Students Acting to Address Personal, Social & Environmental Harms Linked to Science & Technology

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ABSTRACT

While there is much to celebrate about roles played by scientists, technologists, engineers and mathematicians (‘STEM’) in societies, it seems that citizens need to be vigilant in critically evaluating products and services they help generate and, where problems are found to exist, take personal and social actions to address them. It is apparent that governments — with considerable assistance from trans-national organizations and influential individuals — have rallied an immense collection of living, non-living and symbolic entities, including STEM fields and STEM education, in ways that appear to prioritize private profit over wellbeing for all individuals, societies and environments. Since 2006, however, the ‘STEPWISE’ teaching and learning framework has been developing and used with teachers — in various educational contexts — to help generate societies oriented towards active promotion of wellbeing for all. Its central focus is on helping students/citizens to develop expertise, confidence and motivation to self-direct research-informed and negotiated actions to address power-related problems they perceive in relationships among fields of science and technology and societies and environments (‘STSE’). In this chapter, rationale and approaches for uses of the STEPWISE framework are provided. In addition to uses of constructivist learning theories, the approach involves an ‘apprenticeship’ framework and, embedded in that, case methods and guided practice — with particular attention to actor network theory to enhance conceptions of and actions to address problematic STSE relationships. Also included, however, is discussion about challenges to such approaches — and possible ways to meet such challenges.

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Many people agree that fields of science and technology have had numerous positive effects on the wellbeing of individuals, societies and environments (WISE). In some contexts, humans enjoy longer life spans, for example, largely because of advances in life sciences and medicine and in agriculture. There are those who claim otherwise, however. Many point, for example, to climate change as our most pressing problem (Klein, 2014). According to the Intergovernmental Panel on it, Earth is on course for catastrophic loss of life and physical disruptions, unless drastic changes in public policy and private practices are made in the next few years. There are many other potential problems, however — including health and social justice concerns relating to: fast foods (e.g., deep-fried chicken) and other processed foods (e.g., cookies with trans-fats), pharmaceuticals (e.g., drugs with negative side-effects), various biotechnologies (e.g., seeds with a gene making it sterile), toxic chemicals in everyday things (e.g., Bisphenol A in plastic bottles) and agricultural research and practices (e.g., agro-toxics).

Perhaps in acknowledgement of many potential harms to WISE associated with fields of science and technology, school science systems have, for at least the last forty years, placed some emphasis on lessons and activities in science education that involve consideration of relationships, as depicted in Figure 1, among fields of professional science & technology (& engineering) and societies & environments (STSE) (Pedretti & Nazir, 2011). In doing so, there has been a tendency to focus on controversies in such relationships — such as whether or not to de-regulate chemical companies’ uses of potentially toxic ingredients in household cleaning and hygiene products (Leonard, 2010). A popular related movement involves focus on so-called socio-scientific issues (SSIs) (i.e., social controversies with bases in fields of science). Although there seem to be many ways to engage students in issues/controversies, students are frequently encouraged to consider data, findings and claims from various ‘stakeholders’ (e.g., scientists and politicians) and negotiate with peers their personal positions on issues (Levinson, 2013). Such personal choice approaches to SSI education have, apparently, led to some significant benefits for students — including development of socioscientific reasoning skills (Sadler et al., 2007) and learning about nature of science (Khishfe & Lederman, 2006).

Despite some educational gains associated with engaging students in taking personal, well-reasoned, choices on STSE issues, limiting SSI education to personal-choice approaches may be problematic. According to Levinson (2010, 2013), for instance, common SSI practices tend to place students in roles emphasizing dependency on scientists and other experts to provide information needed for their decision-making. Such personal choice roles may be appropriate for citizenship in representative democracies — in which citizens exercise democratic choices largely through periodic election of political representatives, often informed by experts like scientists, engineers, lawyers and other professionals (Wood, 1998). Some scholars and others suggest, however, that science education needs to help prepare people for more active citizenship in participatory forms of democracy (Bencze & Alsop, 2014; Hodson, 2011). On the one hand, it seems reasonable to leave decisions regarding matters of science and technology to experts, who are highly trained and have access to sophisticated equipment, etc. On the other hand, some people are concerned about influences powerful members of societies sometimes have on fields of science and technology that frequently seem to result in various harms to the wellbeing of individuals, societies and/or environments (Mirowski, 2011). In many places in the world, for instance, companies have rights to minimize their costs in order to maximize profits (McMurtry, 2013). This can mean reductions in labour costs at stages from resource extraction through transportation, sales and marketing and on to disposal (e.g., lower wages, benefits and working conditions) of commodities. Costs for materials (e.g., less expensive ingredients in foods, sometimes lacking in nutritional value) also can be minimized. Such reductions can, in turn, lead to numerous compromises to the quality of goods and services generated through fields of technoscience that can contribute to many personal, social and environmental harms. Exacerbating such compromises appears to have been legal decisions (e.g., in 1980 in the USA) allowing contracts between university-based technoscientists and companies/financiers, which tended to shift their foci from knowledge generation for general wellbeing to that of private interests (Krimsky, 2003; Mirowski, 2011). There are numerous examples, therefore, of compromises to products/services generated with assistance from fields of technoscience that are linked to various personal, social and environmental harms. Leonard (2010) suggests, for example, that many manufactured products contain numerous untested potentially hazardous chemicals. Similarly, pharmaceutical companies apparently have compromised product quality — such as by testing drugs with young subjects, who are less likely to experience negative side-effects (Angell, 2004). Perhaps very seriously, some companies have been known to encourage engineers to design products to quickly fail — which may lead consumers to discard commodities and replace them with the latest innovations (Leonard, 2010). Consequently, humans and our living and non-living environments are threatened by such common commodities as: cigarettes
In light of such problems that appear to stem, in part, from government-sanctioned ‘business-science’ associations, it seems clear that more citizens need to be prepared to critically evaluate processes and products of fields of science and technology and, where they perceive problems, develop and implement plans of action to try to bring about a better world.

STEPWISE TOWARDS ACTIVE CITIZENSHIP

STEPWISE Frameworks: Rationale and Structures

In 2006, the ‘STEPWISE’ theoretical framework was developed for encouraging and enabling students to self-direct sociopolitical actions to address harms they perceived associated with fields of science and technology. This framework is a tetrahedral schema that arranges five teaching/learning domains to indicate that they co-affect each other (e.g., Skills Education ↔ STSE Education); but, at the same time, all domains on the outside may inform (and benefit from) students’ STSE Actions — such as petitions, posters and/or Twitter™ feeds, etc. to politicians, businesses, citizen activists, etc. Placement of STSE Actions in the centre of the 3-dimensional tetrahedron is meant to indicate that students may ‘spend’ some of their cultural (and social) capital (i.e., as literacy in the four peripheral domains) (Bourdieu, 1986) not just on themselves but also on ‘altruistic’ efforts to bring about a better world.

Convincing students to use some of their education for helping other living and non-living environments may not be easy, particularly in parts of the world where citizens are strongly encouraged and/or need to focus on consumption of goods and services and compete for jobs and social status (Baudrillard, 1998). Accordingly, a key aspect of STEPWISE is to encourage and enable students to develop confidence, expertise and motivation for self-directing research (e.g., as studies and experiments) to learn more about STSE relationships. By having increased control over decisions about conclusions from their research, students may gain deeper senses of belonging to such conclusions (claims) about STSE issues (Wenger, 1998) and may, therefore, be more motivated to take actions to address problems they perceive. For similar reasons, giving students control over decisions about how to use their findings from their research as, at least partial, bases for their actions can give them strong attachments to and motivation for such actions. With more citizens prepared to critically evaluate STSE relationships through their own research and to take actions to address problems they perceive in them, we may move towards more participatory forms of democracy — which, as argued above, appears necessary in light of ways in which powerful people and groups in societies may not be providing the most trustworthy leadership. These aspects of STEPWISE align with Levinson’s (2010) recommendation that, to encourage more democratic participation where citizens monitor and challenge sources of power, students should engage in ‘Praxis’ (critical, reflective, practice; such as self-led research) as part of their participation in ‘Dissent and Conflict,’ such as socio-political actions on socioscientific problems.

Shortly after developing the tetrahedral version of STEPWISE, teachers in various school contexts were encouraged to use it as a basis for teaching and learning with students. It very quickly became apparent, however, that they found the tetrahedral version of it too complex — preferring a more systematic schema, like that in Figure 2 (Bencze & Carter, 2011), which is a re-arrangement of all domains of the tetrahedral framework. In this approach, students are, generally, first provided with one or more sets (cycles) of ‘apprenticeship’ lessons and activities to help them gain expertise, confidence and motivation for eventually self-directing research-informed and negotiated action (RiNA) projects to address STSE problems of their choice. The teacher may or may not choose to repeat (one or more times) the 3-phase apprenticeship cycle, depending on the age and comfort level of students and, indeed, the teacher’s comfort level with various strategies within the schema. Students unfamiliar with this approach often require repeats.

<Figure 2: STEPWISE Pedagogical Framework>

Although students may have many very useful pre-conceived ‘ASSE’ about STSE relationships and RiNA projects, many of them often can benefit from having the teacher explain some common examples of these. Teachers could, for example, show videos, Prez™ documents, written documents, PowerPoint™ slides, etc. to teach students about problematic STSE relationships (e.g., companion use of poor labour in distant countries to make cell phones, running shoes and computers). It seems ‘effective’ actions to show are the ability to conduct small projects conducted by others (e.g., former students, citizen activists, etc.) to address such problems. Connected to teacher presentations about STSE & RiNA, students also should be asked to carry out various activities to analyze, evaluate and perhaps plan such projects.

Because students often arrive in classes with pre-conceived ‘ASSE’ (Attitudes, Skills & Knowledge) relating to ASSE teachers tend to promote, but often are not aware of many of them, teachers may facilitate students to express them in different forms (e.g., speech, drawings, writing). Here, teachers may provide stimuli like typical products and services from fields of science and technology (e.g., cell phones) and ask them to express STSE relationships relating to them, problems for the wellbeing of individuals, societies & environments (RIPE) relating to them, possible actions to address these problems and preparation (e.g., research) they may need to undertake to develop such actions.
**Apprenticeships: Express, Learn, Apply**

The 3-phase apprenticeship in Figure 2 is based on basic constructivist learning theory (Osborne & Wittrock, 1985), which suggests that learners frequently have existing attitudes, skills and knowledge (‘ASK’) that interact with incoming information from learning situations (e.g., observed behaviour of magnets) to form (construct) ASK that are unique to each student; and, critically, may not match those of the teacher, scientists or other professionals. Because learners’ pre-conceived notions about phenomena often are subconscious, constructivism-informed pedagogical practices sometimes involve asking students to ‘express’ (e.g., describe in words, drawings, 3-D models, etc.) their pre-instructional ASK. Accordingly, as detailed below, apprenticeships may begin by asking students to express their pre-conceived notions about STSE issues and RiNA projects. Because students often could benefit from developing other ASK about these, however, the teacher would then conduct lessons and student activities to ‘Teach RiNA Projects’. Finally, because students can become more attached to issues and actions by being given more responsibilities for decisions about them, the teacher would then engage students in ‘Mini-RiNA Projects’ — with teacher guidance, as needed. At the end of one of these cycles, students can be returned to the first phase of the cycle; that is, to again ‘Express STSE Issues & RiNA’. At that point, the teacher might then judge whether or not to continue with a second set of apprenticeship lessons and activities or, as indicated in Figure 2, engage students in student-directed RiNA projects.

**Apprenticeships: Teaching/Learning Strategies**

To help educators implement the schema in Figure 2, some concrete suggestions are provided below for each stage of the apprenticeship — as well as some examples of student-led RiNA projects. As is the case for students, however, teachers eventually need to take more control over development and implementation of such pedagogical activities — to not only address a broader repertoire of topics but also to develop deeper understanding of and commitments to such teaching/learning practices.

- **Students Express STSE Issues & RiNA:** Briefly, this phase is meant to stimulate students to ‘express’ (e.g., say, draw, build, etc.) their pre-instructional attitudes, skills and knowledge (ASK) about power-related problems and/or issues in STSE relationships (refer to Figure 1) and actions they could take to address problems of interest to them (as well as preparations they should take prior to such actions).

  **Problematic Aspects of Science & Technology: Activities for Expressing Preconceptions**

  Before proceeding with examples, it may be helpful for teachers to think of a more reduced version of STSE relationships in Figure 1; that is, as:

  \[
  \text{Sci&Tech} \leftrightarrow \{+/-}\leftrightarrow \text{Soc&Env.}
  \]

  In this conception, we recognize that fields of science and technology (Sci&Tech) often collaborate with each other. As a result, we can imagine fields of Sci&Tech being influenced by and having positive or negative effects on societies (and individuals in them) and environments (Soc&Env). We can then use various strategies for getting students to express their views about such relationships. Teachers could, for instance, ‘expose’ students to various aspects of Sci&Tech and ask them to evaluate their effects on the wellbeing of individuals, societies and/or environments (WISE) and what might be done to address any problems they perceive. While it may sometimes be impractical, for instance, to take students to places where scientists and/or engineers do their work, teachers could connect them with products of their work; e.g., laws, theories and inventions/innovations. Because laws and theories are relatively abstract, however, perhaps it may be better to first expose students to various inventions/innovations. Indeed, as noted above, current emphases in Sci&Tech appear to favour generation of innovative new products and services for sale (‘commodities’). Getting students to interact with common commodities could be done in a relatively personalized way, asking students to name, list, bring to class, etc. products and services they and/or family members purchase/use — such as cars, bicycles, cell phones, cosmetics, hygiene items, fast and manufactured foods, etc. This could be supplemented with pictures or other media of commodities (e.g., videos of people using them). Students could then be asked to evaluate such products/services/commodities — first, very broadly; e.g., asking, ‘What is ‘good’ and ‘bad’ about these __[products/services]__?’ After some time, the teacher could then ask them more convergent questions like, ‘In what ways might this __[product/service]__ be good and/or bad for WISE? Explain,’ ‘What individuals and/or groups are likely most responsible for problems you note? Explain,’ ‘Explain what you think needs to change about this __[product/service]__ to make a better world?’, ‘How could you learn more about this __[product/service]__ to make decisions about how it should be changed?’ and ‘In what ways could you encourage powerful people and/or groups to act to improve this __[product/service]__?’

  Perhaps after focusing students’ attentions on products of S&T, the teacher could turn their attention to common problems for WISE linked to fields of S&T. Students might, for instance, be taken to or shown pictures of various WISE problems, such as: polluted waterways; garbage in recycling bins; cancer rates from smoking; poor workers (working long hours) manufacturing commodities for wealthy people; pictures of brutal animal testing (with appropriate warnings); etc. In time, the teacher might proceed with asking students to evaluate actions that could be taken to address apparent problems. These could include questions about various ‘stakeholders’ linked to the commodity; such as: ‘Governments should set stronger laws to control what food companies can place in fast foods,’ ‘Teenagers older than 16 should be able to smoke cigarettes without consent of their parents/guardians’ and ‘Teenagers should write letters to managers of movie theatres asking that they remove violent and sexy advertisements.’
The Nature of Apprenticeship Activities: Control-of-Learning Model

Overall, in planning and analyzing/evaluating activities for this phase of the apprenticeship (and the other phases and students’ projects), the schema in Figure 3 has been useful (Lock, 1990). It consists of two intersecting continua for judging the nature and extent of control of student learning. On the horizontal axis, topic choices and methods can be fully teacher-directed (TD) or fully student-directed (SD) or some combination of the two. The continuum on the vertical axis, meanwhile, tracks control of conclusions from activities — from closed-ended (CE), meaning there is only one pre-determined conclusion (usually set by teachers and textbooks), through open-ended (OE), in which there are many possible conclusions (usually determined by students’ judgements, based on available evidence and theories). For the first phase (‘Students Express STSE Issues & RiNA’ of the apprenticeship in Figure 2, it seems that many activities should be mainly SD/OE. Clearly, however, to stimulate students to react to phenomena (e.g., pictures of commodities), there must be some teacher direction and, arguably, students’ conclusions may not be fully open-ended (e.g., because of teachers’ decisions about stimuli to provide). But, if these activities are to be about students expressing their pre-conceived notions, activities should primarily be SD/OE. Accordingly, when teachers evaluate students’ responses to their instructions/questions in this phase, it seems that they should mainly be given credit for reasonable efforts they demonstrate in their responses — rather than having ‘correct’ responses (which would make them closed-ended).

• Teachers Teach RiNA Projects: Although the first phase of the apprenticeship in Figure 2 can help the teacher and students to become more conscious of students’ pre-conceived notions about STSE relationships and possible problems and actions, students may still benefit from having the teacher teach some power-related problems in specific STSE relationships and about effective RiNA projects conducted by others to address them. Such teaching is not meant to replace students’ pre-conceived notions, which should be honoured, but to expand their repertoires of them. To ensure students do develop at least understanding of specific ASK intended by the teacher, lessons and activities should be relatively teacher-directed and closed-ended (in terms of conclusions about STSE relationships and approaches to RiNA).

Typically, teachers will teach students about STSE issues, research and actions in the context of subject matter of ‘products’ (e.g., laws & theories) of science and technology for particular units under study — such as about cell biology, electrical circuits or chemical reactions. Teaching about STSE-RiNA should not, however, be used as a basis for students to ‘discover’ products of science and technology. Frequently, students (particularly disadvantaged ones) struggle with such discoveries. Accordingly, so that knowledge of such products is not a limiting factor in STSE-RiNA education, teaching about them should occur separately from, although in parallel with, teaching of STSE-RiNA.

Activities for Teaching STSE-RiNA: Cases and Case Methods

Among approaches for teaching STSE-RiNA, it is very popular to use ‘cases’ and ‘case methods’ — with the former being a documentary of STSE relationships and/or relevant RiNA projects and the latter being a set of instructions and/or questions for engaging students in interactions with the cases in order to achieve desired learning outcomes. For this second phase of the apprenticeship, lessons and activities should provide students with opportunities to develop understanding of and attitudes towards: i) problems in power-related STSE relationships; ii) secondary and primary research and dissemination methods; and, iii) socio-political actions to address perceived STSE problems. In the third phase of the apprenticeship (refer below), students will be given more control over decisions about these three components so that students might deepen their ASK regarding them.

STSE cases come in various media formats. Still being used are traditional ‘text-based’ cases, featuring ‘static’ text and graphics. They often provide some details (e.g., data and inventions) about science and technology relating to a phenomenon and corresponding societal and environmental relationships. Often, problems in such relationships are identified in the cases and indications of actions — including preparation, such as secondary and primary research — people and/or groups have taken to address them also are described. One example of this is the case given in Appendix A about so-called ‘blood diamonds’; i.e., diamonds mined at the expense of lives and wellbeing of many poor workers. Teachers might use it, for instance, in coordination with teaching about the element carbon.

In many jurisdictions, it is very common to use multimedia cases and case methods for STSE education. If a teacher is teaching about biology, for instance, an excellent source of cases is ActionBioscience. There are, however, many other such sites on the Internet, and teachers can find many through searches of YouTube™. While showing students videos of issues and actions developed by adults can be helpful, students can be particularly drawn to those produced by other students of similar ages.
example, after a teacher showed students videos of speeches made by the Royal Society for the Arts (RSA), in which audio is synchronized with relevant animations, students created a similar video about climate change effects relating to fossil fuel driven automobiles as compared to other modes of transportation. In addition to its creative nature, this video could be used to teach about all 3 goals (above) of the second phase of the apprenticeship. In terms of problematic STSE relationships, for instance, the students clearly emphasized environmental problems (e.g., climate change) from products of technology (e.g., cars). They also illustrate considerable secondary (e.g., statistics on car use in the USA) and primary (e.g., girls’ vs. boys’ home-to-school transportation choices) research. Their choice of actions include more ecologically-sustainable modes, including use of bicycles and public transit. While not being overly critical, however, the teacher might point out to students that the students who produced this video could have made more references to issues of power, such as government (de-)regulation of automobile industries favouring petroleum-powered vehicles. The teacher could, as well, point out other forms of action that students could use — such as: lobbying of power-brokers (e.g., petitions and letters to governments and automobile companies), educating communities (e.g., Twitter™ campaign) and engineering of more sustainable forms of transportation (e.g., efficient person-powered wheelchairs, perhaps with fly wheels and efficient gearing).

As noted above, to ensure students gain conceptions of the 3 goals of this phase of the apprenticeship, we recommend teachers maintain considerable control of learning. Having said that, students’ motivation for such learning often relates to the extent to which they are allowed to make relevant decisions. Accordingly, there appears to be merit in providing students with instructions and questions for engaging in more personal ways with cases. Some of these can focus, of course, on understanding, while others might encourage students to analyze unfamiliar situations, propose alternatives and evaluate claims. For the three outcomes above, some instructions and questions could include: i) Problems in Power-related STSE Relationships: ‘Briefly, explain how diamonds are formed;’ Explain why some diamonds may be considered bloody;’ and, ‘Using arrows, show a sequence of people involved with diamonds from ‘beginning to end’; ii) Secondary and Primary Research and Dissemination Methods: ‘Based on this case, how may researchers have learned about violence relating to diamond mining?;’ ‘List two facts about climate change students likely determined through secondary research’ and ‘To learn about your classmates’ knowledge about problems with diamond mining, give a pair of variables you could monitor for a ‘correlational study’ (comparison of possible effects of one naturally-changing variable on another variable); and, iii) Socio-political Actions to Address Perceived STSE Problems: ‘Should governments carefully label diamonds that were mined in warring areas?;’ and, ‘Should governments make diamond mining illegal, making companies replace them with synthetic diamonds?’

Expanding STSE-RiNA Education: Using Actor Network Theory

Perhaps because science educators may not want to cast fields of science and technology in a bad light, a common problem with STSE-RiNA cases is that they may not make adequate references to certain potentially-embarrassing entities — such as corporations that may have reduced costs to increase profits. In this light, Pierce (2013) has recommended that science educators teach students about actor-network theory (ANT) (Latour, 2005) and, accordingly, to build actor network maps to represent STSE relationships (and, presumably, RiNA projects). ANT suggests that all entities ('actants') are part of multiple reciprocal relationships among living, non-living and symbolic entities. STSE relationships might, therefore, consist of human actants not normally depicted in science education contexts — such as transnational economic organizations, including, for example, transnational corporations, the World Bank, the International Monetary Fund, the World Trade Organization and the Organisation for Economic Co-operation and Development. Meanwhile, non-human entities/actants that may be included in networks could include: equipment
and computer software used in science laboratories; objects of study (e.g., fish, molecules, quarks); transnational trade agreements (e.g., North American Free Trade Agreement); and, particularly in the case of advertisements, idealized symbolic actants, such as 'cool,' 'hot' and 'sexy,' associated with commodities like perfumes, cars and clothing.

Although helping students to learn about ANT may be more democratic, constructing actor-network maps is not easy — because, for example, of their complex, uncertain and dynamic nature. A series of presentations, discussions and student activities regarding ANT are, therefore, likely necessary. One common technique is to name a commodity often used by students, such as a cell phone, and to conduct a Socratic lesson with them — in which the teacher and students build a simple network map to depict living, non-living and symbolic actants connected to the commodity. In association with such instruction, students could be asked to view *The Story of Stuff* video, follow certain teacher instructions and answer questions posed by the teacher and by them. To supplement this work, an excellent concept to teach students is that of how commodities often are like a 'Trojan horse'; that is, while consumers focus on positive symbolic actants — such as 'sexy,' 'powerful' & 'smart' — that may be evident on the 'outside' of commodities, they may be distracted from noticing harmful actants on the 'inside' (e.g., toxic chemicals, addictive substances & polluting by-products). After such instruction and related secondary research, three students in a 10th-grade 'Academic' (university-qualifying) science course developed the actor-network map reproduced in Figure 4. Having learned about problems with commercial hairspray, students then conducted some primary research — in the form of surveys of fellow students' uses and knowledge about hairsprays. Based on their research findings and, likely, their pre-conceived ASK about hairspray, they then developed and tested a formula for home-made hairspray that they considered safe and environmentally sound. To promote this action, they then advertized their product using posters like that shown in Figure 5. These actions had some elements of ANT, in the sense that a poster was combined with information, an invention and pictures of test subjects.

Through teaching and learning associated with the above suggestions, students may develop new conceptions of STSE relationships stemming from examination of powerful actants (e.g. transnational corporations with government support) and from research-informed actions taken by groups of people to address STSE problems. Their ASK in this regard are, however, unlikely to be fully changed or formed after such lessons and activities. This may require opportunities, as described in the next sub-section, for them to engage in teacher-facilitated RiNA projects to address STSE issues of their choice (and, later, student-led projects of this type).

**Teaching Nature of Science: The Scientific Profile Theory**

Prior to the next stage of this apprenticeship, educators may want to help students to develop their conceptions of the nature of science (NoS) (and, to some extent, technology). Schools tend to promote beliefs in relatively logical and unbiased science methods leading to relatively certain conclusions about the world — views not well-supported by studies in history, philosophy and sociology of science (Hodson, 2008). A convenient way to think of such views is in terms of Loving's (1991) *Scientific Theory Profile* (STP), depicted in Figure 6. Like the framework in Figure 3, the STP consists of two intersecting continua; in this case, to depict
different views about the nature of science. The horizontal axis concerns views about the extent to which scientists use 'pure' logic in making judgements about theories (often relevant to data). At one extreme, 'Rationalists' claim that scientists strictly base judgements on logic, reason and systematic thinking. At the other extreme, 'Naturalists' claim that, in addition to logic, etc., scientists cannot avoid being influenced by a range of psychological and sociological factors — such as gender, mood, desire and in terms of perspectives of wider culture, politics, economics, etc. Meanwhile, positions on the 'truth value' of scientists' claims is considered on the vertical axis. 'Realists' posit that scientists' claims (e.g., laws & theories) can match entities being studied; while 'Anti-realists' believe that scientists' claims cannot match phenomena of the world, although they may construct approximations that can have collegial support. Such viewpoints about science can be helpful in considering STSE relationships and subsequent actions to address perceived problems. While there are many aspects of NoS to be considered using the STP, of particular interest in terms of STSE may be relationships between financiers and corporations and scientists (and engineers) and their respective institutions. It seems clear that individuals (including students) holding Rationalist-Realist positions about science are not as likely as Naturalist-Antirealists to support contentions that scientists often are significantly-influenced by the private sector and that, moreover, many such influences can compromise the integrity of fields of science and technology that often result in harms to the wellbeing of individuals, societies and environments (Krimsky, 2003; Mirowski, 2011).

Depending on educators' positions on the STP, they may want to help students to understand Naturalist-Antirealist positions — which, again, may lead students to accept problems resulting from business-science partnerships. Although there are various approaches to NoS education, it seems that students can benefit from a so-called 'Inductive-Deductive Dialectic Immersion' (IDDI) strategy (Bencze & Elshof, 2004). This may be thought of as an 'applied constructivist' approach, in which students explore (inductively) their pre-conceived notions about NoS, are taught some perspectives about NoS and then have opportunities to evaluate (deductively) — and, perhaps, discover new — perspectives about NoS through realistic science investigations and application activities. This may begin, for instance, by having students play the NoS 'card exchange game,' in which they: i) rank about 6 statements about NoS (on separate file cards) in terms of those most aligned with their views about science; ii) try to trade with classmates cards containing statements to which they least agree (receiving cards with statements they favour); and, iii) sit with classmates holding similar views to write a general statement about NoS (Cobern & Loving, 1998). They may (or may not) conclude, for instance, that statements like the following align with Naturalist-Antirealist views: i) Funding influences the direction of science by virtue of the decisions that are made on which research to support; ii) The scientific enterprise is situated in specific historical, political, cultural, and social settings; thus, scientific questions, methods, and results vary according to time, place, and purpose; and, iii) Scientists in one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective (p. 81). Following this, while teaching students about various STSE cases, teachers may then point out instances in which different behaviours of scientists (and, perhaps, engineers, too) align with different positions on the STP. Later, when engaged in different RiNA projects dealing with specific STSE relationships, teachers may then encourage students to re-consider their NoS views relevant to the STP.

**Teachers Guide Students’ Mini-RiNA Projects**: Lessons and activities described in the above sub-section tend to be relatively TD/CE. Students need, however, opportunities to assume more control over decisions about STSE relationships and RiNA projects in order to develop deeper understanding of and commitments to them. Accordingly, in this third phase of the apprenticeship, the teacher may ask students to develop and implement a small-scale RiNA project to address an STSE issue of their interest, providing guidance where necessary. Depending on the ages and stages of students' ASK regarding STSE-RiNA, teachers may vary their support for relevant student decisions. In other words, in terms of the framework in Figure 3, activities below may fall somewhere in the middle of each continua — although, for some students, under some conditions, teachers may allow more SD/OE control.

**Activities for Choosing STSE Issues: Thinking About Commodities**

Students needing little guidance may be able to self-determine their STSE issue/problems, develop appropriate research methods and, then, develop and implement suitable actions based on findings. Most students, however, seem to require at least a list of possible controversies — especially if this is the first time they have been through an apprenticeship. Students may, for instance, be able to draw from the set of technologies and/or actions from the first phase of the apprenticeship, described above. Teachers also may be able to develop lists of issues for particular content areas. These could be as simple as questions, like 'To what extent should oil and gas extraction be permitted in polar regions?,' 'What, if anything, should be done to minimize corporate influences on topic choice, methods, outcomes and dissemination of findings in science and technology?' or 'To what extent should governments invest money in space exploration?' Or, teachers could develop small case descriptions of controversies, such as these: a) Energy drinks: Energy drinks, which contain high levels of caffeine, sugars and flavours, are designed to improve alertness and increase cognitive performance. Excess consumption, however, can lead to negative side effects including insomnia, irritability, anxiety, arrhythmia, and stomach upset. In addition, the names and slogans of different drinks targeting adolescents are controversial (e.g., Rockstar, Monster, Big Buzz, Cocaine). Parent groups ... are mobilizing to ban energy drink sales to minors; and, b) Snack food labels: As consumers are increasingly mindful of their health, many companies are attempting to make their products seem more nutritious by including catch phrases like 'whole grain,' 'low fat,' 'made with real fruit' and 'organic' on their
packages. A more careful look at ingredients and nutrition information reveals that many of these products are not as healthy as they might appear.

**Activities for Choosing STSE Issues:**

*Multi-Actant Documentaries*

A much more detailed approach, yet one that still requires students to learn more through research, is to present students with 'multi-actant documentaries' (MADs), as a type of case, and provide them with case methods that require them to conduct research and, eventually, actions to address problems that interest them. As described above, it is apparent that private sector interests often do not want citizens to concentrate on certain potentially-problematic actants — such as transnational corporations and transnational trade agreements. To provide students with more realistic depictions of STSE contexts, therefore, we have prepared MADs for several commodities. Using the online tool, Prezi™, our MADs provide short multimedia documentaries for several living, non-living and symbolic actants — one of which is illustrated in Figure 7 for fast and manufactured foods. Crucially, we have purposely omitted lines between actants that would suggest relationships among them; and, as well, we urge teachers to ask students to study individual actants in whatever order and for lengths of time that interest them. We feel that this will give students more choice and more motivation for developing actions for controversies and/or problems they perceive.

**Supporting Skills for STSE-RiNA:**

*Experiments and Studies*

Once students have STSE issues to explore from resources like those above, they would then set about to plan and implement research to learn more about them and determine particular problems to address. Having learned more about the issue/problem, they would then conduct their research and, eventually, use their findings to inform decisions about actions to develop and implement. To guide students in such RiNA projects, teachers could use a planning and evaluation form like that given in Figure 8. As we have indicated, the degree of guidance in such a form and in interactions between the teacher and students working on RiNA projects will depend on students' ages and stages of familiarity and comfort with ASK within these apprenticeships.

An aspect of science and/or technology not often addressed in schools that often is a limitation on students' RiNA projects is expertise, confidence and

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**Figure 7: MAD (Fast & Manufactured Foods).**

**Figure 8: RiNA Project Planning & Evaluation Guide.**
motivation for self-directing research and dissemination (and action) activities. Accordingly, it is often necessary to provide students with apprenticeship lessons and activities in this regard — especially early in their STEPWISE experiences. A first consideration along these lines, however, is to determine what to teach; including decisions about which skills, strategies, etc. scientists typically use in science investigations and dissemination activities. Gott and Duggan (2003) have suggested, for instance, that scientists may use various ‘concepts of evidence,’ such as control of variables, duplication of tests and instrumental (vs. human) error, in many science inquiries. These are sometimes placed in sequences like those depicted in Figure 9. Such lists and sequences should be used with caution, however, since studies of scientists in action suggest that they may not always use all such skills, strategies, etc. or use them in particular sequences, depending on various factors. Accordingly, it appears best to teach about them in the context of whole science inquiry and/or technology design projects (Hodson, 2008). As situations arise in student projects, the teacher might take students aside and use combinations of ‘Modeling’ and ‘Guided Practice,’ as given in Appendix B. A simple place to start, depending on students' ages, is with various ‘toys,’ such as paper ‘helicopters’ — which are made from single sheets of paper folded and cut to form a pair of ‘blades’ and a ‘rotor’ that can rotate through the air as they are dropped from different heights. The teacher could ask students to brainstorm factors (‘variables’) that could influence the helicopters’ drop speed, such as: mass (with added paper clips); blade length; height; cross winds; paper thickness; colour of wings, etc. Through some trial and error, the teacher could discuss with students concepts from Appendix C about ‘experiments,’ such as: duplication of tests; control of variables; and, range of values of the ‘cause’ variable. Depending on the age and stage of students' ASK regarding such skills and strategies as those in Figure 9 and Appendix C, teachers may engage them in further such relatively teacher-guided activities from other sources.

In investigating STSE relationships, it is often particularly important to carry out studies, instead of experiments. Because many variables in STSE relationships are potentially harmful (e.g., cancer development), it is more ethical to observe (study) natural changes in them than to force them to occur (as in experimentation). Studies can be qualitative and/or quantitative. Qualitatively, it is very common, for instance, to interview people (e.g., about their opinion on water bottle uses) and/or to describe changes in nature (e.g., various aging processes in living things). In terms of quantitative investigations, meanwhile, investigators often use *correlational* studies; that is, empirical inquiries in which investigators measure naturally-changing variables and then compare changes among such variables to determine the extent to which changes in one variable appear to be influencing changes in another variable. As with experimentation, teachers can use different approaches to introduce students to correlational studies — which tend not to be stressed in science education, perhaps because of relative ease of variable control in experiments as compared to studies (Bencze, 1996). A common way to introduce studies, as compared to experiments, is to ask students how they may determine relationships between variables that involve harmful outcomes, such as how to find out the extent to which cigarette smokers' fingers become yellowed with increased smoking. Some students may quickly suggest asking people who already smoke to allow an investigator to 'measure' (e.g., with paint strips) yellowing of their fingers, after which the person would be asked how many cigarettes he/she smokes, on average, per day. The teacher could then show students sample graphs of different studies — such as: cancer rates vs. distance to power lines; cigarette smoking rate vs. cancer rate; and, automobile seating capacity vs. average carbon footprint. Afterwards, students could be asked to complete the exercise in Appendix D — which provides them with some practice in using *concepts associated with* correlational studies.

Approaches like the above have had some remarkable successes in terms of students being able to take more control over RiNA projects to address STSE problems of their interest. A good example of such a project was that conducted by a 10th grade student who conducted secondary and primary research on cosmetics and determined that there were, for example, various personal, social and environmental problems associated with such products; and, that advertising was an overwhelming influence on teenage girls in her school in choosing to use them. So, after a network analysis of STSE relationships

![Figure 9: Skills & Strategies for Science & Technology.](image-url)
regarding cosmetics, she produced a very sophisticated activist video that she posted to YouTube™. This video clearly illustrates potential problems linked to influences of powerful people/groups on science and technology. Although there was no evidence of the student's primary research, which she did provide in her project report, the video was aimed at the younger teenage demographic — which her research indicated was most vulnerable to advertising.

**Supporting Skills for STSE-RiNA: Reflective Practice**

Clearly, not all students are able to develop such sophisticated activist videos or other forms of action. As with many classes in various contexts, 'achievement' is distributed across a 'bell curve' — with a few 'poor' projects, many 'average' ones and a few 'excellent' pieces of work. When this occurs, teachers may be reluctant to ask all students to self-direct RiNA projects on STSE issues of their choice (as indicated in Figure 2). To make this more feasible, however, one approach that seems to have been successful in preparing students for self-directing projects is to ask students to reflect and share perspectives on the nature of STSE relationships and RiNA projects. This tack is based on metacognition, the idea that developing general ideas about one's learning and then using them (possibly revised through thought and discussion) to guide future learning (Niemi, 2002). For example, after their second set of guided mini-RiNA projects, students were asked to complete the review form in Figure 10, in a 'think-pair-share' fashion — with students first completing it privately and then sharing their responses with their group members. This was then used as a basis for a whole-class discussion, in which the teacher (Krstovic) invited students to share responses to their questions and offered some new ideas — such as the possible role of emotions in such projects — for student consideration.

**Student-led RiNA Projects: Challenges and Opportunities**

When the teacher has decided that students are ready for it, s/he should introduce students to a student-led RiNA project to address an STSE issue of their interest. In the context of schooling, however, it is very difficult for teachers in formal education systems to fully detach themselves from students' projects. One of the biggest challenges is encouraging student decision-making while, at the same time, providing students with a scheme that will be used to evaluate each stage of the project and, frankly, to motivate students to complete them. The RiNA project assignment provided in Appendix E represents one attempt to balance student decision-making and schools' desires to evaluate and report student achievement. Because of the need to evaluate and report student progress, much of the independence afforded by such projects will depend on the teacher's flexibility in accepting a range of levels of achievement as 'satisfactory.' Such judgements are, undoubtedly, complex — based on various factors, such as the teachers' judgements about students' capabilities, in terms of their age, stage of learning, etc. and, as argued above, the teacher's beliefs about the nature of science. Teachers holding more Naturalist-Antirealist views about science are, arguably, more likely to accept a wider range of student performances than teachers adhering to Rationalist-Antirealist views.

From our experiences, if a range of conditions align, including having a teacher committed to critical STSE education and self-directed RiNA projects, supportive school personnel (e.g., administrators and teaching colleagues) and curricular mandates for STSE education and student-led research, it is very likely that students will be able to self-direct high-level RiNA projects on STSE issues of their choice after only one or two sets of apprenticeship lessons and activities (older students seem to need only one apprenticeship). Evidence of such achievements can be seen in a special issue of the open-source, non-refereed, journal, *Journal for Activist Science and Technology Education* (JASTE), featuring articles written by high school students about their RiNA projects. This special issue, edited by Mirjan Krstovic, has garnered considerable praise from various sources, including Mirjan's teaching and administrative colleagues and Larry's colleagues, locally and internationally. At a more local level, meanwhile, Mirjan and students received considerable praise from projects presented in the school library at an 'STSE-RiNA Fair' (like a science fair). Teachers touring the projects on display — including the one illustrated in Figure 11 — and engaging students in discussions about their projects were very
impressed with students' creativity, expertise and commitments to addressing complex and important STSE controversies.

SUMMARY & CONCLUSIONS

The STEPWISE pedagogical framework has enabled students to develop and implement plans of action that 'spend' at least some of their literacy on trying to address problems they identify in relationships among fields of science and technology and societies and environments (STSE). In many cases, students appear to develop genuine concern for the wellbeing of 'the other'; e.g., other people and other living and non-living things that appear to be at risk in STSE relationships. Perhaps related to such empathy, students appear to enthusiastically develop expertise that they want to use to learn more about such risks and, based on available knowledge and attitudes, etc., take actions to address perceived problems. In other words, 'seeds are planted' in the minds of many students — ready to 'develop' and 'nourish' themselves and others in various important contexts. We have, moreover, seen some situations improve — such as school authorities improving their recycling programmes — as a result of student actions.

Although it is difficult to 'measure,' it is apparent that students' actions, while enthusiastic, often have had relatively minimal effects beyond their more immediate environments of home, school and local communities. For example, not that it is the best student action from our research, but many academics, teachers and others whom we have shown the video attached to footnote #11, above, have praised this action; but, still, it has been viewed only just over 400 times (by April 1, 2016). It has not gone 'viral.' We are concerned, therefore, that approaches are still needed that seem to generate more widespread benefits from student actions. In a recent ongoing study of citizens' research-informed actions to address a case of environmental contamination in their local community, however, it became apparent that much of citizens' successes seemed to relate to 'networking' of their actions (Bencze & Pouliot, in press). That is, after their initial act of paying to have dust that was accumulating in their environment tested by a local laboratory, a complex network of living (e.g., fellow citizens and groups), non-living (e.g., activist website, class action lawsuit) and symbolic (e.g., a sense of outrage) actants aligned in support of a related cause (e.g., civic and corporate mitigating actions). This 'action-network' seemed to result in some positive responses, including changes in monitoring of air quality and lowering of minimum allowable standards of pollutants (Pouliot, 2015). Accordingly, it seems clear that educators may want to encourage students to network both their research into STSE relationships (Pierce, 2013) and of their actions (Bencze & Pouliot, in press).

Encouraging and enabling students to self-direct networked research-informed and negotiated actions to address STSE problems, while apparently possible in some contexts, seems be a daunting undertaking. As noted above, it has been our experience that achievement of such critical and altruistic projects is rare — requiring alignment of a great range of actants, including a teacher with corresponding expertise, confidence and motivation, supportive colleagues and administrative personnel and official curriculum mandates. Moreover, prospects for their formation seem under particular threat in recent years — perhaps symbolized best by the rapid emergence and widespread influences of 'STEM' (Science, Technology, Engineering & Mathematics) education initiatives. Although there appears to be significant justification for integration and/or interrelationships among the four STEM fields in education, including in terms of professional relationships (Rennie, Venville & Wallace, 2012), studies of curriculum and policy documents in support of STEM education often seem to indicate that they prioritize teaching and learning of widely-accepted knowledge claims and skills of STEM fields while apparently studiously-omitting attention to problems associated with STSE relationships and actions to address them (Gough, 2015; Zeidler, 2016). Apparently, a key to what may be driving STEM education
lies not so much in the fields included; but, rather, in those that are excluded. Particularly absent in the mix are fields of the humanities and social sciences. Discourse in educational policy and curriculum documents appear to affirm this conclusion and, moreover, point to socio-economic drivers of STEM education. The National Research Council in the USA (NRC, 2011), for example, which helped facilitate development of that country’s ‘Next Generation Science Standards’ (Achieve [a private company], 2013), stated in its document, Successful STEM Education, that:

[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). Such discourse seems to suggest that STEM education is primarily concerned with identifying and educating relatively few STEM professionals who can develop and manage mechanisms and personnel for production and consumption of goods and services that may enrich financiers and corporations who largely fund their work (Means, 2013; Pierce, 2013). More broadly, as McLaren (2000) advised, it seems that “the major purpose of education is to make the world safe for global capitalism” (p. 196).

Educators implementing critical and altruistic programmes like STEPWISE may have to face a virtual 'Borg'; that is, a 'human-technology complex' acting as a single being that threatens to assimilate everything in its path into its network. In a study of educational institutions in relationships with private sector entities, for instance, Ball (2012) concluded that members of the private sector maintain their power and influence over societies largely through a vast and expanding interconnected network of actants aligned in support of private profit. In the above-mentioned study of citizens' actions to eliminate what they conclude to be toxic dust being spread across their community, they have expressed concern that actions to eliminate the dust are minimal — largely due to the power of an apparent pro-capitalist network of actants, such as the local government prioritizing jobs and tax revenue and companies associated most closely with the toxic dust dispersal that are prioritizing expansion of their operations and profit (Bencze & Pouliot, in press). In this light, it seems that perhaps the only way for those supporting critical and altruistic educational programmes like those based on STEPWISE need, perhaps ironically, to mimic the private sector — in the sense of rallying many actants to its causes. Such a project would not be like the proverbial 'David vs. Goliath' battle; but, rather, may be more like a mass movement — with perspectives and practices 'going viral,' engaging a great range of adherents.

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