STEM Education as 'Trojan Horse': Deconstructed and Reinvented for All

Larry Bencze, Michael Reiss, Ajay Sharma & Matthew Weinstein

Introduction

A powerful and widespread movement in education focuses on encourage integration and/or interrelationships among fields of science, technology, engineering and mathematics (STEM). While the movement is not universally accepted, many stakeholders, including school administrators, business leaders, government education officials, teacher educators, teachers, students and others, avidly support various forms of STEM education. Indeed, it seems increasingly to be the accepted norm in many jurisdictions. Nevertheless, it is our contention that, like the proverbial Trojan horse, STEM education initiatives sometimes (or often) project idealized images of prosperity, wellbeing and status that may result from their implementation that, however, hide serious STEM-related dangers for the wellbeing of individuals, societies and environments such as dramatic dislocation and disruption from severe climate change. Although constructors and proponents of the STEM Trojan horse are many and varied, we also believe that much of this subterfuge appears attributable to vast global networks of individuals, organizations, technologies, infrastructure, etc. supporting neoliberal capitalism. This is a somewhat nebulous ideology, but it often appears to involve interventions by governments and other entities in economic markets and in societies more generally to promote private sector gains. While we acknowledge that power is distributed across such global networks, it also appears to us that much of the impetus for these networks can be traced to relatively few wealthy individuals and groups. In this chapter, we provide elaboration and justification for these claims and suggestions for some alternatives that we hope may help realize improvements in wellbeing for all.

STEM Education as Trojan Horse

Although STEM education appears to have achieved the status of generalized 'common sense' in many educational contexts around the world, there seems to be much about this movement (acknowledging its diversity) that can be called into question. On the one hand, there are aspects of proposed STEM integration and/or interrelationships that seem reasonable. Many proponents suggest, for instance, that there often are significant connections among professional scientists, technologists, engineers and mathematicians (Rennie, Venville & Wallace, 2012). Of course, many of the instruments, tools, etc. used in fields of science have been developed by technologists and engineers. Similarly, many approaches to data-collection, analyses and representation have been derived, to a great extent, from fields of mathematics. There also is the argument that involvement of engineers in the work of scientists can help expedite translation of abstract knowledge from the sciences (e.g., about the structure of DNA) into useful products and services (e.g., genetically-modified organisms for more efficient agriculture) (Etzkowitz & Leydesdorff, 2000). Moreover, there are arguments for epistemological and ontological relationships between science and engineering, in the sense that conduct of science and engineering often co-influence each other and, therefore, may have characteristics of the other in them (Roth, 2001). For example, translation of phenomena (e.g., trees) into representations of them (e.g., drawings of trees), which

is said to be a major process of science, can affect translation of revised representations (e.g., molecular pathway drawing) into revised phenomena (e.g., engineered trees), which is said to be a process of engineering. On the other hand, despite some apparent similarities and relationships in professional practice, there does appear to be resistance to integration of and/or interrelations among STEM fields in education. Some argue, for example, that there is some 'muddling' in STEM education projects of epistemological and ontological differences among the four STEM fields. In many cases, it appears that teachers of science, teachers of technology, teachers of engineering and teachers of mathematics are now considered, simply, 'STEM teachers.' There is research suggesting, however, that different fields of endeavour in the sciences – such as chemistry, as compared to physics (Thalos, 2013) – are based on different knowledge generation principles and practices. Similarly, think of how we arrive at truth in mathematics. We establish that the number of primes is infinite, that the square root of 2 is irrational and that the sum of the internal angles of a flat triangle add up to 180 degrees in ways that have little in common with ways in which knowledge is constructed in fields of science, technology or engineering. A scientist might head off into the field, gather samples of triangles, bring them back into the laboratory, cultivate them in Petri dishes, measure their three internal angles, sum them and then compute means and some measure of variableness between triangles. Perhaps partly because of such differences, school systems have frequently separated instruction in the four STEM fields. Moreover, in light of such philosophical and methodological differences, there appears to be have been some *antagonism* between science and technology education, with science frequently enjoying higher status while technology has been stigmatized as only appropriate for "less able, concrete thinkers" (Fensham & Gardner, 1994, p. 168). It has long been suggested that school science has been given high status in schools because, to a great extent, scientists have taken advantage of the traditional claim that abstract knowledge they generate is more important than technological knowledge, the former considered more generalizable and, therefore, more powerful than the latter (Fensham, 1993).

Given apparent long and deep traditions of separation of teaching of science, technology, engineering and mathematics in schools and, moreover, apparent special status for science as compared to technology and engineering, it seems clear that STEM education promoters need to work to 'sell' linkages among these historically isolated fields of education. Related to this, because of traditions of isolation from one another, teachers of different STEM fields may have to learn to 'play nice' with each other and, in a sense, be on one discursive team. Breaking traditions of and structures promoting their isolation and bringing teachers of the four STEM fields together seems to require significant resources and resourcefulness. This, in turn, raises questions like, 'Who or what is behind STEM education?' 'What have they to gain from such associations?' and 'How do they appear to be attempting to achieve their ends?' We think clues to answering such questions lie in analyzing which fields of endeavor are *excluded* from many STEM education initiatives. It seems to us that articulation (of STEM fields) occurs simultaneously with disarticulation. By focusing on who is not included, we can start to make visible the ideological work of this stew. Missing in action, it seems, are fields of humanities, sociology, history, politics, anthropology and possibly many others (Zeidler, 2016). Perhaps we can gain clues about sources of power behind STEM initiatives by thinking about what omitted fields like these would reveal about STEM fields.

In examining websites, curriculum policy and instructional materials, STEM education brochures, publications about relevant research, etc. through insights from the humanities and social sciences, it is apparent to us that a – perhaps *the* – driving force determining much of STEM

education is support for *neoliberal capitalism. Neo*(new)-liberalism marks a return, or reference to, economic liberalism of the 18th Century, in which priority was given to private sector freedoms from, especially, government interference in economic affairs. Neoliberals are not merely trying to restore a previous order, however. Their version of free markets is not about a *laissez faire* state; but, rather, involves government intervention in markets, particularly in terms of establishing laws that enable financiers and companies to freely pursue profit-generation activities. Part of the worldview of neoliberals has been an emphasis on perpetual entrepreneurialism (lifelong learning), in which everyone is supposed to see themselves as constantly trying to increase their personal human capital in order to survive in a world in which the market, rather than the state, provides for social needs, and in which there is little security (McMurtry, 2013).

Although its origins are complex and somewhat controversial, many suggest neoliberalism gained traction after the second world war with formation of the Mont Pèlerin Society (MPS), a think tank consisting of economists and philosophers including Friedrich Hayek, Karl Popper, George Stigler and Milton Friedman, which sought to resurrect and renew ideologies supporting personal and market freedoms – suggested in light of harms linked to fascist and communist regimes in Europe (Harvey, 2005). Its efforts have, to say the least, been extremely successful. Now affiliated with the MPS, apparently, is a vast network of neoliberal think tanks (e.g., Atlas Network, Heritage Foundation), banks (e.g., World Bank), financiers (e.g., Filiz Sahenk, Wee Cho Yaw), corporate owners (e.g., Koch Brothers, Bill Gates), media barons (e.g., Rupert Murdoch), university departments (e.g., Department of Economics, University of Chicago), transnational corporations (e.g., Disney), transnational trade organizations (e.g., World Trade Organization), conventions (e.g., World Economic Forum, Davos) and many others (Ball, 2012). Indeed, neoliberalism's capture of supporters worldwide appears so extensive that its network seems like The Borg of Star Trek™ fame, threatening to assimilate everything in its path, stating 'resistance is futile' (https://en.wikipedia.org/wiki/Borg_(Star_Trek)). About neoliberalism, two of its most famous supporters, Margaret Thatcher of Great Britain and Ronald Regan of the USA, famously said, respectively, that: "There is no alternative" and it is "The New World Order."

To gain support for their agendas, neoliberals have sometimes resorted to military force – as famously enacted in the Chilean dictatorship of Augusto Pinochet (in office from 1974-1990). However, it seems they often have preferred battles won by heavily financed *persuasion*. Accordingly, a key element in neoliberal tactics is education of populations in ways congruent with their purposes. Stephen Ball (2012), for instance, in his book *Global Education Inc.*, identifies a vast network of individuals and groups that, funded by numerous millionaires and billionaires, like Eli Broad, the Walton Family, and Bill Gates, have been placing enormous pressure on education systems to enact perspectives and practices of the so-called Global Education Reform Movement (GERM), including: *curriculum standardization*, *international competitiveness*, *testing and reporting* and *emphases on 'core' literacies* (e.g., language(s), mathematics, science and information technology) (Sellar & Lingard, 2013). A major aspect of this in recent years has been promotion of STEM education. In what has become known as the 'neo-Sputnik' race, governments, companies, financiers, universities, transnational trade organizations and others in the USA, the EU and other 'Western' nations have become increasingly concerned about competition over the last decade with countries like China and India and, accordingly, have been urging education systems to focus on identification and education of prospective STEM workers to assist in such economic struggles (Pierce, 2013).

Although vast and complex networks of pro-capitalist entities like those noted above likely use – not, necessarily, consciously – an array of strategies for achieving their ends regarding STEM

education, we suggest that a significant tack is *subterfuge*. Like a magician, if people can be convinced to focus their attention on certain, perhaps common, phenomena, they will not notice what the magician is attempting to conceal. Like the story of the proverbial Trojan horse (see Figure 1 and https://en.wikipedia.org/wiki/Trojan_Horse), it seems that promoters of STEM education often encourage acceptance by portraying it as a wonderful solution to a range of problems in ways that may distract recipients from its hidden dangers. Apart from evidence from analyses of STEM education promotional materials, etc., as described below, it should first be mentioned that this tack appears congruent with capitalists' sales techniques for many or most other commodities such as cars, cosmetics and financial futures (Bencze & Carter, 2015). Consumers are routinely distracted from noticing or addressing personal, social and environmental problems (e.g., harms from climate change) linked to for-profit products and services (e.g., cars) by idealized abstractions such as 'sexy,' 'classy' and 'powerful' associated with them.

[Insert Figure 1 about here; Caption = Trojan horse (https://commons.wikimedia.org/wiki/File:Giovanni_Domenico_Tipeolo,_Procession_of_the_Trojan_Horse_in_Troy._1773..jpg)]

As with marketing of many commodities, STEM education seems to be sold largely on the basis of a set of images to which consumers might identify. Particularly important to STEM education 'sales' appears to be its image as a solution to many economic problems. Apparently aligned with the nature of global economic competitiveness, it is apparent that STEM sales campaigns rely on a common neoliberal tack; namely, disaster capitalism (Klein, 2007). In other words, in order to infuse neoliberal priorities, capitalists may capitalize on natural or manufactured disasters. STEM education promoters often, for instance, appear to adopt salvationary rhetoric – claiming that STEM education should allow individuals and jurisdictions (e.g., states/provinces, countries) to be saved from economic disaster; and, indeed, to prosper, especially in terms of jobs and associated products and services, in the face of increased international economic competitiveness from other countries, like India and China (Pierce, 2013). By dazzling the public and even policy makers with the idea that STEM education is the route to economic security and the solution/avoidance of said disasters, these publics, policy makers etc., are led away from neoliberalism's and even STEM education's contradictions and problems. Warnings of dire consequences associated with purported needs for more STEM workers, for instance, appear exaggerated. With increasing technological advances, it may well be that fewer STEM professionals will be needed than claimed (Frey & Osborne, 2013); and, moreover, there is the suggestion that calls for more STEM workers is intended to glut the market and, consequently, minimize costs for wages and benefits (Pierce, 2013). Indeed, there have been overt statements indicating that relatively few STEM professionals are needed to help direct technological innovation and production; and, moreover, many STEM jobs will be increasingly 'precarious' (part-time and impermanent). The U. S. National Research Council (NRC, 2011), for example, which helped facilitate development of that country's *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013), stated in its document, *Successful STEM Education*, that relatively few STEM professionals are needed to direct many jobs:

> [t]he primary driver of the future economy and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering . . . 4 percent of the nation's workforce is composed of scientists and engineers; this group disproportionately creates jobs for the other 96 percent (p. 2).

Meanwhile, claims that jobs are tied to particular nations also seem illusionary. Competition, often managed by transnational trade agreements (e.g., the proposed Transatlantic Trade and Investment Partnership), is increasingly between financiers and corporations with minimal ties to any one nation (McMurtry, 2013). Jobs in such environments often are moved to nations with the best legal arrangements for profit generation, such as in terms of minimal wages, worker benefits and environmental protections. At the same time, because of companies' legal rights to minimize costs associated with their commodities (e.g., for labour, materials, transportation, marketing and reparation for negative side-effects of commodities), many of them are linked to a range of personal, social and/or environmental harms (Mirowski, 2011), including from: cigarettes (Barnes, Hammond & Glantz, 2006), agro-toxins (Hileman, 1998), fast foods and other manufactured foods (e.g., Weber, 2009), highly toxic household cleansers (e.g., Leonard, 2010), environmentally disruptive biotechnologies (Kleinman, 2003) and, perhaps especially significantly, burning of petroleum products that accelerates global climate change (Klein, 2014).

In light of such problems, perhaps technological innovation and engineering that is so prominent in STEM education initiatives is more about encouraging repeating cycles of production, consumption and disposal of commodities that are not, necessarily, meant to benefit living and nonliving environments. Many such STEM-associated problems are not strongly addressed in STEM education projects (Gough, 2014). Where attention is given to such problems, it seems solutions often involve 'techno-fixes'; that is, applying STEM techniques with little attention, as noted above, to perspectives and practices from the humanities and social sciences. For example, in the U.S.A.'s recently published NGSS (NGSS Lead States, 2013), a secondary school standard for *Earth and Space Science* suggests: "Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean)" (www.nextgenscience.org/pe/hs-ess3-4-earth-and-human-activity). Here, the NGSS suggest that widespread chemical alteration of the oceans and atmosphere is to be treated as a perfectly acceptable solution to human impacts (there is a weird contradiction, of course, in that the goal here is to reduce the human footprint, but one permitted answer is to wildly expand them). Moreover, perhaps mirroring companies' tendencies to employ reputable scientists to dispute science findings that would discredit many of their potentially-harmful commodities (Oreskes & Conway, 2010), school students routinely are invited to view potential problems linked to STEM fields as controversial (Levinson, 2013).

Towards Education for Social and Environmental Justice

Preamble

Although STEM education has a vast and deep set of supporters and although there appear to be some epistemological, ontological and practical merits in integration and/or interrelationships in education among the four STEM fields, we suggest that educators, policy makers and others be wary in accepting a virtual STEM Trojan horse, an apparently convenient construction intended to advance neoliberal capitalist agendas, often at the expense of the wellbeing of many individuals, societies and environments. As university-based science education scholars feeling immersed in a deep and extensive milieu dominated by neoliberal capitalist perspectives and practices that we find problematic, we work to help educate citizens about dangers of aspects of STEM education

and, moreover, provide alternatives that we hope may lead to more democratic control of education and, perhaps, increase worldwide social justice and environmental sustainability.

Socio-political Dissent and Conflict

For at least the last 40 years, scholars and others have been encouraging science educators to teach science in terms of its relationships with fields of technology, societies and environments (STSE) (Pedretti & Nazir, 2011). Such approaches recognize that science does not occur in isolation of other professional fields (e.g., technology and engineering), other members of societies and their living and non-living environments. In our analyses of STEM education initiatives, however, much of this recognition seems to be dissolving. Ironically, in integrating STEM topics, a new isolationism seems to have resulted. In other words, just as STEM brings together (articulates) science with math, engineering and technology, it disconnects (disarticulates) these same fields from political, social, and humanistic inquiries. We strongly believe, however, in reversing this 'erasure' and re-establishing 'STSE' education – or, perhaps, with addition of engineering and mathematics, 'STEMSE' education. Problems faced by humanity appear to need citizenry prepared to attempt to bring about a better world – in part, through more *critical* and *holistic* uses of STEM knowledge, skills, dispositions, etc.

As briefly noted above, it is apparent to us that many attempts over the last several decades to integrate science (and/or technology) with humanities and social sciences have urged students to treat potential personal, social and environmental problems as *controversial*. Perhaps the most popular of these movements has been education regarding *socio-scientific issues* (SSIs), in which students often are invited to consider evidence and arguments that they may use for making reasoned personal choices about controversies (Levinson, 2013). Dana Zeidler et al. (2009), for example, who have had significant influences on the nature of SSIs education, summarize the approach this way:

> Central to this approach is the concerted effort to provide opportunities for students to reflect on issues in order to evaluate claims, analyze evidence, and assess multiple viewpoints regarding ethical issues on scientific topics through social interaction and discourse (p. 75).

Although such personal-choice approaches have been popular and appear to lead to numerous educational benefits for students, many scholars suggest that SSIs (or 'STEMSE') education needs to promote models of citizenship that extend beyond personal choice, giving much more priority to actively addressing, in more collectivist ways, the many problems faced by humanity (Bencze & Alsop, 2014). Many such problems and corresponding actions appear to us to be congruent with ecojustice education, which prioritizes enlightening students about various problems of social justice (e.g., androcentrism, individualism) and environmental sustainability (e.g., anthropocentrism, commodification) and, as argued above, preparing them to engage in socio-political actions to address problems they identify (Martusewicz, Edmundson & Lupinacci, 2014).

[Insert Figure 2 about here]

There are, undoubtedly, many possible approaches to 'STEMSE' education promoting actions to address ecojustice concerns. From our previous research and practice, we provide some examples that may serve as models for further development of such approaches. One set of these

(see Figure 2) draws on Habermas' (1983) perspectives on communicative action. He advanced an emancipatory agenda (its moral dimension) while attending carefully to power in acts of communication. In school science, its adoption would mean students listening carefully and respectfully to views of others (their teachers, textbook authors, their peers), but then challenging them through rigorous enquiry. In a classroom setting, a teacher would want to search for possible consensus, without forcing agreement on students (which is often not possible for contentious issues). Such a consensus should be based largely on reason and genuine debate and take into account established practices of ethical reasoning. At the same time, it should be open to criticism, refutation and possibilities for change. Furthermore, consensus should not be equated with majority voting. It needs to be borne in mind that while a consensus may eventually emerge, there is a time when what is more important is simply to engage in valid debate in which the participants respect one another and seek for truth through dialogue. As noted in Figure 2, however, after students negotiate personal positions regarding merits of nuclear power, this approach then encourages them to develop and implement plans of action to communicate their perspectives to those who may affect change, thus benefiting all concerned (Reiss, 2003).

The approach in Figure 2 provides considerable guidance, although also with significant choice, for students in their explorations and actions to address perceived ecojustice problems – in this instance, connected to the subject of nuclear physics. Guidance can be helpful for certain students, particularly those not familiar/comfortable with freedom of choice in schooling. It is apparent, however, that students also given significant control over decisions about representing phenomena of the world (e.g., graphs of car uses) and uses of such representations to imagine new kinds of phenomena that they then try to realize (e.g., new car uses) can become very committed to educational matters, including ecojustice concerns and actions (Wenger, 1998). However, since students seldom have such choices in schooling, the STEPWISE (Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments [www.stepwiser.ca]) approach illustrated in Figure 3 was developed. It is designed to provide students with apprenticeship lessons and activities intended to encourage and enable them to eventually self-direct research-informed and negotiated action (RiNA) projects to address power-related problems in STSE relationships (Bencze, submitted). Students may, for instance, be concerned about private sector advertising for fast foods that their secondary research suggests have ingredients linked to medical problems and their primary research suggests are commonly used by youth at particular times of day. Drawing on their findings, they may then develop advertising campaigns to enlighten fellow students about possible harms and healthy alternatives.

[Insert Figure 3 about here]

The general approach shown in Figure 3 appears to have been successful in helping several students to self-direct RiNA projects to address STEMSE problems of their concern. Finding that many fellow students were discarding plastic water bottles in garbage bins, a group of tenth-grade students developed a water bottle label that encourages users to recycle the empty bottles (Krstovic, 2014). Although most students seemed highly motivated to engage in various aspects of such RiNA projects, it also was felt that their actions were relatively narrow (e.g., limited to aspects of local contexts, such as encouraging the school principal to provide more recycling bins). To help broaden their research and actions, therefore, teachers turned to actor network theory (Latour, 2005). Pierce (2013), for instance, suggested that helping students to develop actor network maps to depict STSE relationships can help expose them to living, nonliving and symbolic

entities (actants) to which they might not otherwise be exposed. In considering medications, for instance, students may not be aware of roles of governments in developing regulations that allow companies to test drugs in limited situations that, consequently, may lead to adverse side effects in some people (Angell, 2004). Accordingly, in work based on the framework in Figure 3, a teacher encouraged and enabled students to construct actor network maps to represent their analyses of STEMSE relationships regarding commodities they routinely purchase. A focus on such maps seemed, indeed, to enlighten youth about often-unseen actants and, as indicated below by eleventh-grade students' choices for a re-design (innovation) of a men's cologne, also appeared to motivate them to incorporate into their technology designs the wellbeing of a broader spectrum of living things and institutions:

> The cologne itself is made from primarily pure and natural ingredients these include: Bergamot essential oil, cedar wood essential oil, lemon, cinnamon sticks, green tea leaves, and absolute vodka. Many of our ingredients, if not grown in Canada do not contain harsh chemicals so the people working in other countries to harvest cinnamon for example, would not be exposed to dangerous fumes. … [T]he production process of cork is less harmful to the environment then making a glass or plastic lid, the cork is stripped off the trunk of the tree every 9 or 10 years, this does not kill the tree. … Our product would appear more attractive to a consumer because they are able to read and identify all seven ingredients and maybe even have majority of them in their household. (March 21, 2014) (Bencze & Krstovic, submitted)

Aligned with ecojustice education foci, these students used STEM knowledge and skills and incorporated matters of social justice, such as in terms of clarity of consumer choices via labelling, and for matters of environmental sustainability, such as in terms of use of tree bark without killing the trees.

Towards Networked Ecojustice Education

Although we have been encouraged by students' uses of attitudes, skills and knowledge associated with STEM fields (e.g., research, negotiation and innovation) to bring about a better world, their actions often are, overall, relatively narrow; e.g., frequently limited to educating friends, families and others. Moreover, it is apparent that such more altruistic uses of STEM expertise, etc. has been limited to a few teachers' cases, particularly where a range of contextual factors appear to align (e.g., a supportive principal and teaching colleagues). This suggests at least two possibilities for improving our work: i) students could benefit from apprenticeships emphasizing *networking* of their research and actions; and, ii) supporters of critical STEMSE education and RiNA projects could benefit from efforts to further network (distribute) relevant pedagogical perspectives and practices. In other words, like neoliberal capitalists, as described above, those promoting ecojustice goals need to work to encourage a wide range of people, institutions and structures to align in collective support of social justice and environmental sustainability. Critique and disarticulation of hegemonic practices associated with STEM education, albeit necessary, may not be sufficient on its own. This is because liberatory politics needs to involve both deconstruction and reconstruction (Freire, 1997). That is, educators will need "a strategy whose objective is, through a set of counter-hegemonic interventions, to disarticulate the existing hegemony and to establish a more progressive one thanks to a process of re-articulation [merging] of new and old elements into different configuration of power" (Mouffe, 2008, para. 18).

As science education scholars working in university-based teacher education contexts, we can contribute to the formation of an alternative network and infrastructure that support activist ecojustice goals for STEMSE education. One such approach, called STEAMD (science,

technology, engineering, arts, mathematics and democracy) (Weinstein, unpublished work), starts with creation of critical consciousness surrounding our capitalist milieu. Neoliberalism is placed front and center at the level of global, national, local and discipline-specific effects. Students are given an introduction to the history and impacts of neoliberalism (and patriarchy, capitalism and colonialism) in their foundation coursework. This is then reinforced in discipline-specific ways through alternative framings of science, engineering and knowledge more generally in their coursework (methods classes and more general classes on multiculturalism, in which links between science/STEM and colonialism are taught as well as some foundations of sociology and philosophy of knowledge). This approach involves repeated uses of alternative lenses for understanding science and engineering. For engineering, the instructor draws heavily on the work of Richard Sclove (1995) on democracy and technology and Ivan Illich's (1973) *Tools for Conviviality*, both of which emphasize local, easy-to-maintain, and low-impact technological interventions. For science, in addition to the work of Philip Mirowski (2011) and Melinda Cooper (2008) on neoliberalism and science, students benefit from reading Rebecca Skloot's (2011) account of the development of 'HeLa' cells – the first cell line to be successfully produced and commercialized, involuntarily extracted from a dying African American cancer patient, Henrietta Lacks – to help them make curricular the exploration of science as an intersection of nature, economics, colonial/racial social orders, and power.

Running parallel to this social justice focus is an exploration of how teachers are themselves resisting neoliberal rationalities. In the local context, this foregrounds the work of the Bad-assed Teachers Association (BATS [www.badassteacher.org]), a network made possible by social media such as Twitter™ and Facebook™, and which works both on questions of social justice and corporate takeover of teaching. A few students have conducted practice teaching in BAT classrooms and report to their colleagues regularly. It also is possible to have students dialogue with BAT personnel, such as one of the BAT leadership who is also a regional science teacher (and is Chair of a secret science education BAT group on Facebook™). A related approach may be to add a blogger network, such as one that includes young upstarts like EduShyster (http://edushyster.com) and old guard activists like Mike Rose, all of whom are active in creating a counter articulation of education. On a larger scale, there also is the Network of Teacher Activist Groups (TAG [www.teacheractivistgroups.org/]), a U.S. national coalition of grassroots teacher organizing groups – including: Association of Raza Educators (San Diego/Oakland), Education for Liberation Network, Educators' Network for Social Justice (ENSJ) (Milwaukee), Metro Atlantans for Public Schools (MAPS), and New York Collective of Radical Educators (NYCoRE). TAG aims to disarticulate hegemonic practices associated with neoliberal standardization of curricula, high stakes testing and teacher accountability.

Such articulations of preservice teachers with groups like the BATS and TAG, in the USA and elsewhere, may be crucial to networking ecojustice approaches in science/STEM education, as they point student-teachers to where they need to go and how they need to act after finishing their teacher education programs. As Ernesto Laclau (2001) asserted, "no overall historical transformation is possible unless the particularism of the struggles is superseded and a wider 'collective will' is constituted" (p. 8). According to Laclau and Chantal Mouffe (2000), this would require acts of political articulation in which different local struggles strive to engage in common platforms connected by relations of equivalence. That is, educators and educator groups working to disarticulate STEM and re-articulate an alternative progressive vision of school science should benefit from struggles to form global movements against STEM – coordinated mobilization that

has been labeled by scholars as grassroots globalization or 'globalization from below' (Appadurai, 2000).

Overall, we critical science education scholars feel we are merely preparing student-teachers for a life of struggle over the very terms of the job of (science) teaching. From our point of view, the critical seed to plant is that this struggle has to be about more than preserving the professionalism of teachers. It must be mindful of social justice and environmental sustainability and critical of projects that may create worlds of massive deprivation and ecological disaster; sadly, often framed as social justice, but actually arguing for problematic aggressive individualism.

Imagining Critical and Activist STEM Education

Given the claim that all knowledge – and, presumably, curriculum innovations – serves someone's (or a group's) interests (Habermas, 1972), it seems clear that the relatively sudden and comprehensive acceptance of various STEM education initiatives represents a mechanism for achieving particular, pre-determined, ends. In our analyses, and that of others, there is considerable evidence to suggest that it is very difficult to tease out from among the many living, nonliving and symbolic entities and name anyone responsible for STEM education. Nevertheless, it is apparent that, in answer to the fundamental question addressed by this chapter ('Who decides the forms science education has taken, ...'), driving much of STEM education in many places in the world is a relatively small group of people and groups with significant financial power and interests. More particularly, calls for integration and/or interrelationships among STEM fields, which represent significant challenges to traditional perspectives and practices, often seem to appeal to citizens' apparently-conditioned priorities for material and symbolic comforts (e.g., as for-profit goods and services) associated with neoliberal capitalists' pursuit of wealth, often regardless of potential adverse effects on the wellbeing of individuals, societies and environments.

In this chapter, we have suggested that those who may consume (implement) STEM education initiatives consider the extent to which such projects may represent a *Trojan horse*; that is, a kind of commodity that is attractive on the outside, but is, perhaps, hiding dangers within. On the surface, STEM initiatives may promise jobs, including for more women, minorities and the poor (Eisenhart et al., 2015), and economic prosperity in the face of international economic competitions. Indeed, there has been sudden increase in relative proportion of wealth of companies officially linked to Asian countries as compared to those linked to the USA and EU. At the same time, however, it is apparent that many financiers and corporations (which often control STEM fields) have limited connections to individual nation states; and, consequently, have made transnational agreements that prioritize movement of jobs and production etc. to places in the world with the 'best' conditions for profit-generation – including in terms of minimal salaries, benefits, job-security, materials' costs and liability for personal, social and/or environmental harms often linked to their goods and services.

To address many of the personal, social and environmental harms that appear to be linked to neoliberal capitalists' influences on and uses of STEM fields, we suggest that science education needs to educate students about such relationships and, as well, help them to develop expertise, confidence and motivation for eventually self-directing research into such associations and, where they perceive problems, develop and implement socio-political actions to try to bring about a better world. In this chapter, we have, indeed, reported some successes in this regard. At the same time, however, such critical and activist science education seems to be restricted to relatively rare contexts in which several mutually-supportive conditions exist. Moreover, it seems that STEM

education initiatives seem particularly inhibitory for such forms of science education. We recommend, accordingly, that educators and others interested in promoting critical and activist science education 'borrow a page from capitalists' playbook'; in the sense of working to rally large, comprehensive, networks of living, nonliving and symbolic entities in ways prioritizing social justice and environmental sustainability. Rather than an elite few deciding the forms science education takes, perhaps a much broader representation of the public will be influential. In this chapter, we offer cases in science teacher education that seem to offer hope for greater ecojustice in science education through establishment of citizen networks. Nevertheless, we are conscious of needs for continuous work in this regard.

References

Angell, M. (2004). *The truth about the drug companies: How they deceive us and what to do about it*. New York: Random House.

Appadurai, A. (2000). Grassroots globalization and the research imagination. *Public Culture, 12*(1), 1-19. DOI: 10.1215/08992363-12-1-1

Ball, S. J. (2012). *Global education, inc.: New policy networks and the neo-liberal imaginary*. Abingdon: Routledge. DOI: 10.4324/9780203803301

Barnes, R. L., Hammond, S. K., & Glantz, S. A. (2006). The tobacco industry's role in the 16 Cities Study of Secondhand Tobacco Smoke: Do the data support the stated conclusions? *Environmental Health Perspectives*, *114*(12), 1890-1897. DOI: 10.1289/ehp.9385

Bencze, J. L. (editor) (submitted). *Science & technology education promoting wellbeing for individuals, societies & environments*. Dordrecht: Springer.

Bencze, J. L., & Alsop, S. (editors) (2014). *Activist science & technology education*. Dordrecht: Springer. DOI: 10.1007/978-94-007-4360-1

Bencze, J. L., & Carter, L. (2015). Capitalists' profitable virtual worlds: Roles for science & technology education. In P. P. Trifonas (Ed.), *International handbook of semiotics, vol. 1 & 2* (pp. 1197-1212). Dordrecht: Springer. DOI: 10.1007/978-94-017-9404-6_57

Cooper, M. (2008). *Life as surplus: Biotechnology and capitalism in the neoliberal era*. Seattle: University of Washington Press.

Eisenhart, M., Weis, L., Allen, C. D., Cipollone, K., Stich, A., & Dominguez, R. (2015). High school opportunities for STEM: Comparing inclusive STEM-focused and comprehensive high schools in two US cities. *Journal of Research in Science Teaching, 52*(6), 763-789. DOI: 10.1002/tea.21213

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From national systems and ''Mode 2'' to a triple helix of university–industry–government relations. *Research Policy*, *29*(2), 109-123. DOI: 10.1016/s0048-7333(99)00055-4

Fensham, P. J. (1993). Academic influence on school science curricula. *Journal of Curriculum Studies, 25*(1), 53-64. DOI: 10.1080/0022027930250103

Fensham, P. J., & Gardner, P. L. (1994). Technology education and science education: A new relationship? In D. Layton (Ed.), *Innovations in science and technology education*, Volume V (pp. 159-170). Paris: UNESCO.

Freire, P. (1997). *Pedagogy of the oppressed* (New Revised 20th-Anniversay ed.). New York: Continuum.

Frey, C. B., & Osborne, M. A. (2013, September 17). *The future of employment: How susceptible are jobs to computerisation?* 'Machines and Employment' Workshop, University of Oxford. Retrieved April 25, 2014 from http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf

Gough, A. (2014). STEM policy and science education: Scientistic curriculum and sociopolitical silences. *Cultural Studies of Science Education, 10*(2), 445-458. DOI: 10.1007/s11422-014-9590-3

Habermas, J. (1972). *Knowledge and human interest* (translated by J. J. Shapiro). London: Heinemann.

Habermas, J. (1983). *Moralbewusstsein und kommunikatives handeln*. Frankfurt am Main: Suhrkamp Verlag.

Harvey, D. (2005). *A brief history of neoliberalism*. Oxford: Oxford University Press.

Hileman, B. (1998). Industry's privacy rights: Is science shortchanged? *Chemical & Engineering News, 76*(17 August), 36. DOI: 10.1021/cen-v076n033.p036

Illich, I. (1973). *Tools for conviviality* ([1st ed.). New York: Harper & Row.

Klein, N. (2007). *The shock doctrine: The rise of disaster capitalism*. New York: Henry Holt.

Klein, N. (2014). *This changes everything: Capitalism vs. the climate*. Toronto: Simon & Schuster.

Kleinman, D.L. (2003). *Impure cultures: University biology and the world of commerce*. Madison, WI: University of Wisconsin Press.

Krstovic, M. (2014). Preparing students for self-directed research-informed actions on socioscientific issues. In L. Bencze & S. Alsop (Eds.), *Activist science and technology education* (pp. 399-417): Dordrecht: Springer. DOI: 10.1007/978-94-007-4360-1_22

Laclau, E. (2001). Review: Can immanence explain social struggles? *Diacritics, 31*(4), 3-10. DOI: 10.1353/dia.2004.0008

Laclau, E., & Mouffe, C. (2000). *Hegemony and socialist strategy: Towards a radical democratic politics*. London: Verso.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford: Oxford University Press.

Leonard, A. (2010). *The Story of Stuff: How our obsession with stuff is trashing the planet, our communities, and our health - and a vision for change*. New York: Free Press.

Levinson, R. (2010). Science education and democratic participation: An uneasy congruence? *Studies in Science Education, 46*(1), 69-119. DOI: 10.1080/03057260903562433

Levinson, R. (2013). Practice and theory of socio-scientific issues: An authentic model? *Studies in Science Education, 49*(10), 99-116. DOI: 10.1080/03057267.2012.746819

Martusewicz, R., Edmundson, J., & Lupinacci, J. (2014). *Ecojustice education: Toward diverse, democratic, and sustainable communities* (2nd ed.). New York: Routledge. DOI: 10.4324/9781315779492

McMurtry, J. (2013). *The cancer stage of capitalism: From crisis to cure*. London: Pluto.

Mirowski, P. (2011). *Science-mart: Privatizing American science*. Cambridge, M: Harvard University Press. DOI: 10.4159/harvard.9780674061132

Mouffe, C. (2008). Critique as counter-hegemonic intervention. *Transversal*. Retrieved from http://eipcp.net/transversal/0808/mouffe/en

National Research Council [NRC] (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press. DOI: 10.17226/13158

NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. Washington, DC: The National Academies Press. DOI: 10.17226/18290

Oreskes, N., & Conway, E. (2010). *Merchants of doubt*. London: Bloomsbury Press.

Pedretti, E., & Nazir, J. (2011). Currents in STSE education: Mapping a complex field, 40 years on. *Science Education, 95*(4), 601-626. DOI: 10.1002/sce.20435

Pierce, C. (2013). *Education in the age of biocapitalism: Optimizing educational life for a flat world*. New York: Palgrave Macmillan. DOI: 10.1057/9781137027832

Reiss, M. J. (2003). Science education for social justice. In C. Vincent (Ed.), *Social justice, education and identity* (pp. 153-165). London: RoutledgeFalmer.

Rennie, L., Venville, G. & Wallace, J. (Eds.) (2012). *Integrating science, technology, engineering and mathematics: Issues, reflections and ways forward*. New York: Routledge. DOI: 10.4324/9780203803899

Roth, W.-M. (2001). Learning science through technological design. *Journal of Research in Science Teaching, 38*(7), 768-790. DOI: 10.1002/tea.1031

Sclove, R. (1995). *Democracy and technology*. New York: Guilford Press.

Sellar, S., & Lingard, B. (2013). The OECD and global governance in education. *Journal of Education Policy*, 28(5), 710-725. DOI: 10.1080/02680939.2013.779791

Skloot, R. (2011). *The immortal life of Henrietta Lacks* (1st pbk. ed.). New York: Broadway Paperbacks.

Thalos, M. (2013). The lens of chemistry. *Science & Education, 22*(7), 1707-1721. DOI: 10.1007/s11191-012-9443-y

Weber, K. (Ed.). (2009). *Food, Inc.: How industrial food is making us sicker, fatter, and poorer- and what you can do about it: A participant media guide*. New York: Public Affairs.

Wenger, E. (1998). *Communities of practice*. Cambridge: Cambridge University Press.

Zeidler, D. L. (2016). STEM education: A deficit framework for the twenty first century?: A sociocultural socioscientific response. *Cultural Studies of Science Education*, 11(1), 11-26. DOI: 10.1007/s11422-014-9578-z

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgement through socioscientific issues. *Journal of Research in Science Teaching, 46*(1), 74-101. DOI: 10.1002/tea.20281

ACKNOWLEDGEMENTS

Figure 1

Figure 2

- **Research the roles played by such scientists** as Henri Becquerel, Ernest Rutherford, Marie Curie and Lise Meitner. [Lise Meitner played a crucial role in the discovery of nuclear fission but was not awarded the Nobel Prize with Otto Hahn in 1944 for this research.]

- **Plot a map of the distribution of nuclear power stations** around the globe and suggest reasons for the results observed. [Nuclear power stations are expensive to build and require considerable engineering expertise. In some countries public support for new nuclear power stations is lacking; in others, e.g. Germany and Japan, it has changed dramatically in recent years.]

- **Plot graphs of decreases in radioactivity in vegetation** in Cumbria, UK in the years after Chernobyl and compare the results with government predictions. [It has taken orders of magnitudes longer for the radioactive levels to return to safe levels than had been predicted. Science is not always a certain subject.]

- **Explain how carbon dioxide emissions from electricity-producing stations in France fell by two-thirds during the 1980**s. [Expansion of the French nuclear power industry. Over two-thirds of French electricity is generated in this way, a higher percentage than in any other country.]

- **Write to both pro- and anti-nuclear power organisations asking them the same specific questions**, e.g. 'How safe is nuclear power?' and 'How important is nuclear power for electricity generation?'. [Helps students to consider the significance of sources of scientific knowledge and enables them to consider the extent to which such knowledge is value-free.]

- **Examine the medical evidence for and against an increase in the incidence of leukaemia** around certain nuclear power stations. [Controversial. Can help students to appreciate how difficult it may be to see if technologies are safe or not. In addition, to what should the safety of nuclear power stations be compared?]

- **Design and use a questionnaire to investigate fellow students' knowledge of and attitudes towards nuclear power.** [A good learning experience, developing and reinforcing knowledge about nuclear power. The work on attitudes can introduce students in science lessons to both quantitative and qualitative approaches to the gathering and interpretation of data.]

- **Role play a government meeting trying to decide whether to extend a country's nuclear power programme or to scrap it.** [Role plays don't appeal to all teachers and students and can polarise arguments. Alternatives include discussion in small groups. Done well, though, role plays can enhance empathy and understanding of the position of others, especially if one role plays a view different from one's own. Should be followed by de-briefing.]

- **Write an imaginary letter** from one of the service persons or indigenous people on test islands like Bikini Atoll. [Too little writing in science is in such a genre. Also helps pupils realise that issues of sickness and death resulting from nuclear explosions aren't restricted to Japan in the Second World War. NB controversy over use of depleted uranium shells in the Gulf War.]

Figure 3

Unit 1	Unit 2	Unit 3	Unit 4
Intro. Physiology	Light & Optics	Chemical Change	Climate Change

Throughout all units, students may benefit from lessons & activities teaching students about 'products' (e.g., laws & theories) of science & technology in the context of relationships amongst fields of science & technology and societies & environments.

Students Express STSE Issues & RiNA
e.g., suggest positive & negative effects on individuals, societies & environments of cigarettes, and suggest research-informed actions to address potential problems

when students are ready

Student-led Actions
e.g., Posters; Letters; Petitions; Protests; Educational Videos; 'Green' Technologies; Blockades of STSE Problems

Student-led RiNA Projects on Their STSE Problems

STSE & RiNA Apprenticeships
(Teacher-guided)

Teachers Teach About STSE & RiNA Projects
e.g., ask students to read a case documentary of students' RiNA project to address processed foods, and to answer questions about it based on readings

Teachers Guide Students' Mini-RiNA Projects About STSE Problems
e.g., with variable teacher help, students conduct research-informed actions to address issues of their choice dealing with physiology

'RiNA' = Research-informed & Negotiated Action(s)

Teens' Shower Lengths
- 0-5 minutes
- 5-10 minutes
- 10-15 minutes
- 15+ minutes

Gender

60
50
40
30
20
10
0

Males   Females

Student-led Research
e.g., Web Searches; Correlational Studies; Interviews

www.stepwiser.ca