. Theise N (2018) Biography and curriculum vitae. Available at neiltheise.com/cv.php. Accessed October 21, 2018.
16. Richards C, Tenhaaf N (1991) *Virtual Seminar on the Bioapparatus* (The Banff Centre, Banff, AB, Canada). Available at www.catherinerichards.ca/news%20pop%20up/bioapparatus/bioapparatus_1-4_contents.pdf. Accessed October 21, 2018.
17. Yuxweluptun LP (1992) Inherent rights, vision rights. Available at https://www.digitalartarchive.at/database/general/work/inherent-rights-vision-rights.html. Accessed October 21, 2018.
18. Todd L (1996) Aboriginal narratives in cyberspace. *Immersed in Technology: Art and Virtual Environments*, eds Moser MA, MacLeod D (MIT Press, Cambridge, MA; The Banff Centre, Banff, AB, Canada), pp 179–194.
19. Laurel B, Strickland R (1992) Placeholder virtual reality project. Available at tauzero.com/Brenda_Laurel/Placeholder/Placeholder.html. Accessed October 21, 2018.
20. Moser MA, MacLeod D, eds (1996) *Immersed in Technology: Art and Virtual Environments* (MIT Press, Cambridge, MA; The Banff Centre, Banff, AB, Canada).
21. Lachman R (2018) STEAM not STEM: Why scientists need arts training. *The Conversation*. Available at theconversation.com/steam-not-stem-why-scientists-need-arts-training-89788. Accessed October 21, 2018.
22. Smith R, Bossen C, Kanstrup AM (2017) Participatory design in an era of participation. *CoDesign* 13:65–69.
23. Charlton J (2000) *Nothing About Us Without Us: Disability, Oppression and Empowerment* (Univ California Press, San Diego).

24. Cultural Survival (2013) Nothing about us, without us. Everything about us, with us. *Cultural Survival Quarterly Magazine*. Available at https://www.culturalsurvival.org/publications/cultural-survival-quarterly/nothing-about-us-without-us-everything-about-us-us. Accessed October 21, 2018.
25. Treviranus J (2018) What is inclusive design? Inclusive Design Research Centre at OCAD University. Available at https://idrc.ocadu.ca/about-the-idrc/49-resources/online-resources/articles-and-papers/443-whatisinclusivedesign. Accessed October 21, 2018.
26. OCAD University (2018) Our doors are open—nos portes sont ouvertes. Available at https://opendoors.idrc.ocadu.ca. Accessed October 21, 2018.
27. Latour B (1998) *Aramis: The Love of Technology* (Harvard Univ Press, Boston).
28. Lozano-Hemmer R (2018) Projects. Available at www.lozano-hemmer.com/projects.php. Accessed October 21, 2018.
29. Lozano-Hemmer R (2016) Population theatre. Available at www.lozano-hemmer.com/population_theatre.php. Accessed October 21, 2018.
30. Meirelles I (2013) *Design for Information: An Introduction to the Histories, Theories, and Best Practices Behind Effective Information Visualization* (Rockport, Boston).
31. The Art Story (2018) Artists: Yayoi Kusama. *The Art Story: Modern Art Insight*. Available at https://www.theartstory.org/artist-kusama-yayoi.htm. Accessed October 21, 2018.
32. Latour B, Woolgar S (1979) *Laboratory Life: The Construction of Scientific Facts* (Princeton Univ Press, Princeton).
33. Benjamin W (1985) *Illuminations: Essays and Reflections* (Schocken Books, New York).
34. Foucault M (1973) *Madness and Civilization: A History of Insanity in the Age of Reason* (Vintage Books, New York).
35. Kelly M (2018) Mary Kelly. Available at www.marykellyartist.com. Accessed October 21, 2018.
36. Standish RK (2005) The importance of the observer in science. *Proceedings the Two Cultures: Reconsidering the Division Between the Sciences and Humanities, July 2005*. arXiv:physics/0508123 [physics.pop-ph].
37. Parry JD, ed (2011) *Art and Phenomenology* (Routledge, New York).
38. Hansen MBN (2004) *New Philosophy for New Media* (MIT Press, Cambridge, MA).
39. Hansen R (2008) Things v objects. *Art Monthly*. Available at https://www.artmonthly.co.uk/magazine/site/article/things-v-objects-by-rikke-hansen-jul-aug-2008. Accessed October 21, 2018.
40. Davies C (2018) Immersence. Available at www.immersence.com/. Accessed October 21, 2018.
41. Jones J October 8, 2015) Oculus Rift will change the world, but can it change art? *The Guardian*. https://www.theguardian.com/artanddesign/jonathanjonesblog/2015/oct/08/oculus-rift-jon-rafman-art-virtual-reality. Accessed October 21, 2018.
42. Barad K (2014) Invertebrate visions: Diffractions of a brittlestar. *The Multispecies Salon*, ed Kirksey E (Duke Univ Press, Durham, NC), pp 221–241.
43. Jevbratt L (2018) Lisa Jevbratt. Available at jevbratt.com/cgi-bin/index.pl. Accessed October 21, 2018.
44. Willet J (2018) Be-wildering. Available at jenniferwillet.com/home/projects/be-wildering/. Accessed October 21, 2018.
45. Labiotech.eu (2018) Art made with CRISPR aims to raise awareness of antibiotic resistance. Available at https://labiotech.eu/bioart/anna-dumitriu-crispr-antibiotic-resistance/. Accessed October 21, 2018.
46. Kovach ME (2011) *Indigenous Methodologies: Characteristics, Conversations, and Contexts* (Univ Toronto Press, Toronto).
47. Wilson S (2008) *Research Is Ceremony: Indigenous Research Methods* (Fernwood Publishing, Blackpoint, NS, Canada), p 21.
48. University of Wisconsin-Madison (May 8, 2012) Indigenous arts and sciences Earth partnership. *University of Wisconsin-Madison Arboretum News*. Available at https://arboretum.wisc.edu/news/arboretum-news/ias-announce/. Accessed October 21, 2018.
49. Bauer-Armstrong C (2016) Education through ecological restoration: Earth partnership engages youth as environmental stewards. *Green Schools National Network*. Available at https://greenschoolsnationalnetwork.org/education-ecological-restoration-earth-partnership-engages-youth-environmental-stewards/. Accessed October 21, 2018.
50. Chilisa B (2011) *Indigenous Research Methodologies* (Sage Publications, New Delhi), p 153.
51. Cajete G (1995) *Native Science: Natural Laws of Interdependence* (Clear Light Publishers, Santa Fe, NM).
52. Lavallée LF (2009) Practical application of an indigenous framework and two qualitative indigenous research methods: Sharing circles and Anishnaabe symbol-based reflection. *Int J Qual Methods* 8:21–36.
53. Johnson R (2018) Indigenous students unveil digital art inspired by cultural objects at the Royal Ontario Museum. *CBC News*. Available at https://www.cbc.ca/news/indigenous/ocad-digital-art-rom-cultural-artifacts-1.4609095. Accessed October 20, 2018.
54. OCAD University (2018) INVC students offer sneak peek into ROM collaboration. Available at https://www2.ocadu.ca/keyword/bonnie-devine. Accessed October 20, 2018.
55. Diamond S (2012) Performing transformations: Ahasiw Maskegon-Iskwew. Available at ghostkeeper.gruntarchives.org/essay-performing-transformations-ahasiw-maskegon-iskwew-sara-diamond.html. Accessed October 21, 2018.
56. Maskegon-Iskwew A (1995) Talk Indian to me #2. Available at ghostkeeper.gruntarchives.org/publication-mix-magazine-talk-indian-to-me-2.html. Accessed October 21, 2018.
57. Aikenhead G, Mitchell H (2011) *Bridging Culture, Indigenous and Scientific Ways of Knowing* (Pearson, Toronto), p 65.
58. Aikenhead G, Mitchell H (2011) *Bridging Culture, Indigenous and Scientific Ways of Knowing* (Pearson, Toronto), p 11.
59. Aikenhead G, Mitchell H (2011) *Bridging Culture, Indigenous and Scientific Ways of Knowing* (Pearson, Toronto), p 67.
60. Lewis JE (2014) A better dance and better prayers: Systems, structures, and the future imaginary in aboriginal new media. *Coded Territories: Tracing New Pathways in Indigenous Art*, eds Loft S, Swanson K (Univ Calgary Press, Calgary, AB), pp 49–78.
61. Skawennati (2017) She falls for ages. Available at www.skawennati.com/SheFallsForAges/ and abtec.org/#home. Accessed October 21, 2018.
62. Aboriginal Territories in Cyberspace (2018) About. Available at abtec.org/#about. Accessed October 28, 2018.
63. Little Bear L (1995) Foreword. *Native Science: Natural Laws of Interdependence*, ed Cajete G (Clear Light Publishers, Santa Fe, NM).
64. 2bears J (2014) My post-Indian technology autobiography. *Coded Territories: Tracing New Pathways in Indigenous Art*, eds Loft S, Swanson K (Univ Calgary Press, Calgary, AB), pp 12–29.
65. Mills M (2016) Pou Rewa, the liquid post, Maori go digital? *Public 54: Indigenous Art: New Media and the Digital*, eds Igloliorte H, Nagam J, Taunton C (Public Access, Toronto), Vol 27, pp 14–24.
66. L'Hirondelle C (2016) Relating necessity and invention: How Sara Diamond and The Banff Centre aided indigenous new media production (1992–2005). *Public 54: Indigenous Art: New Media and the Digital*, eds Igloliorte H, Nagam J, Taunton C (Public Access, Toronto), Vol 27, pp 25–35.
67. Igloliorte H, Nagam J, Taunton C (2016) Transmissions: The future possibilities of indigenous digital and new media art. *Public 54: Indigenous Art: New Media and the Digital*, eds Igloliorte H, Nagam J, Taunton C (Public Access, Toronto), Vol 27, p 6.
68. Imaginenative.org (2018) Imaginenative invites you to experience the future. Available at www.imaginenative.org/2167/. Accessed October 21, 2018.
69. Hampton C (2017) Forget 2017—these Indigenous VR artists are imagining Canada's future 150 years from now. *CBC Arts*. Available at https://www.cbc.ca/arts/forget-2017-these-indigenous-vr-artists-are-imagining-canada-s-future-150-years-from-now-1.4167856. Accessed October 21, 2018.
70. Benesiinaabandan S (2018) Benesiinaabandan: Projects. Available at www.benesiinaabandan.com/artisticcv/. Accessed October 21, 2018.
71. Winter J, Boudreau J (2018) Supporting self-determined indigenous innovations: Rethinking the digital divide in Canada. *Technol Innovation Manage Rev* 8:38–48.
72. Igloliorte H, Nagam J, Taunton C, eds (2016) *Public 54: Indigenous Art: New Media and the Digital* (Public Access, Toronto), Vol 27.
73. Loft S, Swanson K, eds (2014) *Coded Territories: Tracing New Pathways in Indigenous Art* (Univ Calgary Press, Calgary, AB).
74. OCAD University (2018) Research at OCAD U. Available at https://www2.ocadu.ca/research/projects?_ga=2.229238297.444188634.1527467573-8730638.1519538237. Accessed October 21, 2018.
75. OCAD University (2017) Vision and mission statements. Available at https://www.ocadu.ca/about/vision_mission.htm. Accessed October 21, 2018.
76. OCAD University (2017) OCAD University vision and mission process report. Available at https://www.ocadu.ca/Assets/content/about/Vision+and+Mission+Process+Report.pdf. Accessed October 21, 2018.
77. OCAD University (2017) Strategic directions 2017–2022. Available at https://www.ocadu.ca/Assets/OCAD+University$!e2$!80$!99s+Strategic+Directions+2017-2022+(PDF).pdf. Accessed October 21, 2018.
78. OCAD University (2017) OCAD University academic plan: Transforming student experience 2017–2022. Available at https://www.ocadu.ca/Assets/content/governance/Academic-Plan-2017.pdf. Accessed October 21, 2018.