ISSN 2237-258X

ROADBLOCKS TO CRITICAL AND ACTIVE CIVIC ENGAGEMENT IN/THROUGH SCHOOL SCIENCE: STORIES FROM THE FIELD

Bloqueios ao engajamento cívico crítico e ativo na/através da Ciência Escolar: Histórias do Campo

Barreras para el compromiso cívico crítico y activo en/mediante la Ciencia de la escuela: Historias desde el campo

Larry Bencze*

Sarah El Halwany*

Minja Milanovic*

Nadia Qureshi*

Majd Zouda*

Abstract

For about 50 years, science educators have been promoting education about relationships among fields of science and technology and societies and environments (‘STSE’). Although helping students to understand inter- and/or trans-disciplinarity of science and relevant controversies, STSE education often seems very apolitical. In light of many governments’ difficulties in addressing harms such as those from climate disruptions that appear associated with global pro-capitalist networks, it seems clear that science educators need to encourage and enable students to critically analyze STSE relationships and develop and take actions to address harms they determine. Although educators have had some successes in this regard, they often are restricted to relatively rare contexts. Among ‘road blocks’ to their successes, it seems that ‘STEM’ (Science, Technology, Engineering & Mathematics) education and inquiry-based learning (IBL) approaches are particularly powerful. In our study reported here of four science teachers’ efforts to encourage/enable critical and active civic engagement, it appears that, while STEM education and IBL continue to be limiting, comitted teachers can develop innovative approaches to achieve such goals.

KEYWORDS: STSE Education. Critical civic engagement. Activism

Resumo

Por cerca de 50 anos, os educadores de ciências vêm promovendo a educação sobre as relações entre os campos da ciência, tecnologia, sociedades e ambientes ('CTSA'). Embora ajude os alunos a

* Ph.D Education. Assistant - Associate Professor Ontario Institute for Studies in Education (OISE). University of Toronto (U of T). E-mail: larry.bencze@utoronto.ca.

* M. Science Education. Ph.D student in OISE, U of T. E-mail: sarah.elhalwany@mail.utoronto.ca.

* B.Sc Biology; B.Sc. Genes, Genetics and Biotechnology Specialist and Psychology Minor. Ph.D student in OISE, U of T. E-mail: minja.milanovic@utoronto.ca.

* M.Ed Curriculum Studies. Ph.D student in Curriculum, Teaching & Learning, OISE, U of T. E-mail: nadia.qureshi@utoronto.ca.

* M.Sc. Medical Microbiology. Ph.D student in OISE, U of T. E-mail: majd.zouda@mail.utoronto.ca.

entender a inter- e/ou transdisciplinaridade da ciência e controvérsias relevantes, a educação CTSA geralmente parece muito apolítica. À luz das dificuldades de muitos governos em lidar com danos, como os causados pelas perturbações climáticas que parecem associadas às redes pró-capitalistas globais, parece claro que os educadores em ciências precisam incentivar e permitir que os alunos analisem criticamente as relações CTSA, desenvolvam e adotem ações para enfrentar danos que elas determinam. Embora os educadores tenham tido alguns casos bem sucedidos nesse sentido, eles geralmente são restritos a contextos relativamente raros. Entre os 'bloqueios' para o seu sucesso, parece que as abordagens de educação STEM (Ciência, Tecnologia, Engenharia & Matemática) e de aprendizagem baseada em investigação (IBL) são particularmente poderosas. Em nosso estudo relatado aqui sobre os esforços de quatro professores de ciências para incentivar/permitir o envolvimento cívico ativo e crítico, parece que, embora a educação STEM e a IBL continuam limitando, os professores comprometidos podem desenvolver abordagens inovadoras para alcançar esses objetivos.

PALAVRAS-CHAVE: Educação CTSA. Engajamento cívico crítico. Ativismo

Resumen

Durante aproximadamente 50 años, los educadores en ciencias han estado promoviendo la educación sobre las relaciones entre los campos de la ciencia, la tecnología, las sociedades y los ambientes (‘CTSA’). Aunque ayuda a los estudiantes a comprender la interdisciplinariedad y/o transdisciplinariedad de la ciencia y las controversias relevantes, la educación CTSA a menudo parece muy apolítica. A la luz de las dificultades de muchos gobiernos para abordar los daños, como los de las perturbaciones climáticas que parecen estar asociadas con las redes procapitalistas mundiales, parece claro que los educadores en ciencias necesitan alentar y permitir a los estudiantes analizar críticamente las relaciones CTSA y desarrollar y tomar medidas para abordar daños que determinan. Aunque los educadores han tenido algunos éxitos a este respecto, a menudo se limitan a contextos relativamente raros. Entre los "obstáculos" a sus éxitos, parece que los enfoques de educación ‘STEM’ (Ciencia, Tecnología, Ingeniería y Matemáticas) y de aprendizaje basado en la investigación (IBL) son particularmente poderosos. En nuestro estudio publicado aquí sobre los esfuerzos de cuatro docentes de ciencias para alentar/habilitar la participación cívica crítica y activa, parece que, si bien la educación STEM y la IBL siguen siendo limitantes, los docentes comprometidos pueden desarrollar enfoques innovadores para lograr tales objetivos.

PALABRAS CLAVE: Educación CTSA. Compromiso cívico crítico. Activismo

INTRODUCTION

Schooling in and for elementary and secondary education tends to focus on isolated disciplines, such as science, mathematics, language studies, visual arts, etc. This appears to sharply contrast with research into the nature of disciplines outside of schools, which tend to emphasize — as suggested by studies in the nature of the sciences (SISMONDO, 2008) — that knowledge construction is interrelated to or integrated across many disciplines. Promotion of multidisciplinary and/or transdisciplinary perspectives and practices appears particularly necessary in science and technology education, given strong associations that professional fields of science and technology have with multiple harms to individuals, societies and environments — such as devastation experienced and predicted to be experienced due to climate disruption — caused by societal priorities for continuing excessive combustion of fossil fuels.

For about the last half century, educators and others have been promoting more multi-disciplinary and/or trans-disciplinary perspectives and practices regarding fields of science and technology through 'STSE' (Science, Technology, Society & Environment) education. This movement, while apparently successful in helping to broaden students' conceptions of STSE relationships and determine their personal stances on controversies with them, have not tended to prioritize helping students to develop and implement social actions to overcome harms they perceive in such relationships (PEDRETTI; NAZIR, 2011). It seems that — given severity and persistence of harms and frequent government facilitation of them — concerted efforts are needed for science and technology educators (and others) to promote such critical and active civic engagement (HODSON, 2011).

Some successes have been reported — such as in uses of the 'STEPWISE' (Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments) curricular and instructional framework — in encouraging and enabling students in science and technology education to develop and carry out actions to address harms in STSE relationships that concern/interest them (BENCZE, 2017). Extents of students' actions appear, however, to be limited to special cases in which there exists supportive aggregates ('dispositifs') of entities — including, for instance, allied official curricula, supportive administrators and colleagues, and certain nature of science views of teachers. In light of their problematic influences on fields of science and technology and, indeed, most global entities, it seems clear that resistance for formation of dispositifs supportive of critical and active civic engagement through science and technology education may be at least partly due to hegemonic power of capitalist entities (e.g., financiers, corporations, trade organizations, etc.). Two related movements in science and technology education — STEM education and inquiry-based (IBL) practices — may serve as agents of such pro-capitalist resistance. To investigate this possibility, we conducted a collaborative analysis of narratives of our action research regarding four science educators' efforts to promote student-led critical civic actions. Findings suggest that, while STEM education and IBL learning practices do, indeed, seem to limit such critical and action-oriented education, aspects of these two movements also may be used by educators as bridges to overcome barriers to this kind of education.

Theoretical background

Although societies owe much to fields of science and technology, not the least due, for example, to prolongation of lives through medical and agricultural fields, many research-informed concerns have been voiced about benefits of practices and products of many of these fields. Chomsky (2017) advises — as recently stressed by the Bulletin of the Atomic Scientists (MECKLIN, 2019) — that humanity is facing two existential threats; that is, devastation from nuclear war and from climate change, the latter largely attributed to human fossil fuel combustion (STEFFEN et al., 2018). At the same, there are — among numerous other harms — ongoing illnesses associated with manufactured foods (WEBER, 2009), pharmaceuticals (NORMAN et al., 2011) and tobacco (VERMA, 2009); and, industrial activities are severely compromising many eco-spaces (LEONARD, 2010).

It may seem appropriate to focus blame for harms like those above on scientists and engineers and experts in related fields, like mathematics and engineering. Based on material-semiotic ontological conceptions (*e.g*., FENWICK; EDWARDS, 2012), however, it appears that fields of science and technology (and many related entities) are embedded in vast networks of reciprocal relations and, accordingly, responsibility for various ills may best be considered distributed across such systems of actants. The extent to which intentions, knowledge, etc. are equally-distributed across material-semiotic networks has, however, been questioned. Foucault (2008), for instance, suggests that some actants are able to 'orchestrate' many others in ways that align with their purposes — referring to cooperating sets of actants as dispositifs. Among entities that could rally numerous actants to their causes, many scholars and others suggest that pro-capitalist individuals (*e.g.*, financiers) and groups (*e.g.*, corporations) have been especially influential (*e.g.*, HARDT; NEGRI, 2009; MCMURTRY, 2013). Without perhaps overstating such power distribution, pro-capitalist dispositifs may engender numerous negative side-effects in pursuits of private profit. Indeed, given their embeddedness in such pro-capitalist dispositifs, much research suggests that topic choices, methods, results and dissemination of findings can be adversely-affected by capitalist ties to science and technology and related fields (e.g., MIROWSKI, 2011) — which, in turn, may lead to harms to wellbeing of individuals, societies and environments like those noted above. Many analysts have corroborated this claim, strongly-linking capitalism to, for example, climate change (MOORE, 2015).

Apparently, after a period of social security and infrastructure spending and labour protections that followed devastation from the Great Depression and World War II, neoliberal forms of capitalism developed which — in contrast to earlier, laissez faire forms — actively encouraged alignment of myriad living, nonliving and symbolic entities to work for capitalist aims (SPRINGER; BIRCH; MCLEAVY, 2016). A key feature of neoliberalism has been globalization; that is, worldwide infiltration of capitalist perspectives and practices and, especially, facilitation of such hegemony through work of governments, transnational organizations like the World Trade Organization, International Monetary Fund and World Bank and associated think tanks like the Atlas Foundation (BALL, 2012). This complex transnational programme appears to have served interests of capitalists quite well. Piketty (2014), for instance, suggests that capitalism has intensively concentrated wealth throughout the neoliberal period and, moreover, seems destined to continue to do so at unprecedented rates — largely at expense of many other humans and living things and nonliving environments. Oxfam (2019), for example, suggests that wealth has now concentrated to the point that 26 billionaires have approximately the same total wealth as the poorest 50% of the world's population (~3.8 billion people).

Because governments — and perhaps more consequently, transnational nongovernmental organizations — often facilitate contexts that appear to have contributed to private sector gains, largely at expense of wellbeing of most other living and nonliving things, it seems clear that forms of social consciousness are required that prioritize social justice and environmental wellbeing. Given key roles for fields of science and technology (and related disciplines) in destructive wealth concentration, it seems imperative that educators of science and technology encourage students to act for social and environmental justice (BENCZE; ALSOP, 2014; HODSON, 2011; SANTOS, 2009).

Research contexts and methods

Research Context

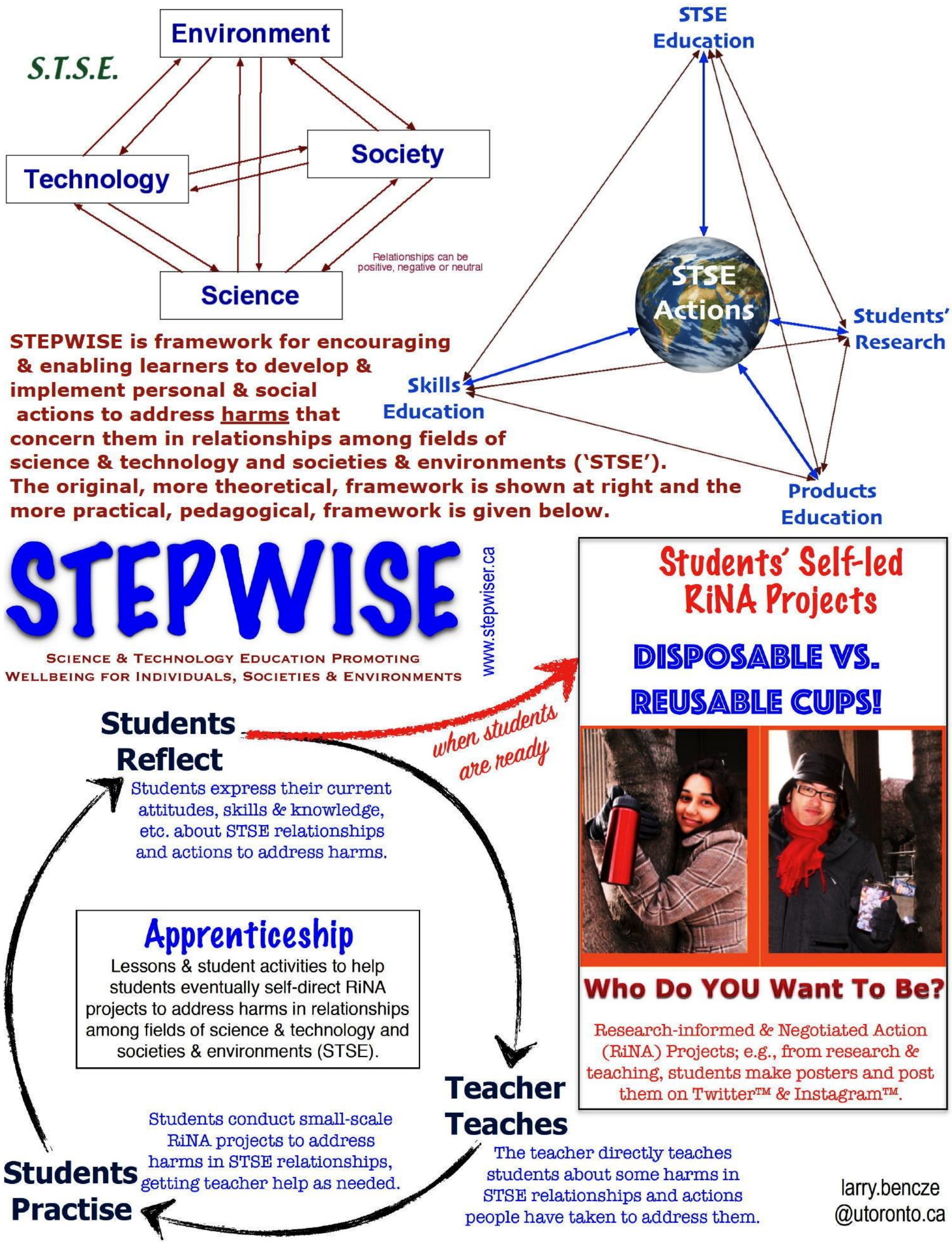
In mid-2006, Larry Bencze (first author here) developed the 'STEPWISE' tetrahedral framework (Figure 1, upper right) for arranging lessons and student activities for addressing teaching/learning goals of Ontario science curricula (MoE, 2008), such as "Products Education" (e.g., laws, theories, innovations) — but also prioritizing helping students to create and implement actions that may, altruistically, overcome harms students determine in relationships among fields of science and technology and societies and environments ("STSE," Figure 1, upper left). With assistance from graduate students (*e.g.*, co-authors here), however, our facilitated action research in different science education contexts led to development of the more linear ('stepwise') schema in the lower half of Figure 1 that science educators found more practical (BENCZE, 2017). This schema suggests that teachers first provide students with 'apprenticeship' lessons and student activities that may eventually enable and motivate them to self-direct research-informed and negotiated action projects ("Students' Self-led RiNA Projects") to address harms in STSE relationships. Depending on various factors, such as students' ages, abilities and stages of learning, 'apprenticeships' may consist of one or more 3-phase constructivism-informed cycles; that is:

i. **Students Reflect**. The teacher often provides students with 'stimuli' (e.g., commodities, like cell phones, generated with help from science and technology) that may encourage students to 'express' (e.g., via discussions, drawings, models) their pre-instructional attitudes, skills and knowledge ('ASK'), etc. regarding STSE relationships (including actions people might take to address harms in them);

ii. **Teacher Teaches**. The teacher directly teaches difficult-to-discover important ASK regarding all elements of the tetrahedral version of STEPWISE (Figure 1, upper right). Often, as well, students are asked to evaluate and deepen their understanding of such ASK through some application activities, such as answering questions regarding documentaries of others' RiNA projects to address harms in STSE relationships;

iii. **Students Practise**. To deepen and more personalize students' expertise, confidence and motivation for them, the teacher encourages students to develop and implement small-scale RiNA projects to address harms in STSE relationships identified by students. Such projects are mostly student-led, but the teacher may assist some students, in different ways (while leaving them open-ended), depending on their needs and requests.

Figure 1 – STEPWISE Schema for Addressing Harms in STSE Relationships.



Source: https://webspace.oise.utoronto.ca/~benczela/STEPWISE.html.

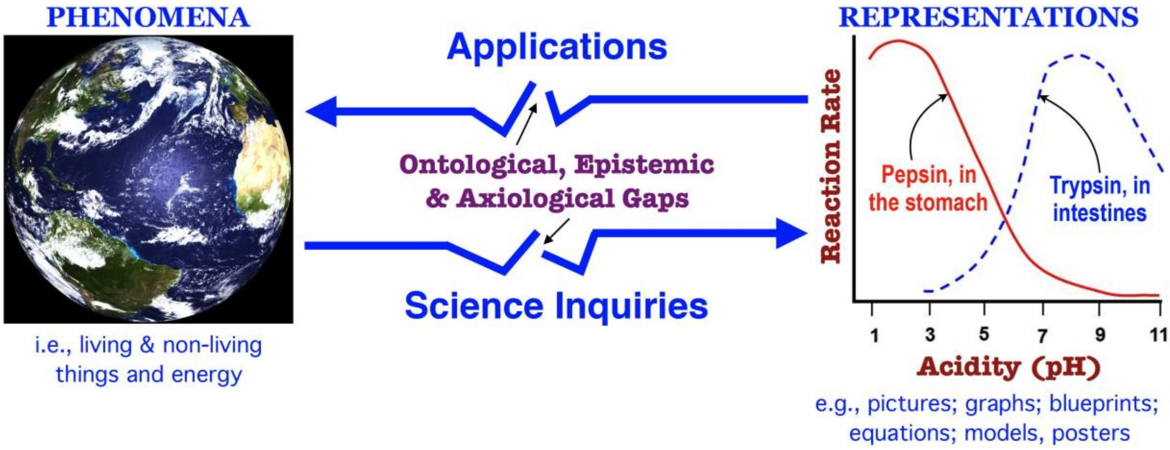
Our research since 2006 with science educators in formal primary, secondary and tertiary (teacher education) education contexts and in after-school clubs indicate that the schema at the bottom of Figure 1 has helped many students to develop significant expertise, confidence and motivation for self-directing (mostly) varied and personally-meaningful RiNA projects — several examples of which can be found in Bencze and Alsop (2014) and Bencze (2017) and in two special issues of the open-source (free to download), non-refereed, journal, JASTE, at: goo.gl/N00b3s; and, bit.ly/2JGIgtf.

Although there appears to be much to be celebrated about successes of the STEPWISE pedagogical schema (Figure 1, lower half), it also seems clear that such successes occur in relatively rare contexts — requiring existence, essentially, of a supportive dispositif, including general alignment, for instance, among: official curriculum goals, school administrative and collegial supports, teacher beliefs in possible adverse influences of powerful people and groups on science and engineering (and related entities), sufficient material resources (BENCZE; KRSTOVIC, 2017).

Relative scarcity of dispositifs supportive of STEPWISE-informed perspectives and practices and difficulties our research teams have generally reported in encouraging administrators, teachers and others to explore their uses suggests there may be some ‘road blocks’ for their implementation. Given influences of capitalists on myriad entities around the world, as discussed above, it may be that they are ultimately responsible for such oppositional situations. Indeed, in a study of community members’ efforts to work with multiple actants (*e.g.*, fellow community members, materials testing companies, an interactive website) to get government officials and others to take actions to address potentially-harmful dust pollution apparently emanating from the local ocean port, evidence suggested that a pro-capitalist ‘development dispositif’ (involving government officials, company executives and others) functioned to inhibit efforts to completely eliminate dust deposition (BENCZE; POULIOT, 2017).

Given intense influences of capitalists in limiting extents to which learners (and other community members) may develop expertise, confidence and motivation for creating and implementing actions to address perceived harms in STSE relationships, it seems appropriate to explore possible actants in such an ‘oppositional’ dispositif. In terms of influences on science and technology education in recent years, two related sets of initiatives — that is, ‘STEM’ (Science, Technology, Engineering & Mathematics) education and ‘IBL’ (Inquiry-based Learning) preferences — seem to be obvious candidates for critical analyses. In his ongoing efforts to conduct action research to learn more about opportunities for students to self-direct research and to use findings to inform personal and social actions to address harms in STSE relationships, Larry and colleagues have published some such critiques (*e.g.*, BENCZE et al., 2018; BENCZE; ALSOP, 2009). Some major aspects of these critiques are summarized below with reference to the schema in Figure 2:

Figure 2 – Model for Science Inquiries and Applications (e.g., Engineering Designs).



Source: Elaborated by the authors.

It seems that STEM education and IBL can largely be explained in terms of the schema in Figure 2, which is an adaptation of a schema presented by Roth (2001) to depict reciprocal relationships between ‘science’ (Phenomena → Representations) and ‘technology’ (and engineering) (Representations → Phenomena). With mathematics involved throughout, the whole schema may represent STEM.

Promotion of IBL appears to have a much longer history than STEM initiatives. Encouraging students to learn science knowledge by doing science investigations dates at least to the mid-nineteenth century in the UK (JENKINS, 1979), has since spread around the world and is, for example, promoted (along with STEM education) in the recent influential US national science education standards document (DUSCHL; BYBEE, 2014). There is considerable variation in interpretations and uses of the ‘inquiry-based learning’ phrase, differing — for instance — in extent of teacher versus student learning control (LOCK, 1990). However, much of it involves teachers presenting students with contexts in which they ask questions that may be answered through empirical (or non-empirical) investigations, designing such investigations and drawing conclusions from findings — with various teacher questions and/or suggestions being provided as students proceed. Schwartz, Lederman and Crawford (2004), for instance, who have written much about IBL, suggest it often can be characterized as follows:

> Within a classroom, scientific inquiry involves student-centered projects, with students actively engaged in inquiry processes and meaning construction, with teacher guidance, to achieve meaningful understanding of scientifically accepted ideas targeted by the curriculum (p. 612).

Such activities seem, with reference to Figure 2, to involve teacher-facilitated student translations between phenomena of the World and Signs (conclusions) representing them that are widely-accepted by scientists and/or engineers — like the following learning expectation for 10th-grade students: “use an inquiry process to investigate the law of conservation of mass in a chemical reaction (e.g., compare the values before and after the reaction), and account for any discrepancies” (MoE, 2008, p. 76).

Teacher-facilitated student activities to support widely-accepted claims of science and technology through inquiry-based learning can be problematic. It seems, for instance, that there are many threats to *social justice*. Although a highly contentious concept, social justice “may be broadly understood as … fair and compassionate distribution of [...] fruits of economic growth [...] [or ‘activities,’ acknowledging inherent problems of perpetual growth]" (UN, 2006, p. 7). Translating such a definition into meaningful expectations for 'learning' in science education is, clearly, extremely uncertain. Nevertheless, it seems difficult for some or many students to discover — depending on the nature and extent of teacher 'scaffolding' — widely-accepted claims ("Representations," Figure 2) about such phenomena through their observations of them. Wellington (1998) noted, for instance, that "[empirical] work is still not a good tool for teaching theory—theories are about *ideas*, not things. Theories involve abstract ideas which cannot be physically illustrated" (p. 7, italics in original). This problem can be understood in terms of basic constructivist learning concepts, which suggest that 'observing' (i.e., interpreting) depends on existence of cognitive structures that may align (to some degree) with sensory information (HODSON, 1986). This problem, in turn, suggests that IBL based on empirical observations can be *discriminatory* — unequally successful among students, given that societies are stratified and, related to that, students vary in their possession of *cultural* (*e.g.*, powerful societal attitudes, skills, knowledge) and *social* (*e.g.*, positive relationships with influential people and groups) 'capital' (BOURDIEU, 1986). Such an unjust goal sometimes, however, seems planned — as suggested by the following statement by the NRC (2011) in the USA:

> The 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)

Besides possibly being discriminatory, IBL practices may be broadly disempowering. As in empirical inquiries, when students access information from secondary sources, such as the Internet, variations in their existing cultural and social capital may limit their interpretations. Additionally, however, available information also may be *biased* — given, for example, that capitalists appear to have paid some people (*e.g.*, scientists) and groups (*e.g.*, think tanks) to discredit research findings, such as from climate change research, that would, if more widely disseminated, discredit commercial products and services (*e.g.*, petroleum-based activities) (ORESKES; CONWAY, 2010).

Even though teacher 'scaffolding' (*e.g.*, questions, suggestions) during student inquiry activities may help students to generate widely-accepted claims, successes with such instructions may be, as discussed above, biased towards those richer in cultural and social capital. At the same time, teacher guidance may lead to some negative side-effects. While students may *believe* they are self-determining knowledge about the world, for instance, teacher guidance may reduce students' self-confidence about inquiring and, moreover, it may reduce depth of their expertise — given that depth and commitments to learning often depend on degrees to which learners control decisions (*e.g.,* in both directions in Figure 2) (WENGER, 1998). Such guidance may, as well, suggest to students that professional science inquiries proceed relatively smoothly from observations, through questions, explorations, etc. to valid and useful claims about the world — conceptions about the nature of science (and technology) not well-supported through science studies (HODSON, 1996). Of greater importance, in terms of influences of capitalists on fields of science and technology and their educational counterparts, it seems that teacher guidance can be relatively *reductionist* (*e.g.*, focused on narrow cause-effect relations, as depicted in Figure 2 on the right) and, crucially, *unproblematic*. Carter (2005), for example, suggests that science teachers tend to avoid or minimize attention to adverse capitalist influences on science and technology and, more recently, discourses in STEM education initiatives (PIERCE, 2013) and in the USA's influential science education standards (HOEG; BENCZE, 2017) punctualize (limit awareness of phenomena's networked connectedness)

(CALLON, 1991) and de-problematize representations of Phenomena of the world (Figure 2).

If students' attitudes, skills and knowledge regarding science claims about "Phenomena" (Figure 2) are, largely, punctualized and de-problematized, their engineering/technology designs (Representations → Phenomena in Figure 2), which appear to be (or, perhaps, *the*) major thrusts of STEM education initiatives (PLEASANT; OLSON, 2018), may emphasize narrow (punctualized), technicist (and de-problematized), goals. On one hand, there are references in STEM education literature to engagement of students in engineering designs associated with ecological sustainability, including to "...engage learners in building a wind or water turbine connected to a generator to light a bulb. An associated driving question or driving problem might be: How can I illuminate a light bulb using water or wind power?" (p. 46). On the other hand, based on analyses of STEM education discourses noted above, discussions of problematic relationships among capitalists (and others), science and technology and other members of societies and environments are likely to be minimized. As Pierce (2013) suggests,

> (…) what the new framework for science education standards advances is an ever-deeper epistemological blindness to purification ([claims that] science is only involved with the objective world) while also simultaneously striving to produce more educational subjects who are involved in the creation of objects of translation such as the AquAdvantage® Salmon [that may be problematic for much of 'WISE'] (p. 127).

Although Larry has been convinced — as described above — that STEM initiatives and IBL practices represent impediments to student-led RiNA projects that are aimed at overcoming harms students determine in STSE relationships, graduate students engaged in action research (NOFFKE; SOMEKH, 2009) with teachers in different contexts have reported, mainly in our weekly research meetings, that there appear to be some contradictions about his concerns. To learn more about such ambiguities, we decided to have each graduate student named in this paper write a short narrative description of their previous action research experiences encouraging teachers in very different educational contexts (*e.g.*, by grade level and country) to help students to develop expertise, confidence and motivation for self-directing RiNA projects. In doing so, they reviewed, for instance, transcripts of discussions with the teacher, samples of the teacher's instructional materials and samples of students' completed assignments — paying particular attention to possible influences (adversely or otherwise) of STEM education initiatives and IBL practices. Drafts of the narratives — which we call "Stories from the Field" (arbitrarily provided below from lower to higher grades) — were reviewed by all of us, after which we edited them in ways that aligned with their conceptions of STEPWISE implementation, STEM education initiatives and IBL practices. Afterwards, all of us collaboratively developed themes and related categories, using constructivism-informed constant comparative methods (CHARMAZ, 2014) regarding the nature and extent of inhibitory effects of STEM education and IBL practices and factors possibly influencing such effects. Results of these analyses are provided in the Summary and Discussion section below, with general conclusions provided in the following Coda section.

Stories from the field

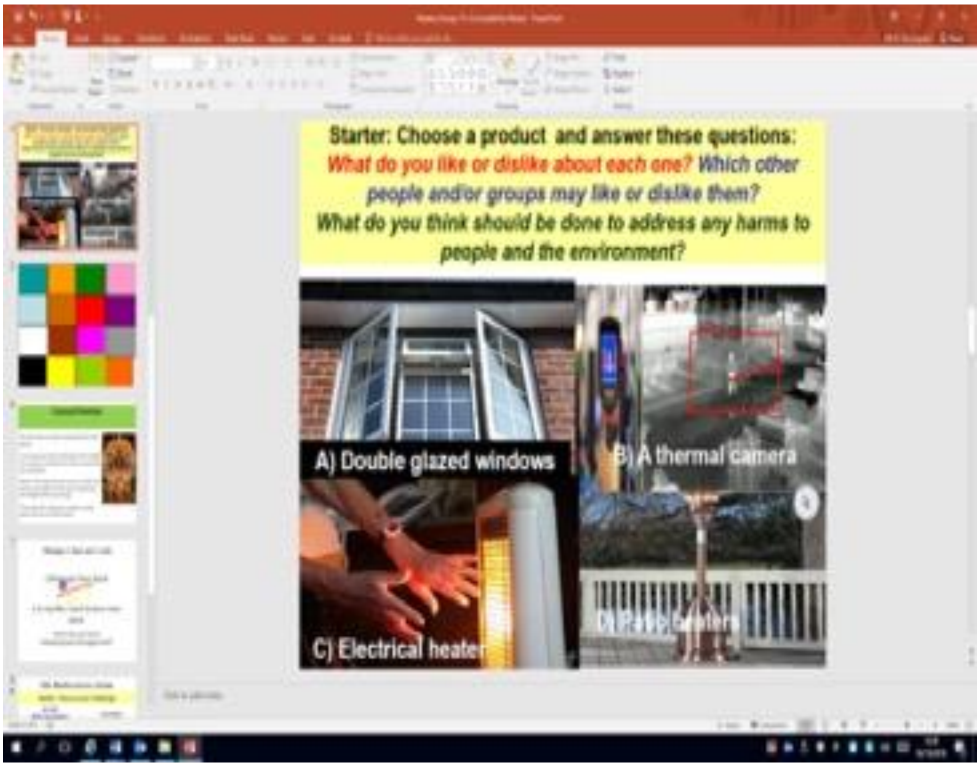
STEPWISE in the UK

'James' is a high-school science teacher in an inner-city school in the UK. With a strong background in environmental education and experiences teaching adult prisoners and refugees in his Mediterranean home country, social justice and environmental sustainability have always been central to his teaching goals. To support his high-school students (grade 8-10) to develop agency and take active roles in changing socio-environmental injustices in their communities, James decided to adopt and employ critical pedagogies in his courses. His online search led him to the STEPWISE framework. He was particularly drawn to possibilities for students to take research-informed actions while exploring socio-environmental and economic aspects of controversial issues and complex power-relations that shape development and outcomes of these issues. In the first year of adopting the STEPWISE framework, James worked on his own. In the second year, he contacted our research team to collaborate in planning, implementation and research.

Besides his inclination to use issue-based activist approaches in science education, James also favoured 'discovery' approaches inherent to inquiry-based learning. This was apparent throughout his implementation of the RiNA apprenticeship, particularly in how he fused the 'Reflection' and 'Teaching' phases (Figure 1): While exploring students' pre-conceptions about science and technology products and concepts (e.g., energy transfer; alcohol consumption, drugs and tobacco uses… etc.) and their related issues (e.g., socio-environmental and economic perspectives and consequences of using different types of energy sources), James also aimed to implicitly teach them about these issues (as he indicated during one of our weekly meetings). For that purpose, he used to provide his students with images of science and technology products, supported with overall guide questions, such as, "What do you like and dislike about [each of these products]?", "Which other people and/or groups may like or dislike them?" and "What do you think should be done to address any harms to people and the environment?" (Figure 3). In his weekly written reflections, James expressed what sounded like disappointment/frustration with his students' inabilities to 'see' complex relations associated with these issues and to reach sophisticated conclusions about them. He also described his efforts of using guiding questions to 'direct' his students' toward more detailed and comprehensive views about these issues. For example, when teaching students in grade 8 about energy transfer, James wrote:

> I kept posing questions, so [students] reached the conclusion that the environment is affected by … energy produced by thermal power plants…. Maybe I could use a diagram on the board to split students' thoughts into sections e.g. economy, environment, society.

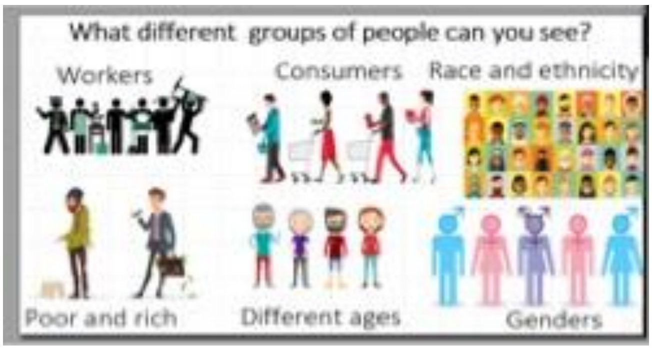
Figure 3 – Slide Activity to Explore Students' Preconceptions

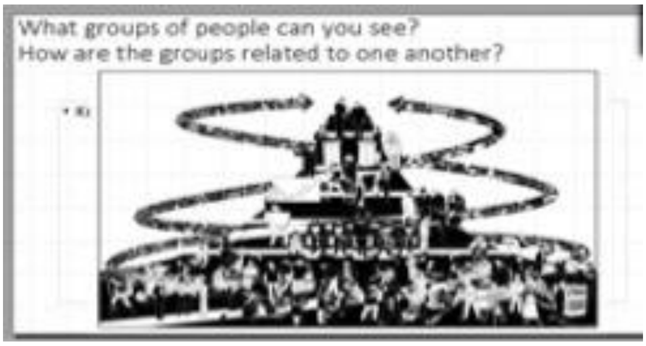


Source: Elaborated by the authors.

Faced by this challenge, and based on our weekly meetings and consultations, James decided to explicitly teach his students about social, environmental and economic aspects of an issue, possible connections between these aspects, possible stakeholders and other living and non-living entities involved, and their power-relations (Figure 4). In these efforts, James indicated that he adopted approaches that are usually used in citizenship education (*e.g., Comparison Alley; What's the Point*) to effectively teach his students about these issues. Gradually, James' students seemed to develop relatively more comprehensive and sophisticated conceptions about the STSE issues that they were examining by, for example, expanding their views about the diversity of human stakeholders, and making more connections among social, economic and environmental realms. Developing more sophisticated and realistic views about STSE issues would probably better enable these students to take more realistic and effective actions.

Figure 4 – Slides to Teach Diversity of Human Stakeholders and Their Power Relations**.**





Source: Elaborated by the authors.

We argued elsewhere that developing agencies to address socio-environmental injustices necessarily entails addressing issues of equity and injustice in science classrooms, and that one way to achieve that is by filling possible learning ‘gaps’ and bringing students to comparable levels of expertise (ZOUDA, et al., 2018). Hence, socially just science teaching and teaching science for social justice (BARTON; UPADHYAY, 2010) become mutually dependent. Our work with James indicates that largely relying on ‘discovery’ approaches to teach complex STSE issues and their hidden/exposed power-relations may not effectively support students (particularly those at risk) to develop sophisticated conceptions of these issues. Students usually draw on what they have and what they can access; therefore, without explicit teaching that simplifies complex concepts and/or exposes difficult-to-discover ideas, learning gaps tend to persist, privileging more experienced students over others in the classroom and perhaps in real world as informed and involved citizens.

Our collaboration with James also indicates that teaching/learning about STSE issues (which are inter/transdisciplinary in nature) not only requires students to utilize concepts and skills from different disciplines to effectively address these issues; science teachers also need to draw teaching approaches and pedagogies usually used in these disciplines to effectively teach different aspects of these issues.

“Environmental issues are not in a Bubble” – A Grade 10 Science Teacher’s Journey with STSE

Our next context takes us to the case of ‘Clara,’ a grade 10 science teacher at a secondary school in the Greater Toronto Area. As a teacher who had previously worked with the STEPWISE approach, she decided to take part in our action research project that encourages students to conduct their own primary and secondary research — culminating in Research Informed and Negotiated Actions (RiNA). Clara used the Environmental Science unit of the provincial curriculum to teach about concepts of correlational studies for conducting primary research; issues of potential harms in science and technology; and varying powers of stakeholders connected to socio-scientific issues. Since she had previously worked with STEPWISE, she had a reference point with which she could refer and compare and on which she could reflect. One example of a marked comparison was that, in the previous year, Clara made uses of her school district’s instructional ‘coach’ offered to science teachers. However, in the latter attempt, she chose to forego this offer of support — as she grew her own understanding and foundation of how to approach these RiNA projects.

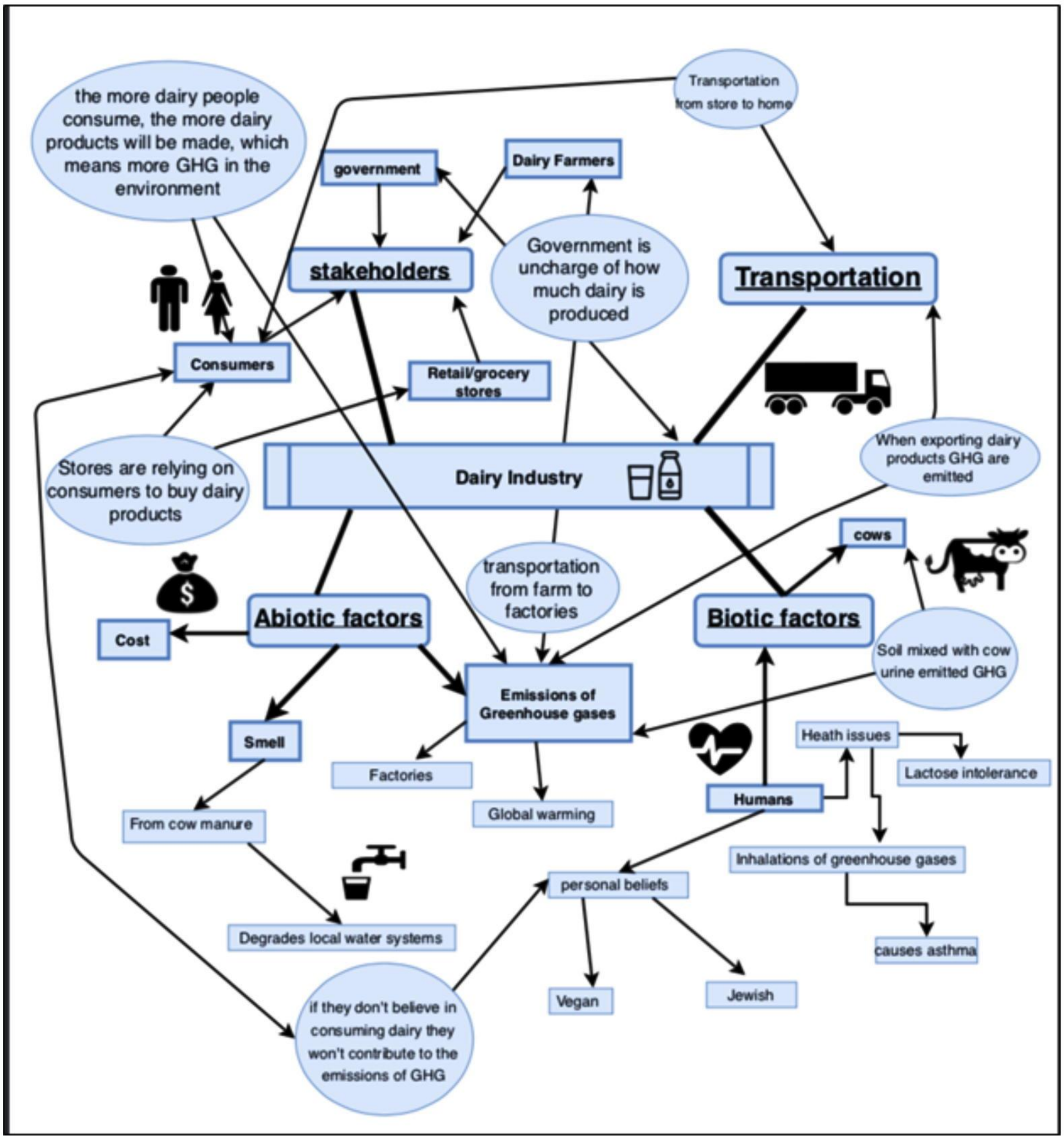
In our analyses, teacher identity — likely from Clara's educational background and training — impacted ways in which she engaged with teaching socio-scientific issues. She had studied engineering, and reflected on how her education and training impacted thinking about correlational studies: "I did a Bachelor [degree] in mechanical engineering and we never did any correlational studies. Correlation was not something I was comfortable with, but then without it, it's now evident surveys are not meaningful." She reflected that using primary research to conduct correlational studies was a meaningful exercise for students to understand "real time science" to which RiNA was conducive. Clara assigned IBL differentially to various STEPWISE components. While she valued direct teaching of skills (such as graphing, developing research questions, calculating R-values), she facilitated students' inquiries to 'discover' STSE relationships and power relations based on their interests and their questions. Thus, there does lie a tension between RiNA and IBL; yet, in her case, Clara viewed RiNA as an opportunity to lead to inquiry. Clara varied back and forth between STEM and some of the propositions advanced by STEPWISE. This was also evident through her insistence in using mathematical 'R-value' with the students' correlational studies.

While Clara found correlational studies to be meaningful, she wavered on roles of teaching power relations in a Grade 10 science class. When asked about this, she responded:

> (…) At the grade 10 level, it's enough to just bring awareness that other groups (stakeholders) exist. I'm pretty happy with that considering it's a science project and we are learning all about environment, about some graphing skills, correlational skills, that environment is not a bubble, and all those people that care about this issue...I am not sure about what [STEPWISE] says, but I think for this age group and for this subject, it's enough.

The reflection above illuminates that students were aware that many stakeholders exist; however, such power relations were not interrogated by them. When viewing a sample of one group's actor-network map (Figure 5), it is evident that the stakeholders listed hold vast power differentials; yet, this was not deeply addressed by students nor the teacher. While students seem to identify critical actants in the map, Clara used a more IBL approach with respect to power relations. In this case, students did not address problematic STSE relationships.

Figure 5 – A Student Group's Actor-Network Map Regarding Dairy Industry Stakeholders.



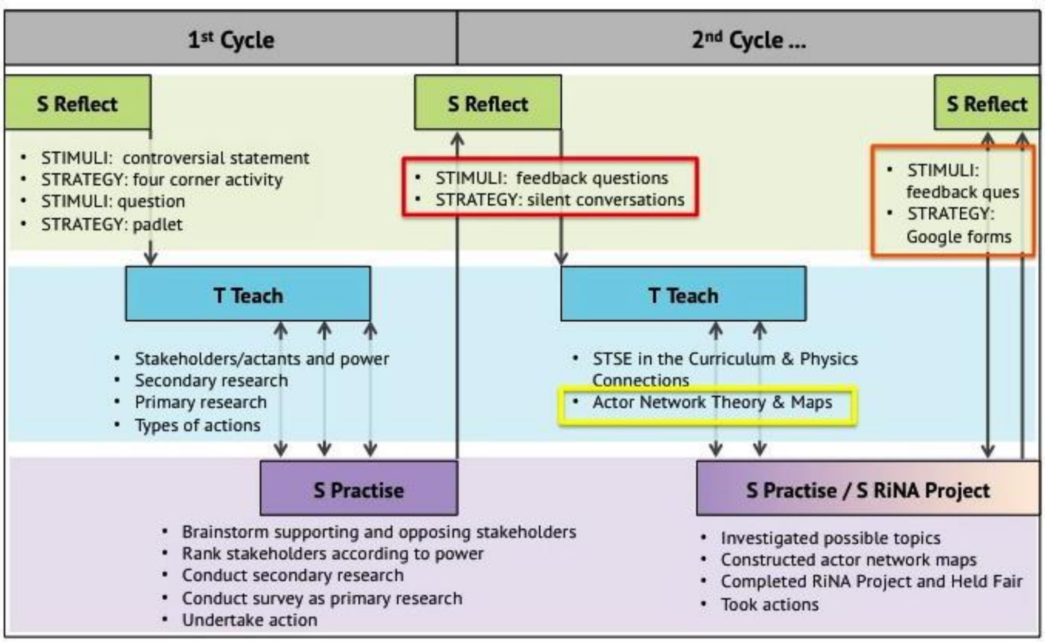
Source: Elaborated by the authors.

Finally, as discussed above, cultural capital of students can limit or enrich an inquiry or research study. From the variables chosen for correlational studies, to the stakeholders included on the actor-network map, students' life experiences and knowledge impact learning when left only to inquiry. Conversely, STEPWISE offers further teacher directed learning so that factors that may not have been considered due to cultural capital limits may be addressed by students. For example, one of the groups in Clara's class chose to conduct a correlational study on family size and frequency of travel by air. The group found a correlation that indicated decrease in family size correlated to an increase in frequency of travel. In discussing results with students, we posed other variables — such as socioeconomic status of families, which had not been taken into account. It was evident that, for this group, flying was a normalized life activity; whereas, this may be starkly different for others. This example supports that IBL can be discriminatory.

“Where is the Physics in this?” — implementing RiNA in Grade 11 Physics

Our collaboration with ‘Suzi,’ a high school teacher who decided to implement the STEPWISE pedagogical schema in her Grade 11 physics classes, is highlighted in this section. She joined our professional development workshops in hopes of finding ways to address the STSE goal in the Ontario science curriculum (*e.g.*, MoE, 2008). While she strongly supported incorporating more activist teaching (through STSE education) in her classes and deemed it important, she also recognized these areas as being outside her comfort levels. Together with an instructional coach and a research facilitator, Suzi engaged students in two cycles of the STEPWISE pedagogical schema: an introductory cycle based broadly on GPS technology and its STSE applications leading to possible current and future issues; and, a secondary cycle, in which students were given greater flexibility to choose their own STSE physics-related topics and complete RiNA projects based on them (Figure 6).

Figure 6 – Flowchart of Lessons and Activities in Suzi’s Case.



Source: Elaborated by the authors.

Throughout implementation of the introductory cycle, our greatest impediment to promotion of critical and action oriented STSE education came, interestingly, from *students* — despite their teacher’s strong support for the pedagogy and project. The following quotes (feedback provided after the introductory cycle, red box in Figure 6) portray students’ struggles to understand roles of such a project in their grade 11 physics classroom:

- “Our time spent on this project could have been used much more effectively towards our physics skills. Maybe even hands on project that has direction and will improve our skills in physics.”
- “The project was barely related to physics. It took away class time that could’ve been spent more productively. We should not get marked on it.”

- “How does this project relate to kinematics? GPS uses vectors but no mathematical skills were necessary to complete this project. It seemed like a project more for a class such as English as most of it was just research.”

Students appeared to be primed for and had ingrained within them reductionist STEM educational initiatives, as this is what they had experienced before. This ‘new’ STEPWISE pedagogy was, thus, ‘out of place’ and felt so foreign that it was a “waste of time” in their eyes.

> Despite feedback from students like that above, Suzi still believed that such projects were critical:
>
> I would love to take the lead...and emphasize the importance of the RiNA project to the students. They need to realize that they are our future, and as such cannot idly sit by as our world is turned upside down. Being uncomfortable with this type of project, shows they should be doing more, not less of them.

We, thus, proceeded with implementation of a secondary cycle and tried to address as much of the student feedback and concerns as possible. Suzi decided that showing the Ontario science curriculum document to the students and drawing their attention to sections under which their projects seem to comply would be prudent. We also suggested to students that they may refer to and use the curriculum to aid in their secondary cycle project topic decisions and visualizing possible relations to ‘physics.’ Additionally, we created a graphic to give students a better understanding of the big picture of the whole project and we organized a RiNA fair, at which students could showcase and share their work with peers, other teachers and school administrators.

A pedagogical emphasis and decision taken by Suzi during this secondary cycle that is worth noting is the manner in which she taught students to construct stakeholder network maps based on actor-network theory (yellow box in Figure 6). She chose to bring to light an interdisciplinary perspective, urging her students to explore issues and construct their maps with an additional beneficial outcome of envisioning possible future careers. She stressed that within their maps there could be relationships between actants leading to creative and interdisciplinary job sectors, uncovering careers about which they may have never conceived. This was an added benefit of completing networked RiNA projects and stepping outside confining boundaries of many STEM initiatives.

Upon completing the secondary cycle and their RiNA projects, some students seemed to reduce their resistance and appeared to be gaining a greater appreciation for roles and importance of RiNA projects. Based on their feedback, many of them experienced a shift in their initial thinking (orange box in Figure 6) — such as may be evident in this student comment:

> The education system is so rigid in its teaching style that we’ve lost a good chunk of creative thinking. This should be an opportunity to learn about things that might not be taught in the curriculum or simply try to develop new skills that could be more applicable to our actual life. Students are taught to look towards their teachers for answers but they should start leading themselves. This project is starting to move forward away from that old teaching style and really embodies the future.

A Look at College Education

In this section, we illustrate and further interrogate our earlier propositions with regards to STEM and inquiry-based education, specifically considering contexts of higher education (in this case, college education).

For the past 3 years, we have been interacting through various research projects with a college instructor, Nurul, and students enrolled in the Biotechnology Program at a community college in the Greater Toronto Area. Nurul has been infusing his microbiology lab. project courses with STEPWISE approaches to get students to think about science beyond mere cause-effect relationships (*e.g.*, comparing oral flora of smokers and non-smokers) to equally consider vested interests of powerful stakeholders involved in production and marketing of various science and technology products (*e.g.*, tobacco-based products) with repercussions on wellbeing of individuals, societies and environments.

The biotechnology program seems to be geared towards producing STEM professionals, as advertised on the college's website: "Our Biotechnology program prepares you to work as a laboratory technician (in quality control and quality assurance) in the food, pharmaceutical and cosmetic industries." As laboratory technicians, students are often expected to use their technical skills to perform pre-set protocols, alienating them from processes and products of science and technology, and perhaps conditioning them to relations of dependency that may hinder their abilities to critically interrogate their relationships to powerful entities. Having said that, students are expected to take a global citizenship course as part of the biotech program — a course aimed at allowing "students to develop a sound understanding of what it means to be a global citizen, both personally and professionally, and the ways in which they can make a contribution to an equitable society and world". In other words, this college seemed to value compatibilities between STEM education and issues of social/environmental justice.

We further traced such compatibilities to project courses in microbiology labs. In observing Nurul's attempts to incorporate RiNA projects with mandated components of laboratory work (*i.e*., design and execution of experimental protocols), we noted instances whereby efforts to bring awareness to social and environmental injustices were not necessarily incongruent with experimental protocols in which students were already engaging. As Nurul prompted his students to look at "bigger picture behind their products" and to "consider who is benefiting and who is harmed," those discussions seemed an add-on to students' experimental projects — *complementing*, rather than conflicting with, their own expectations for the course. Students expressed how,

> (…) after the course, we saw everything outside the box, we could connect all points, could see whole picture" [and how] before, we saw science only in positive terms, now we also started to see the negative. People don't think about the end goal, how the product will eventually have implications. They just think that it's profitable.

In response to our question related to experiences with STEPWISE, a student mentioned how she became more reflexive when working with chemicals in the lab.: "I became more self-conscious, not to overuse, thinking how it's going to affect the environment. Even like with disinfectants, you don't need to use so much, just use a little bit, that thing comes out of you automatically when you are onto those things". In this instance, STEPWISE may have affected a student's disposition to become a more *caring* STEM technician.

With regards to how inquiry unfolded in the lab., students worked in groups to self-direct experiments to test anti-microbial effectiveness of a science and technology product of their choice (*e.g.*, antibiotics, probiotics, shampoos). In doing so, students designed experimental protocols, accounting for materials and chemicals that were available to them in the lab. While this course could be considered to provide students with authentic opportunities for open-ended inquiry-based learning, it later came to our attention that students were adapting pre-existing protocols found on the Web. Thus, what appeared to be self-directed experiments were mere confirmation of prior science investigations with similar products. Interestingly, when students' analyses showed a discrepancy with 'expected' outcomes, their immediate reaction was to put the onus of responsibility on themselves: "We must have done an experimental error" (student's comment). In those instances, inquiry seems to be reduced to mastering technical skills for reaching pre-set outcomes by following specific protocols. Closed-endedness of such protocols might conform technicians to their roles in quality assurance, limiting extents to which they might feel empowered to question stakeholders' interests regarding products of science and technology. This was specifically evident when students would repeatedly ask their instructor to verify and approve of their correlational studies as part of their RiNA projects. The instructor noted students' difficulties with problematizing power groups when developing their survey questions. As correlational studies are meant (in STEPWISE) to be relatively student-led (*i.e*., students are free to develop their own surveys), students' constant turns to the instructor as the authority revealed their conditioning to educational practices that are more or less convergent with predetermined and depoliticized outcomes.

Summary and discussion

Preamble

Broadly, our collaborative narrative study suggests that there do appear to be adverse influences of STEM education initiatives and IBL practices on extents and characteristics of students' RiNA projects aimed at overcoming possible harms that they determine in STSE relationships. Nevertheless, there also was evidence suggesting that aspects of STEM education and IBL practices may, perhaps ironically, serve — to some extents — as segues into STEPWISE-informed practices. While acknowledging complexities and uncertainties in determining causes and effects, given, for example, dynamic and unpredictable characteristics of actor-networks (LATOUR, 2005), we discuss below some isolated factors possibly influencing effects — for sake, perhaps, of communicative effectiveness.

Roadblocks

All four teachers in our study *chose* to, metaphorically, 'drive down the road' towards greater STEPWISE implementation. Most of them had implemented STEPWISE-informed practices in at least the semester prior to our studies reported here, and all of them had become familiar (in different ways) with basic tenets of the framework. Despite their enthusiasm and general preparedness, however, each teacher ran into various 'roadblocks' in their 'journeys.' Although they had general supports for their pedagogical goals and practices from their jurisdiction's science curriculum and from school administrators and colleagues, which often are essential for STEPWISE implementation, all teachers studied here appeared to experience various degrees and sources of (sometimes unstated) resistance — but, mainly, from *students*. Broadly, while such reticence likely was manifested in different forms, much of this can be explained in terms of students' conditioning to science education paradigms that prioritize, as discussed above, uses of empirical activities, with some teacher instruction, leading to knowledge and understanding of widely-accepted products of science and technology — usually without references to interactions among other societal members and with environments. Particularly near the beginning of the course, for instance, 'Suzi' said her students in grade eleven physics criticized relevance of STSE education and RiNA projects, suggesting it was compromising their foci on learning physics knowledge and skills — which appears to be prioritized in many STEM education initiatives. Similarly, although amenable to uses of correlational studies, as well as experiments, to generate knowledge, students in Nurul's class tended to expect relatively systematic methods to generate relatively certain results — minimizing student self-determination of knowledge and actions, key priorities of STEPWISE.

Segues

Faced with general student reticence to move beyond *status quo* perspectives and practices for science education, teachers employed different adaptive tactics to engage students in STSE education and RiNA projects. Many of these seemed comparable to Wenger's (1998) concept of boundary entities (objects, agents, processes, etc.) that may relatively-seamlessly bridge gaps between communities of practice or (loosely-speaking) paradigms. That all students of the college in which Nurul worked were required, despite traditions in their institution of focusing on unproblematic knowledge and skill development, to take a course in 'global citizenship' gave Nurul a 'licence' to expand students' conceptions of science. At the same time, that empirical investigations were normalized in all of the contexts we studied seemed to help teachers to justify suddenly encouraging students to use correlational studies, as well as experiments, as empirical data sources for claims.

In actively encouraging and enabling students to engage more deeply in STSE education and RiNA projects, teachers in this study did not, of course, act alone. Also serving as boundary entities were researchers, all of whom functioned as researcher/facilitators (R/Fs) in action research approaches. This enabled Minja (working with a school district instructional coach), for instance, to co-teach students in Suzi's class about how to make actor-network maps for depicting STSE relationships. While somewhat reluctant to explore such broader relationships with science, Suzi's suggestion that students particularly focus on STEM careers (as actants) seemed to serve as effective boundary entities. Although Clara had chosen not to work with the school district instructional coach, she had done so the previous year; and, so, his function as a boundary entity cannot be discounted — particularly given that he had implemented STEPWISE-informed practices over six semesters when he was a teacher in the school district.

CODA

This study supports earlier research (BENCZE; KRSTOVIC, 2017) suggesting that STEPWISE-informed perspectives and practices may be implemented when a supportive *dispositif* (FOUCAULT, 2008) is in place. In the contexts studied here, for instance, this involved collaboration among government curricula (MoE, 2008), boundary entities (*e.g.*, instructional coach, research/facilitators, traditions of empirical verification, etc.) and committed and experienced teachers. Having said that, it appears that students' RiNA projects, while expanding their conceptions of STSE relationships, research approaches and uses of science findings, were largely limited to *awareness* of relationships among a range of living, nonliving and symbolic actants — including different economic entities — (as in Figure 5, above). Actions arising from such new conceptions were, in turn, largely (with some exceptions) limited to educating peers about problematic STSE relationships. A video summary of projects by students in Suzi's class (www.youtube.com/watch?v=tG7VKgMRI2M) may help support this claim for readers. As appears to be the case in much STSE education (and, related to that, socioscientific issues education), such elaborated — but, much less *politicized* — education seems aligned with Roberts' (2007) 'Vision II' category of science literacy (e.g., useful to most citizens and recognizing citizen interactions with scientists and engineers). It makes one wonder about the extent to which STEM education initiatives and IBL practices largely limit science/STEM education to Vision II types of science literacy. Noting such possible limitations, and in light of severity and persistence of many problematic STSE relationships associated with powerful global actants, Sjöström et al. (2017) suggest that more efforts are needed to encourage what they call 'Vision III' types of science literacy — in which most students are educated about such power-related harms and prepared, largely in *embodied* ways (*e.g.*, via dynamic interactions with circulating emotions), to engage in socio-political actions to try to overcome harms of their concern. Given earlier studies of STEPWISE implementation (*e.g.*, BENCZE; KRSTOVIC, 2017), such a transformation in perspectives and practices may be realized if educators and others consciously work in multipronged directions to help form dispositifs that are more broadly supportive of critical and action-oriented science and technology education.

REFERENCES

BALL, S.J. *Global education inc.*: New policy networks and the neo-liberal imaginary. New York: Routledge. 2012.

BARTON, A.C.; UPADHYAY, B. Teaching and learning science for social justice: Introduction to the special issue. *Equity & Excellence in Education*, v.43, n.1, p.1-5. 2010.

BENCZE, J.L.; ALSOP, S. (eds.) *Activist science & technology education*. Dordrecht: Springer. 2014.

BENCZE, J.L. (ed.) *Science & technology education promoting wellbeing for individuals, societies & environments*. Dordrecht: Springer. 2017.

BENCZE, J.L.; ALSOP, S. A critical and creative inquiry into school science inquiry. In W.-M. Roth; K. Tobin (Eds.), *The world of science education*: North America (pp. 27-47). Rotterdam: Sense. 2009.

BENCZE, J.L.; ALSOP, S. (eds). *Activist science & technology education*. Dordrecht: Springer. 2014.

BENCZE, L. et al. Ecojust STEM education mobilized through counter-hegemonic globalization. In K.J. SALTMAN; A.J. MEANS (Eds.), *The Wiley handbook of global education reform* (pp. 389-411). Hoboken: Wiley-Blackwell. 2018.

BENCZE, L. et al. Promoting students' critical and active engagement in socio-scientific problems: Inter/Trans-national perspectives. In MCLOUGHLIN, E.; FINLAYSON, O.; ERDURAN, S.; CHILDS, P. (Eds.), *Contributions from science education research*: Selected papers from the ESERA 2017 conference. Dordrecht: Springer. (in press).

BENCZE, L.; KRSTOVIC, M. Resisting the Borg: Science teaching for common wellbeing. In BENCZE, J.L. (Ed.), *Science & technology education promoting wellbeing for individuals, societies & environments* (pp. 227-276). Dordrecht: Springer. 2017.

BENCZE, L.; POULIOT, C. Battle of the bands: Toxic dust, active citizenship and science education. In BENCZE, J.L. (Ed.), *Science & technology education promoting wellbeing for individuals, societies & environments* (pp. 381-404). Dordrecht: Springer. 2017.

BENCZE, L. et al. STEM education as ‘Trojan horse’: Deconstructed and reinvented for all. In BRYAN, L.; TOBIN, K. (Eds.), *13 questions*: Reframing education’s conversation: Science (pp. 69-87). New York: Peter Lang. 2018.

BOURDIEU, P. The forms of capital. In RICHARDSON, J.G. (Ed.), *The handbook of theory*: Research for the sociology of education (pp. 241-258). New York: Greenwood Press. 1986.

CALLON, M. Techno-economic networks and irreversibility. In J. LAW (Ed.), *A sociology of monsters*: Essays on power, technology and domination (pp. 132–161). London: Routledge. 1991.

CARTER, L. Globalisation and science education: Rethinking science education reforms. *Journal of Research in Science Teaching*, v.42, n.5, p.561-580. 2005.

CHARMAZ, K. *Constructing grounded theory* (2nd ed.). New York: Sage. 2014.

CHOMSKY, N. *Optimism over despair*: On capitalism, empire, and social change. Chicago, IL: Haymarket. 2017.

DUSCHL, R.; BYBEE, R.W. Planning and carrying out investigations: An entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education*, v.1, n.1, p.1-9. 2014.

FENWICK, T.; EDWARDS, R. (eds.) *Researching education through actor-network theory*. Chichester, West Sussex, UK; Malden, MA: Wiley-Blackwell. 2012.

FOUCAULT, M. *The birth of biopolitics*: Lectures at the Collége de France, 1978-1979 (Ed., M. Senellart). New York: Palgrave Macmillan. 2008.

HARDT, M.; NEGRI, A. *Commonwealth*. Cambridge: Belknap Press of Harvard University Press. 2009

HODSON, D. The nature of scientific observation. *School Science Review*, v.68, n.242, p.17-29. 1986.

HODSON, D. Laboratory work as scientific method: Three decades of confusion and distortion. *Journal of Curriculum Studies*, v.28, n.2, p.115–135. 1996.

HODSON, D. *Looking to the future*: Building a curriculum for social activism. Rotterdam: Sense. 2011.

HOEG, D.; BENCZE, L. Values underpinning STEM education in the USA: An analysis of the Next Generation Science Standards. *Science Education*, v.101, n.2, p.278–301. 2017.

JENKINS, E.W. *From Armstrong to Nuffield*: Studies in twentieth-century science education in England and Wales. London: John Murray. 1979.

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

LEONARD, A. *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. 2010.

LOCK, R. Open-ended, problem-solving investigations—What do we mean and how can we use them? *School Science Review,* v.71, n.256, p.63-72. 1990.

LOVING, C.C. The Scientific Theory Profile: A philosophy of science model for science teachers. *Journal of Research in Science Teaching*, v.28, n.9, p.823-838. 1991.

MECKLIN, J. (ed.) *A new abnormal*: It is still 2 minutes to midnight, 2019 Doomsday Clock statement. Chicago, IL: Science and Security Board, Bulletin of the Atomic Scientists. 2019.

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

MINISTRY OF EDUCATION [MoE] *The Ontario curriculum, grades 9 and 10:* Science. Toronto: Queen’s Printer for Ontario. 2008.

MIROWSKI, P. *Science-mart*: Privatizing American science. Cambridge, MA: Harvard University Press. 2011.

MOORE, J. W. *Capitalism in the web of life*: Ecology and the accumulation of capital. London and New York: Verso. 2015.

NATIONAL RESEARCH COUNCIL [NRC] *Successful STEM education*: Identifying effective approaches in science, technology, engineering, and mathematics. Washington, DC: National Academies Press. 2011.

NOFFKE, S.E.; SOMEKH, B. (Ed.) *The SAGE handbook of educational action research*. Los Angeles and London: Sage Publications. 2009.

NORMAN, G.A. et al. (eds.) *Clinical ethics in anesthesiology*: A case-based textbook. Cambridge, MA: Cambridge University Press. 2011.

ORESKES, N.; CONWAY, E. *Merchants of doubt*. London: Bloomsbury Press. 2010.

OXFAM. *Pubic good or private wealth?* Oxford, UK: Oxfam International. 2019.

PEDRETTI, E.; NAZIR, J. Currents in STSE education: Mapping a complex field, 40 years on. *Science Education*, v.95, n.4, p.601-626. 2011.

PIERCE, C. *Education in the age of biocapitalism*: Optimizing educational life for a flat world. New York: Palgrave Macmillan. 2013.

PIKETTY, T. *Capital in the twenty-first century*. Cambridge, MA: Cambridge University Press. 2014.

PLEASANT, J.; OLSON, J.K. What is engineering?: Elaborating the nature of engineering for K-12 education. *Science Education*, v.103, n.1, p.145-166. 2018.

ROBERTS, D.A. Scientific literacy/science literacy. In S.K. ABELL; N.G. LEDERMAN (Eds.), *Handbook of research on science education* (pp. 729-780). Mahwah, New Jersey: Lawrence Erlbaum Associates. 2007.

ROTH, W.-M. Learning science through technological design. *Journal of Research in Science Teaching,* v.38, n.7, p.768-790. 2001.

SANTOS, W.L.P. dos. Scientific literacy: A Freirean perspective as a radical view of humanistic science education. *Science Education*, v.93, n.2, p.361-382. 2009.

SCHWARTZ, R.S.; LEDERMAN, N.G.; CRAWFORD, B.A. Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry**.** *Science Education*, v.88, n.4, p.610-645. 2004.

SISMONDO, S. Science and technology studies and an engaged program. In E. J. HACKETT; O. AMSTERDAMSKA; M. LYNCH; J. WAJCMAN (Eds.), *The handbook of science and technology studies* (3rd ed.). (pp. 13-31). Cambridge, MA: MIT Press. 2008.

SJÖSTRÖM, J.; FRERICHS, N.; ZIN, V.G.; EILKS, I. Use of the concept of Bildung in the international science education literature, its potential, and implications for teaching and learning. *Studies in Science Education*, v.53, n.2, p.165-192. 2017.

SPRINGER, S.; BIRCH, K.; MACLEAVY, J. (eds.) *The handbook of neoliberalism*. New York: Routledge. 2016.

VERMA, M. (ed.) *Cancer epidemiology*: Modifiable factors. Totowa, NJ: Humana Press. 2009.

STEFFEN, W. *et al*. Trajectories of the Earth system in the anthropocene. *Proceedings of the National Academy of Sciences of the United States of America*, v.115, n.33, p.8252-8259. 2018.

UNITED NATIONS [UN] *Social justice in an open world*: The role of the United Nations. New York: United Nations. 2006.

WEBER, K. (ed.) *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. 2009.

WELLINGTON, J. Practical work in science: Time for a re-appraisal. In J. WELLINGTON (Ed.), *Practical work in school science*: Which way now? (pp. 3-15). New York: Routledge. 1998.

WENGER, E. *Communities of practice*. Cambridge: Cambridge University Press. 1998.

ZOUDA, M. et al. Activist science education: Spaces for equity and inclusiveness. *Annual conference of American Educational Research Association*, New York, April, 2018.

Recebido em: 08/10/2018
Aprovado em: 10/01/2019