Invited manuscript accepted for publication in the *Canadian Journal of Science, Mathematics and Technology Education*, August 2018

Beyond Tinkering and Tailoring: Re-de/signing Methodologies in STEM Education

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Abstract
This commentary responds to the seven articles in this Special Issue by reading them through lenses of tinkering and tailoring, juxtaposing and extending them with other writings across a range of fields. Disrupting and displacing methodologies in science education is not something new. There are multiple examples from two and more decades ago where science educators and researchers have drawn attention to the need to approach science education research and pedagogy differently. However, the authors in this issue have worked from different theories in their efforts to go beyond tinkering and tailoring and rede/sign methodologies in STEM education. We are inspired by the contributions and hope that these new approaches will achieve the changes that have eluded many similar arguments in the past.
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Keywords
Science education . STEM education . Nature . New materialism. More-than-human . Feminism. Research methodologies

The editors of this special issue framed their call for manuscripts with a 'non-exhaustive list of potential ideas' that discuss 'disrupting and displacing methodologies in STEM education for new knowledge production within the context of "from engineering to tinkering with theory for eco-social justice^ (Higgins et al. 2017, p. 243). The seven articles included here sample across their questions, but there is plenty of potential for the theme to continue in future issues with articles that address the remaining, and other, questions. The editors also highlight the differences between engineering approaches, which focus on the movement from the ends to the means and results in research as 'best fit' and 'best practices' (design), and tinkering, which utilizes tools and techniques intended for other ends (de/sign).

All authors of the articles argue for different approaches to science/STEM education from those currently practiced. Perhaps not unexpectedly, many authors refer to the currently fashionable feminist 'newmaterialist' work of scholars such as Karen Barad. But others introduce newer (and less familiar) sources into their essays.

Sara Giodorno reminds us that 'tinkering' has traditionally in the West been thought of as a white male messing about in a trial and error way. She also outlines how the field of synthetic biology has recovered the term, 'through recourse to a (mythical) U.S. national, protestant ethos of supporting the hard-working, underdog that may have the effect of reifying racialized and gendered disparities in access to scientific knowledge production.' All of the articles exceed this traditional notion of tinkering in playing with theories for eco-social justice.

Of course, 'tailoring' has also been a predominantly male occupation but not one that involves messing about in a trial and error way. Rather, tailoring is to some extent analogous to engineering in considering the relationship between design and de/sign that the editors of this Special Issue frame its explorations by reference to 'the dichotomous metaphors of engineering and tinkering.' Like engineering, tailoring involves a movement from the ends to the means, whereby the tailor makes appropriate selections from the discourses of formal logic, picking concepts, categories, and constructs already purposed for their process.

Giodorno refers to how 'the modern day biological tinkerer, attempts to replicate the methods of evolution to create new organisms or new functions for existing organisms.' This reminds us of Stefan Helmreich's (2009) discussion of how the tree of life is dissolving because what counts as biological life is changing, as are ther elation between 'life forms' and 'forms of life,' and what counts as native or alien, familial or other. She also discusses playfulness and a hands-on praxis rooted in feminist pedagogy as integral to feminist tinkering practices. She draws on Maria Lugones' (1987) explanation of praxis, but it is also useful to think of feminist praxis as having the reconstitution of knowledge as a central concern (see, e.g., Stanley 1990).

We particularly liked the playfulness of Giodorno's feminist tinkering in re-working the quotation from Bernadine Dohrn (in Dubner 2009) as a situated approach to understanding our world in that moment: We have to intra-act as we can, becoming answerable for what we learn how to see, and continue to intra-act.

Although much has already been written about the need for feminist science and feminist pedagogy in science education, Giodorno's article makes a significant contribution to disrupting and displacing traditional STEM education and re-de/signing it from a feminist praxis perspective, as very different from (male) tailoring.

Like Giodorno, Maria Wallace, Marc Higgins, and Jesse Bazzul engage in tinkering, but from a different perspective. Wallace et al. are interested in response-ability, in their case how Thinking with Nature (TwN) can provoke an enactment of ethico-political response-ability in research on science education, whereas Giodornois interested in a way of potentially understanding and becoming response-able for the results of feminist hands on praxis.

Consistent with Barad and others, Wallace et al. capitalize Nature, 'to indicate Nature itself, or the totality of nature and all of its interconnected space-time-matterings.' This prompted us to think about how 'nature' is often configured in Western ways, as Senda (1992) emphasizes with respect to concepts of nature in Japan:

> European concepts of nature and culture as formulated in the late seventeenth century were adopted wholesale in Japan virtually without criticism until now…The time has come to consider the traditional Japanese idea of nature as Kami (gods) in comparison with the binary opposition of nature/culture which derives from modern rationalism. Kami who represent elements of nature belonged to a Pantheon in ancient Japan…In ancient Japan people believed that natural landscapes were created and inhabited by these Kami, and that the will of these Kami controlled the cultural domain. (pp. 129–130).

Wallace et al. focus on activating concepts to '(re)turn science educators' attention towards the preexisting possibility of Nature as a contour of inquiry' and 'further fracture, or destabilize, prevailing anthropocentric regimes of science education.' This argument resonates with Carolyn Merchant's (2016) recent work in which she rereads familiar authors and events and discusses nature as an active, sometimes disruptive and unruly entity in the twenty-first century. She traces the problems of prediction and control of autonomous nature from ancient times—when nature was seen as unpredictable, unruly, and recalcitrant through

the post Scientific Revolution scientists who sought ways of predicting and controlling the world around them, and into the twenty-first century. Here, she sees humanity as being 'in the throes of a paradigm shift, one that is triggered by two factors: the rise of the new sciences of chaos and complexity and by climate change as the most widespread catastrophe for the human future' (p. 1), and we are now in a society where 'the comforts of mechanistic science have been superseded by the uncertainties of chaos and complexity theories' (p. 155). Her discussions of the terms *natura naturans* (nature creating, evolving, and changing) and *natura naturata* (nature as experienced in the everyday world) (p. 8) are resonant with Wallace et al.'s discussion of Nature and nature.

Notions of evolution, becoming, and entangled nature are becoming more complex, and the holobionts discussed by Wallace et al. share much with the more-than-human assemblages discussed by Probyn (2016) and Helmreich (2009) and the evolutionary complexities created by gene transfer between microbes. Biology is no longer simple, and we need new methodologies, epistemologies, and ontologies for scientific research and education such as those raised by Wallace et al.; as they say 'we need lines of thinking/flight toward these becomings; toward what does not yet exist.'

Elizabeth de Freitas and Nathalie Sinclair disturb the assumption that reasoning with and about uncertainty can be tailored to classical probability theory—rules regarding the distribution of probabilities across outcomes and the impact of order and conjunction on probability. As these authors point out, humans do not always reason according to the rules of classical probability. They explore quantum probability as a possible alternative formalization of reasoning with uncertainty by situating it as part of a quantum turn in the social sciences, with particular reference to the work of Barad.

There are a number of historical antecedents to de Freitas and Sinclair's suggestions concerning the educational implications of quantum mechanics' defiance of the causal logic of classical Newtonian science, such as their speculation that quantum probability might help reevaluate developmental evidence regarding children and learning. They

> wonder if quantum probability models might shed a different light on such experiments. Perhaps these children are reasoning through uncertainty in ways that are at odds with classical logic and abstraction. Indeed, it may be that they are mobilizing very different onto-epistemologies in which uncertainty is directly linked to the inherent indeterminacy of concepts such as shape and number.

This question was addressed so by the late William E. Doll Jr. (1986) who argued that, since the midseventeenth century, the Newtonian paradigm governed not only science but also social science, including education, and provided the foundation of the 'measured curriculum.' He suggested that the dependence of American psychologists and educators on Newton's scientific paradigm might explain their misinterpretation of Piaget's work on adaptive biological and cognitive structures, which have more in common with Prigogine's work on self-organizing chemical and biological structures.

We were reminded of both Doll and Prigogine by the epigraph to Nikki Rotas' article, 'How should we think of measurement?' which she attributes to one of Prigogine's sometime co-authors, Isabelle Stengers (Rotas's choice of this epigraph also reminds us that tailoring involves a great deal of measurement). In a study that in some ways complements de Freitas and Sinclair's, Rotas draws on a yearlong research project to examine 'how robotic design is a diffractive practice that is integral to understanding measurement as a quantum process that values the dynamic patterning of transdisciplinary learning.' In her abstract, Rotas refers to 'the feminist new materialist practice of "diffraction" (Barad 2007) in an afterschool robotics club,' and subsequently states that '[t]hroughout the years, Barad (alongside Haraway) has

been developing a diffractive methodology through a questioning of science, measurement, matter and materiality across disciplinary boundaries.' We are disposed to historical accuracy and would therefore prefer to acknowledge that Haraway (1994), not Barad, initiated 'diffraction' as an approach to inquiry, although we recognize the merits of Barad's (2014, p. 168) recent refinements of the concept as 'an iterative (re)configuring of patterns of differentiating-entangling.'

Rotas' essay diffracts the concept of a measurement 'apparatus' very generatively by juxtaposing X-ray and ultrasound machines with the brittlestar, an eyeless echinoderm that composes with its environment in ways that are attuned to movements of potential (i.e., fertilization) and constraint (i.e., predation). We suggest that the brittlestar's ability to reconfigure the boundaries and properties of its body is significant not only for (re)conceptualizing the machineries of measurement but also for 'debugging' understandings of the 'human' and more-than-human.

This reminds us of Naomi Mitchison's (1962) story of intra-species communication in which Mary, a human communications officer, seeks to learn how to communicate with any sentient creatures she encounters during her travels. Mary's encounters confront her with the limitations of human knowledge/perception patterns and practices. A key illustration of such limitations occurs when Mary encounters an alien species that she calls 'radiates.' She describes them as 5-armed starfish-like intellectual beings (that is, they physically resemble Earth's echinoderms). Mary reflects: 'One is so used to a two-sided brain, two eyes, two ears, and so on that one takes the whole thing and all that stems from it for granted. Incorrectly, but inevitably. My radiates had an entirely different outlook.' (Mitchison, 1962, p. 17). By learning to think with and communicate with the alien echinoderm-like radiates, Mary is able to understand how they might have evolved (Mitchison 1962, p. 17).

Haraway (2007, pp. 4–5) describes the entangled partnerships developed through such encounters between species in terms of

> the cat's cradle games in which those who are to be in the world are constituted in intra- and interaction…consequent on a subject and object-shaping dance of encounters…they are also always meaning-making figures that gather up those who respond to them in unpredictable kinds of 'we.'

Rotas rightly refers to the brittlestar as demonstrating that '[vi]isuality grounded in human-centred optical models of reflection evokes dualist frameworks and relative movements of interaction that create static images of thought.' Similarly, we can say that Mitchison's imagined 'radiates' demonstrate that rationality grounded in human-centered either/or reasoning evokes dualist frameworks that limit explorations of alternatives.

Shakhnoza Kayumova,Wenbo Zhang, and Kathryn Scantlebury's contribution to this special issue also attends to questions around visually by revisiting data excerpted from a previous study as an assemblage of texts and graphic vignettes. This study makes a powerful case for seeking to move past the stereotypes of what constitutes research in STEM, and seek research methods that makes the invisible visible, and attends to bodily and affective dimensions. This is especially apparent in graphic-texts 1 and 2 which visualizes Haraway's (1991, p. 191) understanding of totalizing claims for scientific authority provided by the 'godtrick' of a view from nowhere. The invisible in this instance is made visible through a graphic rendering of Kayumova's physical distance and separation from her research-partners (students) which, although a common practice in classroom-based fieldwork, clearly invokes the hegemonic ideologies that she was seeking to disrupt through her research.

Kayumova et al.'s article is multi-layered and we recommend a reading strategy that attends to the different types of work performed by the various layers. It might be useful to first 'read' the pictures before reading the field notes that accompany them and then the critical analyses that follow each cluster of graphic-texts. We also note that this article makes an implicit case for adding the 'A' (for arts) to STEM research, because it derives much of its richness and value from the artist's contributions.

Michelle Wooton's cartographic approach also benefits from illustrations. Wooton begins by considering that the research practices of academics of science teaching and learning (which she somewhat awkwardly abbreviates as 'academics-of-*st&l.*' We understand the desire to abbreviate but not what is signified by italicizing two components of it) as constituting a connected, constructed landscape, the peaks of which are shaped by accumulations of like practices, marking researchers and their methods within various degrees of recognizability. Metaphorically conceptualizing research practices as a landscape that can, therefore, be mapped is a very reasonable tactic, but the merits of this approach are perhaps best demonstrated by Wooton's consideration of cartography as a disruptive methodology in research on science teaching and learning, based on the assumption that because a research landscape is a constructed terrain, it is therefore amenable to being reconstructed. Thus, she appraises disruptive shifts in normative research practices, firstly by reference to her own thinking about research assumptions, purposes and methodologies, and secondly by focusing on cartographic concepts and ethics.

We see both parallels and convergences between Kayumova, et al.'s approach to decolonizing taken-for-granted knowledge-making practices in STEM education research and Wooton's approach to disrupting normative research practices through cartographic landscape reconfiguration.

Stacia Cedillo's article introduces BlackCrit and draws attention to the specificity of anti-blackness studies in STEM education. Her paper reminds us of indigenous Australian Melissa Lucashenko (1994) who argues that it is meaningless to equate Black women's powerlessness with white women's powerlessness, because white women are often complicit in the situation which has resulted in Black women becoming powerless. Lucashenko further argues (1994, p. 23):

> The most you can contribute to Black feminism at present is to examine your own attitudes and beliefs and information about indigenous people. The major obstacle to totally effective Black feminism is white racism in the feminist movement...
> The task of white women who wish to be allies of Aboriginal women is... crucial. Their task lies mainly in the white community, and in the challenge to interrupt racism wherever they see it, be it in the street in the media, in the women's movement or in themselves.

Cedillo, as a non-Black, biracial white, and Latina scholar, has taken on such a role—interrupting racism as she sees it. Acknowledging Cedullo's arguments around the historic, political, economic, and racialized context of STEM, an important way of encouraging Black involvement is, as Sandra Harding (1991, p. 268, emphasis in original) suggests, is to move from

> *including* others' lives and thoughts in research and scholarly projects to *starting from* their lives to ask research questions, develop theoretical concepts, design research, collect data, and interpret findings... that would provide less partial and distorted accounts of nature and social relations.

Nandy (1986, p. xv) argues similarly that we must choose the slave's standpoint, not only because the slave is oppressed but also because the slave represents a higher-order cognition which perforce includes the master as human, whereas the master's cognition has to exclude the slave except as a 'thing.' This is particularly relevant to Cedillo's discussion of master-slave relations.

Cedillo raises inquiry as problematic in science education from a BlackCrit perspective. How inquiry as an educational pedagogy is not necessarily empowering is addressed by Elizabeth Ellsworth (1989) who raises many questions grounded in her classroom experience of critical pedagogy.

Cedillo's proposals are consistent with Sandra Harding's (1993, p. 1) argument that 'science educations rarely expose students to systematic analyses of the social origins, traditions, meanings, practices, institutions, technologies, uses, and consequences of the natural sciences that ensure the fully historical character of the results of research.' They are also relevant to situations outside of African American—as demonstrated by Glen Aikenhead's (1997) writings around cultural border crossing with First Nations people in science classrooms, and his research with Aikenhead and Jegede (1999) which investigated border crossings and collateral learning across non-Western and Western cultures, among others. However, as Rowhea Elmesky (2011) argues, there are also more subtle ways in which economically and racially marginalized students remain outsiders to the culture of science—and it is vital for teachers to value students' dispositions and communicate this valuing to students through flexibility, openness, and knowing the students. For example, Elmesky's (2011) reports on her efforts to make an African American science classroom a more creative environment. She adopts an inquiry approach and takes us into the rap space she shared with student researchers as they developed creolized forms of school science where canonical science discourse and lyrics about non-science subjects began to merge in the students' hybridized identities and rap practices. Cedillo sees problems with using inquiry pedagogies in science education without reviewing the successes experienced by these researchers. Rejecting inquiry in STEM education seems to have elements of throwing the baby out with the bathwater as inquiry pedagogy can start from students' lives to ask the science questions that matter to them and thus avoid anti-Black constructs.

Conclusion

Disrupting and displacing methodologies in science education is not something new. There are multiple examples from two and more decades ago where science educators and researchers drew attention to the need to approach science education research and pedagogy differently. However, some of the authors in this special issue demonstrate an amnesia to this previous work which could enhance their arguments. Nevertheless, we are inspired by the contributions and hope that these new approaches will achieve the changes that have eluded many similar arguments in the past.

Compliance with Ethical Standards

Conflict of Interest The authors declare that there is no conflict of interest.

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