A Summary for Science Educators

J.L. Bencze, 2016

Introduction

This article provides science educators (and others) with an introductory summary\(^1\) of the ‘STEPWISE’ framework for science and technology education. ‘STEPWISE’ is the acronym for Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments; and, as its name implies, it is a framework for organizing teaching and learning to encourage and enable students to use at least parts of their science education (and other intellectual, physical and social resources, etc.) to take personal and social actions — as critical and activist citizens — to investigate and try to rectify problems they perceive in relationships among fields of science and technology and societies and environments.

Rationale for Critical and Activist Citizenship Education

Rather than orienting students’ science education towards using at least some of their education (and other resources) towards trying to improve the world around them, school science systems often appear to be organized to encourage each student to achieve their maximum potential literacy to be used for their own advancement. A common way of describing this is to suggest that students’ science education should make them ‘scientifically literate,’ which often has been defined in ways similar to that below:

A scientifically and technologically literate person is one who can read and understand common media reports about science and technology, critically evaluate the information presented, and confidently engage in discussions and decision-making activities regarding issues that involve science and technology (MoE, 2008, p. 3).

Although few can, perhaps, argue that such a goal for all students is not appropriate, it is apparent that school science (and, perhaps, other subject areas) needs to also prepare students/citizens for using at least some of their literacy for trying to rectify problems they perceive associated with science and technology (and, likely, other fields). Among reasons for this claim is that there is evidence to suggest, that powerful people and groups often influence fields of science and technology (and other fields) in ways that can endanger the ‘wellbeing of individuals, societies and environments’ (WISE).

Many people believe that fields of science and technology (and related fields, like engineering & mathematics) have had numerous positive effects on WISE. Humans enjoy longer life spans, for example, largely because of advances in life sciences and medicine and in fields of agricultural science and technology. There are those who claim, however, that processes and products of fields of science and technology are contributing to what they perceive as significant problems for the WISE. Many point to climate change as our most pressing problem. According to the Intergovernmental Panel on this matter, Earth is on course for catastrophic habitat disruption and loss of life, assuming currently-predicted dramatic increases in average global temperatures (Klein, 2014). There are many other potential problems, however, including health and social justice issues relating to: fast foods (Weber, 2009) and other processed foods, pharmaceuticals (Angell, 2004), various biotechnologies (Krimsky, 2003), toxic chemicals in everyday things (Leonard, 2010) and agricultural research and practices (Kleinman, 2003).

Although there likely are many reasons for possible problems in relationships among fields of science and technology and societies and environments (STSE), several scholars suggest that many are related to matters of political economy. This is evident in the case of financiers’ and corporations’ contractual agreements with scientists and engineers (e.g., Mirowski, 2011). Although it has long been the case, it is apparent that scientists and engineers have recently been under increasing pressure to orient their work towards promotion of rapid cycles of production and, especially, consumption of for-profit products and services on behalf of financiers and corporations. There are those who suggest that contractual agreements between university-based scientists/engineers and businesses and/or financiers can be positive. Some suggest, for example, that universities can gain independence from

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\(^1\) This summary is based on published articles, especially:
government regulation and that businesses can become more academic — such as through promotion of training and knowledge dissemination (Etzkowitz & Leydesdorff, 2000). Others argue, however, that contemporary business-science partnerships may, too often, compromise the integrity of knowledge development and dissemination in fields of science and technology/engineering (Ziman, 2000). This appears to be a result of processes of intensification undergone by capitalist systems in the last several decades, increasingly on a global scale.

Although capitalism has existed for centuries, it has evolved into a very aggressive form — known as neoliberalism — that has come to dominate the zeitgeist of many societies (Springer, Birch & MacLeavy, 2016). Under this ideology, governments and supranational organizations (e.g., World Trade Organization) may intervene in markets to maximize investor profit. Fields of science and technology/engineering, so essential for production and consumption of for-profit goods and services, appear to be extremely vulnerable to neoliberal influences (Krimsky, 2003; Mirowski, 2011). One way to evaluate neoliberal effects on practices and products of science and technology/engineering is through use of Merton's Norms of practice for the sciences. Briefly, although he acknowledged that his norms were not and, perhaps, could not always be followed, he argued that scientists should strive to be communal (e.g., collaborative), universal (e.g., non-exclusive), disinterested (e.g., unbiased), original (e.g., creative) and skeptical (e.g., critical of self and others). When profit-oriented entities (e.g., companies) associate themselves with scientists and/or technologists/engineers (e.g., in university or industrial contexts), such norms may be compromised (Ziman, 2000). For example, the pharmaceutical industry seems to compromise Communalism when results are exclusively owned by private research companies, Universalism may be compromised when conflicts-of-interest in regulatory agencies [e.g., the FDA] privilege certain investigators’ claims, Disinterestedness may be compromised when drug companies own the patent on the drug scientists are testing, Originality may be compromised when ‘new’ drugs are, actually, minor variations of existing ones and Skepticism may be compromised when refereed journal articles reporting drug trials are ‘ghost written’ (i.e., scientists are paid to have their names used as ‘authors’ for papers written by scientists working for companies). A particularly important aspect of such compromises relates to business contracts with academic scientists, most of whom work in universities. It appears that the profit motive has caused many university-based scientists to establish private businesses and orient their work towards development of for-profit commodities, often compromising Merton’s norms. Regarding work of Dr. Craig Venter (Figure 1), a molecular geneticist who worked on the human genome project, and became quite wealthy in the process, Kellogg (2006) discussed struggles between defenders and opponents of Merton’s Norms involving he and his company. While defenders of ethical practices in the science remain, compromises to the integrity of science and technology relating to the profit motive can, in turn, compromise the quality of many products and services — posing considerable risks for the wellbeing of individuals, societies and environments.

STSE Education

In light of apparent compromises to WISE associated with neoliberalism-influenced science and technology, it seems clear that science education — likely with other subjects — needs to prepare citizens to critically examine fields of science and technology (and, likely, other fields) and, where problems are perceived, be prepared to take personal and sociopolitical actions (e.g., recycling, educational posters for citizens, petitions and letters to politicians and business people) to address them.

A mandate for such critical and activist science (perhaps with other subjects) education has existed for at least the last forty-five years in terms of promotion of so-called ‘STSE’ (relationships among fields of science & technology and societies & environments) education (Pedretti & Nazir, 2011). Students may, for instance, determine through research that the private sector (segment of society) has compromised ingredients in many manufactured foods (technologies, based, to some extent, on science) in ways that are associated with health problems (e.g., diabetes and heart disease) and, consequently, develop and implement plans of action to try to improve human health.

Despite government support and researchers’ development of relevant perspectives and practices, implementation of STSE education of any sort in schools has been limited. The greatest emphasis, instead, seems to be on instruction in ‘products’ (e.g., laws & theories) of professional science and engineering — commonly supported by cycles of lectures and teacher-guided ‘lab’ activities (Bell, 2006). Such a narrow and didactic approach to science education can significantly limit students’ development of science ‘literacy’; an albeit nebulous concept that, however, may be conceived in terms of four broad learning domains:

1. Learning Science & Technology: developing useful understanding of ‘products’ (e.g., laws, theories & inventions) of science and technology;
2. Learning About Science & Technology: developing understanding of the nature and methods of science and technology, an awareness of complex interactions among science, technology, society and environment, and a sensitivity to personal, social and ethical implications of technologies;
3. Doing Science & Technology: engaging in and developing expertise in science inquiry and technology design; developing confidence and competence in tackling a wide range of ‘real world’ technological tasks;
4. Engaging in Sociopolitical Action: acquiring the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern (Hodson, 2003, p. 658).

Figure 1: Dr. Craig Venter.
In these terms, school science systems tend to emphasize instruction in the first domain above, compromising learning in the other three domains.

Although there are various ways to analyze such compromises, they can be understood in terms of the claim that education, generally, and school science, in particular, are greatly influenced by neoliberal capitalism (refer above). One major way in which school science seems to be affected by this ideology is how it resembles and contributes to consumerist cultures (Bencze, 2001). For instance, students may be implicitly conditioned into habits of consumption through a steady diet of conclusions (‘products’) that can stifle their desires to ask questions, critique claims, and develop their own conclusions. Moreover, because of relative lack of control of learning, students may not develop deep conceptions of knowledge, skills, etc. Based on knowledge duality theory (Wenger, 1998), deep meaning arises when people engage, under their control, in ‘Phenomena ↔ Representation(s)’ relationships (Figure 2). If students’ science education is too teacher-directed, students may not have opportunities to induce their representations (e.g., laws) from phenomena (e.g., lawn health varying with salt concentrations) and, then, deduce/predict and evaluate their (perhaps revised) representations (e.g., actions pertaining to salt uses) in relevant phenomenal contexts (e.g., among neighbours). Even when students are engaged in commonly-used teacher-assisted inquiry-based learning, the depth of their understanding and expertise can be compromised because the teacher exercises control over some or many of the decisions. With more superficial learning, students’ choices and abilities may be limited and, consequently, they may end up being most equipped to serve as consumers of others’ products and services.

Contributing to students’ orientation towards consumerism are various ways in which their attitudes towards others are affected. Because science knowledge often is delivered so quickly, access to understanding it is individually competitive. This may lead students to lack empathy for those less ‘successful’ than them. Regarding scientists and their work, on the other hand, students’ attitudes can be unrealistically positive when their education is like a consumer experience. Although there are many ways to analyze this, a convenient framework is Cathleen Loving’s Scientific Theory Profile (Loving, 1998) as shown in Figure 3. Essentially, it is apparent that school science tends to portray professional science as a Rationalist-Realist endeavour — suggesting, for example, that science usually is highly logical and successful in determining truths. More broadly, school science also may idealize professional science by ignoring above-mentioned problematic aspects of business-science partnerships (Naturalist-Antirealist positions) (Hodson, 2008).

Because school science systems often appear to place students in the role of consumers of knowledge, rather than critics and/or creators of knowledge, teachers may be inhibited from encouraging students to critique and act to rectify problematic STSE relationships (and socio-scientific issues, as described above). Hodson (2003), for example, suggested: “[i]t is almost always much easier to proclaim that one cares about an issue than to do something about it!” (p. 657; emphases added). This situation can be understood in different ways, although Hodson (2003) suggested that STSE education can be developed and analyzed in terms of at least four levels of sophistication; that is, planning/finding that students in various programmes:

2 Based on constructivist epistemological positions, ‘pure’ induction — which, theoretically, involves a direct translation from phenomena of the world to representation(s) of them — does not occur. Development of representations, accordingly, may be thought of in terms of abduction; that is, use of cognitive structures in interpreting phenomena (Lawson, 2005).

3 The horizontal axis spans a continuum ranging from Rationalist through Naturalist positions regarding the nature of theory negotiation in the sciences. Rationalists tend to believe in highly systematic methods of science, including rational judgements about theory. Naturalists, by contrast, assume that the conduct of science is highly situational and idiosyncratic, depending on various factors, including psychological, social, cultural and political influences. The vertical axis, meanwhile, depicts a continuum reflecting the truth-value of knowledge, with Realist through Antirealist positions. Realists believe that scientific knowledge corresponds to reality, while (extreme) Antirealists claim that each person’s constructions are valid. These continua have ‘ordinal’ scales. On the Rationalist-Naturalist continuum, for example, placing a mark close to the ‘Rationalist’ end indicates a ‘strong’ Naturalist view about science. Placing a mark about mid-way between the two poles, by contrast, indicates that science has moderately Rationalist and Naturalist features.
I. appreciate the societal impact of scientific and technological change, and recognize that science and technology are, to some extent, culturally determined;
II. recognize that decisions about developments in science and technology are taken in pursuit of particular interests, and that benefits accruing to some may be at the expense of others. They also may recognize that developments in science and technology are inextricably linked with the distribution of wealth and power;
III. develop their own views and establish their personal underlying value positions; and,
IV. prepare for and take action on SSIs.

In terms of the above schema, there is considerable evidence that education about STSE relationships often is limited to ‘level III.’ Although Pedretti and Nazir (2011), for instance, suggest that there have been six ‘currents’ (emphases) in STSE education, it is apparent that this aspect of science education is dominated by focusing students on controversies in such relationships — often called socioscientific issues (SSIs) (Sadler, 2011). Students might debate and form personal, reasoned opinions, for example, about merits of conflicting data and expert opinions relating to use of nuclear power generation (perhaps compared to other energy sources) and merits of government (de-)regulation of food manufacturing companies. While negotiating decisions with peers, students often are expected to weigh diverse data and claims and develop personal well-argued defences of their position(s) on issues (Hodson, 2011; Levinson, 2010, 2013). There are numerous such socio-scientific controversies, and evidence suggests that engaging students in making personal reasoned decisions about them has led to some significant learning gains — including, for instance, development of socioscientific reasoning skills (Sadler et al., 2007); learning of products of science (e.g., laws & theories) (Venville & Dawson, 2010) and, learning about the nature of science (Kishishe & Lederman, 2006). It seems such outcomes may largely account for the apparent popularity — when implemented — of student engagement in science (Khishfe & Lederman, 2006). It seems such outcomes may largely account for the apparent popularity — when implemented — of student engagement in science and technology that frequently seem to result in various harms to the wellbeing of individuals, societies and/or environments (as discussed above). Some scholars and others suggest, therefore, that science education needs to help prepare people for more active citizenship in participatory forms of democracy (e.g., Bencze & Alsop, 2014; Hodson, 2003, 2011; Roth & Désautels, 2002; Santos, 2009). Regarding his hierarch of citizen participation in controversies, Levinson (2010), for example, recommends that SSI (and STSE) education needs to promote more ‘praxis’ (critical, reflective, practice) and ‘dissent and conflict’ (critique and activism) so that more citizens are prepared to review processes and products of professional science and technology and, where problems are perceived, be prepared to take personal and socio-political actions to address them. Forms of action students might take include: educating others (e.g., via posters and pamphlets), lobbying power-brokers (e.g., via petitions and letters), developing potentially-improved products and systems (e.g., an electronics item with recyclable components) and/or making personal improvements (e.g., using a travel mug) (Bencze & Carter, 2011).

Rationale for promotion of more participatory forms of democracy in terms of socioscientific issues/problems are complex and varied, but may include:
• The Seriousness of SSIs. Many SSIs are considered so serious that societies need to become activist as soon as possible. Climate change, for example, already is considered a major perhaps neoliberalism-influenced global threat (Klein, 2014);
• Actions Promote Deep & Attached Learning. To act on an issue is to apply it in a specific context and, again referring to knowledge duality theory (Wenger, 1998), deep, attached, learning occurs when learners control inductive and deductive thinking between phenomena and their representations;
• We Have Responsibilities Towards Others. Because each human is connected to other people (and their technologies and other products) with whom they have interacted (directly or indirectly), each person’s successes can be attributed to some of those interactions. A famous example is that Bill Gates’ wealth can be partly attributed to electronics, electricity and transportation developments and educational systems that supported him (Alperovitz & Daly, 2008);
• We Can Benefit from Helping Others. Because we are connected to many other people in our society (and, likely, worldwide), actions we take to improve their wellbeing may be returned to us. Doing ‘random acts of kindness’ can, for example, cause many more people to do the same and the person initiating the kindness may have someone do something nice for her/him (Batson, 1994).
The ‘STEPWISE’ Framework

In 2006, I developed the ‘STEPWISE’ theoretical framework (Figure 4) for encouraging and enabling students to self-direct sociopolitical actions to address harms they perceived associated with fields of science and technology. Since then, it has been used (in a more ‘practical’ form, as discussed below) as a basis for action research (learning from pedagogical actions) as educators promoted critical and activist science education in various educational contexts — including in science teacher education, school science and in after-school science clubs (Bencze, accepted; Bencze & Alsop, 2014). This schema suggests that science and technology education should acknowledge 2-way relationships among five educational domains, including: i) STSE Education (relationships among fields of science & technology and societies & environments); ii) Skills Education (e.g., using a microscope and designing experiments); iii) Products Education (e.g., laws & theories from science & technology); iv) Students’ Research (e.g., findings from student-designed studies); and, v) STSE Actions (e.g., petitions & YouTube™ videos). With STSE Actions in the centre, the emphasis is on students using their education in the other domains to inform socio-political actions they can take to address potential problems they perceive in S-T-S-E relationships. This schema encourages an altruistic science and technology education — one that makes provision for students to ‘spend’ (i.e., via personal and social actions) at least some of their cultural and social capital (Bourdieu, 1986) on trying to make a better world. In theory, such an altruistic education can be accomplished through implementing the STEPWISE framework in ways that best suit teachers’ teaching/learning contexts. Descriptions of its implementation are provided below, given — in light of Bruner’s (1960) concept of the spiral curriculum — progressively more detail.

A More Pragmatic Form of STEPWISE

To make a long story short, although there appears to be considerable theory to support use of the tetrahedral version of the STEPWISE framework (Figure 4), a range of action research experiences suggest that teachers, student-teachers and youth leaders often struggle to attempt it (Bencze & Carter, 2011). Among challenges are that this tetrahedral schema implies that students (perhaps even individual students) could, in theory, start at any position in the tetrahedron and move in any direction around it. This seems fairly unmanageable with large classes of students. Moreover, the schema implies that students should be taking into consideration one or more of the domains in the framework at the same time. For example, while learning about STSE relationships, students need to draw on (and learn) Skills (e.g., experimentation) and Products (e.g., laws & theories), etc. School systems tend not to support such complex and individualized learning.

Given educators’ struggles with use of the tetrahedral version of STEPWISE (Figure 4), my action research led me to conclude that they tended to prefer a more linear version of it, one example of which is provided in Figure 5. This schema is a re-arrangement of all domains of the tetrahedral framework. It is arranged to prioritize students’ development of expertise, confidence and motivation for self-directing ‘research-informed and negotiated actions’ (RiNA) projects to address STSE relationships that students judge to be problematic.

Broadly, this more pragmatic version of STEPWISE addresses all aspects of typical science and technology curricula (such as the four aspects of literacy suggested by Hodson (2003) above), but pays particular attention to helping students to develop: i) critical understandings of relationships, especially involving powerful individuals and groups, in STSE relationships; ii) expertise, confidence and motivation for self-directing secondary (e.g., Internet searches) and primary (e.g., studies and experiments) research to learn more about STSE relationships; and, iii) expertise, confidence and motivation for self-directing personal and social actions, based to a great extent on their self-directed research into STSE relationships. A fundamental aspect of this schema is that it recommends that students should provide students with one or more sets of ‘apprenticeship’ lessons and activities before expecting them to self-direct RiNA projects. These lessons and activities are structured in three phases, based on constructivist learning theory (e.g., Osborne & Wittrock, 1985) (including social constructivist forms). These suggest that learners can benefit from first reflecting on and expressing their pre-instructional conceptions (“Students Reflect”), about which they often are not

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4 ‘STEPWISE’ is the acronym for Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments. To learn more about this framework for teaching & learning and research, and to access relevant instructional resources, visit: www.stepwiser.ca.
consciously-aware, before a teacher provides them with alternative conceptions (“Teacher Teaches”) and then encourages them to evaluate competing conceptions through various personally-meaningful implementation activities (“Students Practise”). As indicated in the inset in Figure 5, such apprenticeship activities should vary in terms of the extent to which teachers or students control decisions (Lock, 1990). In the “Students Reflect” phase, it seems that, while teachers need to provide stimuli (e.g., looking at a picture) for reflections, most interactions should be student-directed and, if students are to freely express their conceptions (without feeling pressure to provide ideas planned by the teacher, for instance), such activities should be open-ended; that is, not pre-determined by the teacher and dependent on each students’ prior experiences and preferences. Afterwards, however, because students in many classes will vary in their cultural and social capital (Bourdieu, 1986), the teacher should use relatively teacher-directed and closed-ended approaches (in the “Teacher Teaches”) phase to ensure all students have full access to attitudes, skills and knowledge (“ASK”) that may benefit them. In the last phase of the apprenticeship (“Students Practise”), students are given considerable control over decisions, to the point of being nearly, if not fully, student-directed and open-ended. Teachers can, however, provide students with support (more teacher-directed) when students request it. If, moreover, the teacher feels it is necessary, students can be provided with a second apprenticeship cycle before being asked to self-direct projects.

**Student-led RiNA Projects**

Before providing more specific suggestions for implementation of the schema in Figure 5, a brief description of the kinds of RiNA projects students may conduct may help readers envisage goals of this approach. Figure 6 provides, for example, a summary — supplemented with some suggestions of alternatives — of a project conducted by students in grade 10 to investigate and act on problems they perceived relating to climate change. Students began with secondary research, mostly using Internet searches, to learn more about climate change. In doing so, assuming they had learned from apprenticeship lessons and activities (more about this to follow, below), they investigated roles of various aspects of STSE relationships; including, for instance, roles of scientists and technologists, other members of societies (including powerful ones, like members of governments and the private sector), and environments. In light of the topic, they likely found much information about harmful effects of, for instance, excessive uses of fossil fuel energy forms on the wellbeing of individuals, societies and environments. To supplement this research, however, they also conducted a correlational study to determine, in their case, how uses of hot showers (using energy and contributing to climate change) may vary by gender — results of which may help them make decisions about appropriate actions to address climate change. Using results of their secondary and primary research, students then negotiated conclusions and collaboratively developed plans for action that they could implement to address climate change.

Figure 6 provides a list of actions students might take to address climate change and/or other problems they perceive in STSE relationships. The students in grade 10 who conducted the shower length study developed posters and pamphlets to convince classmates and others to reconsider their uses of energy through uses of hot showers. They also said that their study had led them to consider reducing their own shower lengths (Krstovic, 2014a). Such a study, however, could have led students to carry out other actions, such as protest marches, boycotting of certain high-energy fuels and submission of protest letters to key stakeholders, such as members of government and industry.
Using the framework in Figure 5, students have been able to develop some excellent RiNA projects, several of which are reported by Krstovic (2014b) in a special issue of the Journal for Activist Science & Technology Education (see link).

**Apprenticeship Tips**

In the spirit of the spiral curriculum concept promoted by Bruner (1960), more teaching/learning suggestions, with rationale and examples for each stage of the apprenticeship in Figure 5, are provided below.

**Products Education**

Operating in parallel with the apprenticeships depicted in Figure 5 should be lessons (not shown in Figure 5) aimed at helping students to develop understanding of various ‘products’ (e.g., laws, theories & inventions) of science and technology. To assist with the apprenticeship, such ‘products education’ lessons can be connected to education about STSE relationships (and, perhaps, RiNA projects). Indeed, it is apparent that students can be motivated to learn ‘products’ through some sort of (brief or detailed) introduction of a relevant STSE issue (Venville & Dawson, 2010) and, through exposure to the issue, perhaps also want to take action(s) to address problems they perceive. An interesting issue is the question of the extent to which governments should allow companies to add ‘trans-fats’ (trans-fatty acids) to manufactured foods (Webber, 2009). These are liquid oils that have been turned into more solid pastes by adding hydrogen. Shortening used in baking typically contains trans-fats. Today, many foods contain them, including cereal, cookies, crackers, etc. Research suggests that trans-fats are more likely to lead to heart attacks and strokes than untreated oils or, even, natural fats. Nevertheless, companies continue to use them — partly because trans-fats preserve foods for their typically long trips from factories to stores. Despite research indicating health problems with trans-fats, governments often still allow companies to add them to manufactured foods. This gives greater priority to profit margins than to consumers’ health. Companies claim, however, that health risks are overstated and that trans-fats are relatively safe. Teachers can introduce students to such a controversy using, for example, videos or written documentaries that depict different stakeholders’ (e.g., scientists, food companies) perspectives. To help ensure students understand the issue(s), teachers likely will have to teach some of the chemistry and biology of trans-fats and, then, ask students to determine their positions on the issues and perhaps to argue for or against it with others. A popular approach is to set up a role-playing situation (sometimes called a ‘Town Hall Meeting’), in which students pretend to hold different positions (e.g., that of scientists, people in business, average citizens, activists for NGOs and governments officials) about the issue and engage in arguments with others about it. There is, clearly, much more that could be said — something that has not been, but could be further pursued — about associations between Products Education and STSE and RiNA apprenticeships.

**Students Reflect.** Moving on to the apprenticeship cycles, based on fundamental principles of constructivist learning theory (Osborne & Wittrock, 1985) (refer above), because learners’ previous experiences are likely to cause them to develop preconceived notions about phenomena that may interact with incoming stimulus information (sounds, sights, touches) to form new ‘constructions,’ which may or may not align with dominant conceptions (e.g., scientists’ laws, theories), and because many of learners’ pre-conceived notions are unconscious (learners are unaware of them), there appears to be some merit in spending time in education to encourage learners to reflect on and express their prior notions (Once they do so, learners may become more conscious of their pre-conceived notions and be able to more consciously consider revising them, if they feel it is necessary). More specifically, teachers should begin apprenticeships depicted in Figure 5 encouraging students to first reflect on and express their pre-conceived notions (Once they do so, learners may become more conscious of their pre-conceived notions and be able to more consciously consider revising them, if they feel it is necessary). More specifically, teachers should begin apprenticeships depicted in Figure 5 encouraging students to first reflect on and express their pre-conceived notions about STSE relationships and RiNA projects. In doing so, however, there appear to be a number of important considerations — which, likely, should be considered as a whole prior to implementing such reflection/expression activities:

1. **Control of Reflection:** Again, in thinking about arranging reflection/expression activities, given the importance of providing students with freedom to express their attitudes, skills and knowledge (ASK), it is important that such activities be mostly SD/OE (see Figure 5). Having said that, as discussed below, teachers typically have to provide students with stimuli (e.g., objects about which to reflect) and instructions and questions — including in terms of forms students’ expressions of pre-instructional ASK should take. These, of course, mean that such activities have small, but perhaps unavoidable, teacher-direction aspects — although, to ensure students’ ASK are as freely expressed as possible, they should be open-ended, meaning that the teacher needs to be prepared to accept (e.g., in terms of assessment & evaluation) whatever responses students provide, as long as, perhaps, students demonstrate sufficient effort. A related concept in terms of learner control is the extent to which suggestions/questions are divergent (with many possible responses) vs. convergent (with predetermined responses), with the former, of course, preferred (Hudson, 1967).
This is, indeed, important in terms of a related concept; that is, intellectual (in)dependence (Munby, 1980; Norris, 1997). The more control teachers exert over student decisions, it seems the greater students’ intellectual dependence; that is, dependence on others for decision-making.

ii. Topics of Reflection: With control of learning in mind, teachers need to consider the kinds of responses from students they hope to witness. Again, because of variations in students’ cultural and social capital (Bourdieu, 1986), this likely will vary considerably from student to student. Broadly, however, teachers may imagine that students may, at some point in their education (remembering the spiral curriculum), might discuss — with varying levels of specificity and complexity — aspects of STSE relationships, generally as depicted in Figure 7. Within that model, there is, naturally, a great range of possible claims students could make. There is a tendency for students to note various problems, such as climate change, for societies and environments due to various products of science and technology (Krstovic, 2014a). They may not, however, discuss powerful members of societies — such as members of government and the extent to which they may regulate businesses, positions of people and companies in business, and — perhaps most unlikely — transnational entities, such as the World Bank and World Trade organization, which can have great influences over governments and societies (McMurtry, 2013). This stage of the apprenticeship, however, as discussed above, is not the time to teach such ideas — which must happen, according to the model in Figure 5, in the “Teacher Teaches” phase. Deeper conceptions of STSE relationships, indeed, may arise from students after they have been taught some principles of actor network theory (Latour, 2005) — which, briefly, posits that any entity is influenced by and influences (to varying extents) a range of other ‘actants,’ which can be living, nonliving and abstract (‘semiotic’). In the context of expressing a range of ASK regarding STSE relationships, however, students also recommend some actions that could be taken — such as recycling or non-use of plastic water bottles, letters to companies to stop extracting public water from aquifers, and/or writing of letters of politicians demanding companies not bottle public water at their expense. Finally, prior to recommending such actions, students also may suggest relevant research to justify such actions. Again, as with much of such reflecting, students are likely to provide a range of responses and all should be accepted by the teacher, as long as it is apparent that the student(s) have done so responsibly.

iii. Stimuli for Reflection: As noted above, teachers need to establish some kind of balance between stimulating student reflection and allowing free reflection. In stimulating reflection/expression, moreover, there is a range of choices to make. In principle, the teacher could ask students to consider any item (actant) within relevant STSE relationships (Figure 7). In science courses, however, it seems relevant to ask students to consider relevant products of science and technology, such as: cell phones in studies of electronics; cosmetics in studies of chemistry; or fast foods in studies of animal systems (e.g., digestion). To do so, teachers can use various prompts, such as pictures or actual samples of such products (Krstovic, 2014a). Alternatively or along with such consideration of products, teachers may ask students to consider various possible actions (e.g., ‘Governments should ban all cigarette smoking in public places’ and/or ‘Companies should be left to decide for themselves which ingredients to include in manufactured foods, since they hire experts to determine these.’). It is one thing to provide objects for reflection; but, of course, teachers typically also need to attach instructions and/or questions to them. Again, there are choices to be made in terms of learning control (as above). However, to help with such decisions, a possibly-useful framework is Bloom’s Taxonomy (Anderson et al., 2001) — which suggests that students can be engaged in a range of levels of thought, including memorization, analyses and evaluations. Relevant resources are at: www.nwlink.com/~donclark/hrd/bloom.html

iv. Forms of Reflection/Expression: Finally, in providing instructions and posing questions, teachers can ask students to represent their pre-instructional ASK in many different forms. These include, but are not limited to: speech; written text; drawings; graphs; models; actor network maps (refer below); sketches; and, poems. Again, decisions about these will depend on students’ age and stage of development in abilities and understanding of STSE, research and actions and ways of expression of them — much of which will depend on the extent to which such ASK have been previously taught and learned.

**Teacher Teaches.** In science education, it is common for educational scholars, administrators and others to engage students to so-called ‘authentic’ inquiry-based learning experiences — such as experiments scientists might conduct — and, although prompts may be given, expect students to derive relevant laws and
theories of science. Schwartz, Lederman and Crawford (2004), for instance, who have done considerable work in this area in the USA, have said that such experiences 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 a conception of teaching, where particular, pre-determined, learning is expected, seems flawed (Bencze & Alsop, 2009). One problem is that not all students will ‘discover’ or interpret phenomena in the same way, since all of them have had different prior experiences and, consequently, have different mental structures in their brains that may or may not match stimuli from the world. As the black and white image in Figure 8, some people may ‘see’ a woman, others may ‘see’ a male saxophone player and others may ‘see’ something else (Hodson, 1986; Osborne & Wittrock, 1985). A particularly problematic aspect of expecting students to discover certain pre-determined, ASK is that, due to differences in cultural and social capital (Bourdieu, 1986), disadvantaged (e.g., poorer) students are less likely to discover intended ASK and, therefore, social stratification is reinforced (and, perhaps, magnified) through such approaches. With such problems associated with inquiry-based learning, it seems most appropriate to recommend that teachers use more teacher-directed (and, perhaps, closed-ended) approaches to ensure all students have access to ASK (in this case, about STSE relationships and RiNA projects) that may be useful to them. On the other hand, as elaborated in the next sub-section (“Students Practise”), direct teacher instruction is likely to be insufficient for deep, meaningful, learning. Such instruction must, apparently, be combined with opportunities to practise ASK that has been taught. Logic for this comes from knowledge duality theory (Wenger, 1998), which posits that deep, meaningful, learning occurs best when students have maximum control over both inductive and deductive aspects of learning (see Figure 2, above). Teachers should, accordingly, often attempt to balance teacher instruction with student practice in contexts having meaning for students.

Although teachers can choose from a range of approaches, including lecturing, Socratic lessons, using demonstrations, photographs, drawings, videos, etc. to teach students about particular STSE relationships and RiNA projects, a common approach, which often combines deductive and inductive thinking, is use of case methods; that is, documentaries (‘cases’) summarizing phenomena (e.g., STSE relationships and, often, controversies and problems and RiNA projects) and instructions and questions (‘methods’) to engage students in learning from and through the cases (Bencze, Hewitt & Pedretti, 2001). A common — and very effective kind of case/documentary for teachers to use is one (or more) depiction(s) of STSE-RiNA projects conducted by students of a similar age as those in the class. An example of this is given in Figure 9, which is a display board presented by students at an ‘STSE-RiNA Fair,’ at which shows students giving a report of their study of content (e.g., minerals) of different types of bottled water and tap water, along with their action banner. Other such examples could be taken from the special issue of the Journal for Activist Science & Technology Education containing several reports of student-led RiNA projects (Krstovic, 2014b).
excellent source of cases are provided by The Story of Stuff project (storyofstuff.org), which includes videos about such controversial commodities as bottled water, cosmetics and electronic devices (e.g., cell phones and digital music players). Teachers could develop such cases into case methods by asking students to read the reports and answer a range of questions about them that would help students to understand aspects of STSE relationships and research-informed and negotiated action projects that could be conducted.

There are, of course, many aspects of STSE relationships and RiNA projects that could be taught, depending students’ age and stage(s) of progress in this regard. Perhaps most fundamentally, students should understand cases like those above in terms of the STSE model in Figure 7, above. Discussions with students about roles of various ‘stakeholders’ associated with problems for the wellbeing of individuals, societies and environments (WISE) might include influences, for example, of government-sanctioned private sector funding of science and technology on WISE problems (e.g., Mirowski, 2011). Actions that people could take to address such problems might be discussed, for example, with reference to a schema like that in Figure 10; e.g., in terms of “Lobby[ing] Power-brokers.” In discussing such actions, however, it also is important for teachers to advise students of the importance of conducting effective research (with more suggestions below) as bases for action decisions. An effective technique in this regard is to show students a hoax video (www.youtube.com/watch?v=A58X14pzGU0) warning students that people can often agree to actions based on minimal evidence or, perhaps, in terms of social cues like friends’ status. A perhaps particularly important lesson for students to learn is that it may be that some research is highly biased, such as that generated by scientists employed by companies to either promote their products or cast doubt on others’ research that, if more widely known and/or given credence, would inhibit people from purchasing products and services (Oreskes & Conway, 2010 [www.merchantsofdoubt.org]).

Indeed, an especially important lesson for students to learn about problematic STSE relationships pertains to adverse influences of neoliberalism-oriented private sector individuals and groups (refer above) on fields of science and technology (and, likely, on fields of engineering & mathematics, etc.). Under influences from neoliberalism, there is considerable emphasis on abstract knowledge production and uses. Besides encouraging market speculation, for instance, particular focus is to encourage moderately to very wealthy citizens to engage in repeated cycles of consumption and disposal of goods and services, partly because techniques for production of physical commodities had increased to the point of saturating markets (Barber, 2007; McMurtry, 1999; Usher, 2010).
In terms of the schema in Figure 11, although production of products and services (World), like cars, perfumes and manufactured foods is important, emphasis is placed on the *representation* (Sign) end of the World-Sign relationship — in order to encourage repeated consumption (and disposal) of such commodities. It may be more accurate, however, to say that emphases are placed on *misrepresentations*. On the one hand, there appear to be natural inefficiencies — called *ontological gaps* — in humans’ translations between different ontological entities of the World (e.g., a tree) and Sign (e.g., drawing of a tree). On the other hand, humans may *purposely mistranslate* between World and Sign — creating what may be called *ideological gaps* — to serve certain purposes. To encourage consumption, it is apparent that engineers (often with marketers) can create designs that research suggests may cause people to envisage certain idealistic abstractions that may cause certain emotional attachments to commodities — such as certain ‘sleekness’ of car design that may be associated with a higher level of social class. Additionally, or in concert with such designs, marketers may create advertisements — such as showing a well-dressed person driving such a car — that reinforce such idealistic abstractions. Indeed, it is apparent that consumers can be convinced to strongly associate designers’/marketers’ idealized abstractions with commodities — thus creating various forms of brand identity and often very enthusiastic loyalty in commodity-consumer relationships. According to various authors (e.g., Barber, 2007; Usher 2010), who have drawn on foundational work of Baudrillard (1998), effectiveness of idealized abstractions derives largely from their relative detachment from the actual phenomena, which allows designers and marketers to continuously re-design the abstractions without having to significantly re-design the commodity — which can convince consumers to discard commodities in favour of newly-designed/marketed idealized abstractions (Barber, 2007; Leonard, 2010). Although there is considerable generation of a range of solutions to personal, social and environmental harms through technology<–> science (technoscience) developments, much of the innovation and entrepreneurship encouraged by capitalists, educators, government officials and others seems to prioritize creativity in development of sequences of idealized abstractions for promotion of cycles of consumption and disposal.

With people mainly focusing on idealized abstractions linked to cycles of consumption and disposal, capitalists can be free to reduce their associated costs in order to generate profit (McMurtry, 2013). This can mean, for instance, reductions in costs for labour at stages from resource extraction through transportation, sales and marketing and on to disposal (e.g., lower wages, benefits and working conditions) and materials (e.g., less expensive ingredients in foods, sometimes lacking in nutritional value). 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 (some of which were described above). Exacerbating such compromises appears to have been legal decisions (e.g., in 1980 in the USA) to allow contracts between university-based technoscientists and companies/financiers, a move that tended to shift their foci from knowledge generation for general wellbeing to that of private interests (Krimsky, 2003; Mirowski, 2011; Ziman, 2000).

Based on arguments above, consumers are, in a sense, purchasing (and often discarding) ‘Trojan horses,’ commodities that, through idealized abstractions (e.g., ‘sexy’) on the surface mask harmful features within (e.g., trans-fats in foods) (Bencze & Carter, 2015). An important way to think of this is through the actor network concept of *punctualization*; that is, making a network of relations appear as a single entity (Callon, 1991). As indicated in Figure 12, for example,
genetically modified salmon can be seen as a wonderful source of food compared to wild salmon, perhaps distracting customers from possibly-problematic actants such as “Government Regulation Policies (FDA)” and “sea lice” (Pierce, 2013). A similar sort of masquerade appears to apply to use of microbeads (tiny balls of plastic mixed into numerous hygiene and beauty products — which many activists want banned: storyofstuff.org/plastic-microbeads-ban-the-bead/). In Appendix A, Mirjan Krstovic, a teacher who has used STEPWISE for several years, provides readers with a lesson plan he has used to teach students about actor network theory and the Trojan horse metaphor regarding commodities.

Actor network theory also can be used to teach students about the nature of activism. A good example of this pertains to an ongoing ‘conflict’ between advocates for continued expansion of shipment of nickel ore through the port of Québec City, Canada, and citizens calling for more precautions against dispersal of the nickel dust across their neighbourhoods — which they claim contains numerous toxic heavy metals, such as lead, cobalt and arsenic (Pouliot, 2015). This conflict can be understood in terms of Foucault’s (2008) concept of a dispositif; that is, an aggregate of actants that cooperate in a common cause. In this case, activists have rallied, for instance, other citizens, data about the dust content and source (from a professional laboratory), banners, citizen marches, petitions, class action suits for their dispositif. A dispositif supporting increases in ore shipments, with minimal precautions against dust dispersal, includes politicians, members of the port authority, the shipping company and (according to activists) techniques to pacify citizens, including water cannons to soak the dust piles and water trucks to clean the streets (Bencze & Pouliot, accepted).

Finally, although we might like to think that our teaching about STSE and RiNA projects fairly and accurately represents them, it seems that educators are likely to be — in ways perhaps not unlike that of neoliberal capitalists — subject to ontological and ideological gaps (Figure 11). Those producing educational materials (e.g., textbook publishers, school district personnel & teachers) may, to some extent, misrepresent the ‘World’ in their ‘Signs’ (e.g., Powerpoint slide series, videos, written cases, etc.) that, in turn, may be translated (Sign —> World) into misinterpretations of the ‘World’ (e.g., of STSE & RiNA) by students. There are, perhaps, many opportunities for such mis-translations. According to Pozzer and Roth (2003), for instance, there may be a series of steps in World —> Sign translations (Figure 11) that involve progressive loss of detail (and representativeness) — such as: flower —> picture —> drawing —> graph (e.g., rate of photosynthesis vs. light intensity) —> chemical equation (e.g., photosynthesis). In this light, accordingly, teachers need to be mindful of potential for mis-representation, depending on the nature of objects (e.g., photographs vs. drawings) they use. Students may, for instance, receive printed copies of cells or they may view them on a screen containing a projected image of a cell. In such translations, one can imagine ontological and ideological gaps. The former are, likely, unavoidable. The latter, however, may depend on teachers’ purposes. For example, if the cell image already is idealized, perhaps the teacher may want to point this out to students. There are, however, situations in which science teachers (perhaps often without their intentionality) may mis-represent STSE relationships through omission of certain problematic details. This often appears to be the case, for instance, with regards to the extent to which ‘business-science partnerships’ are avoided in school science (Carter, 2005).

**Students Practise.** In light of problems of authenticity of representation of STSE relationships and RiNA projects, despite merits of purposely teaching students about some of them and teachers’ attempts to accurately represent them, it seems that students need opportunities to engage more directly in them. Their learning about STSE-RiNA should not be — essentially — vicarious. Indeed, given Wenger’s (1998) claim that deep, committed, learning occurs when learners have considerable control over both directions of the World —> Sign dialectic (Figure 11), the more students have opportunities to influence decisions over representing (researching) the World of phenomena and over using (acting with) their representations (Signs) to attempt to affect changes to the World. Accordingly, students need to be engaged (perhaps in groups) in practice RiNA projects to address problematic STSE relationships of their interest (“Students Practise” in Figure 5). Such projects may be thought of, again, in terms of the schema in Figure 11, with ‘research’ involving World —> Sign translations and ‘action(s)’ involving Sign —> World translations. Again, depending on students’ age and level of expertise, confidence and motivation (e.g., with more less experience with such projects), teachers may have to provide some supports for student projects.

There are, naturally, a range of kinds of supports teachers can provide for students’ practice RiNA projects. As discussed above, an overall goal is to make such projects as student-directed (SD) and open-ended (OE) (Figure 5) as possible. It is common, however, for students to benefit (and desire) lists of possible STSE issues/problems. These can be presented in different forms. Brief descriptions of controversies, such as that below, can be helpful:

**Energy drinks, which contain high levels of caffeine and sugars, 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 targets towards adolescents are controversial (e.g., Rockstar, Monster, Big Buzz, Cocaine). Parents groups in Canada are mobilizing to ban energy drink sales to minors.**

More detail, particularly in terms of the nature of a range of actants, can be provided through ‘commodity actant arrays,’ such as that in Figure 13. Such resources, of course, give students results of some initial secondary research — while leaving room, perhaps, for them to conduct more secondary and primary (e.g., a correlational study of age, gender, etc. vs. battery (non-)use) that students can then use for informing their development and implementation of action(s) they deem appropriate. More information-rich versions of such arrays have been prepared using Prezi presentation software; e.g., at: goo.gl/zuBb7w.
In examining various stimuli for topics like those described above, students (perhaps in small groups) should then be required to develop STSE cases. This will involve secondary research (often via the Internet) to determine positive and negative effects on the wellbeing of individuals, societies and/or environments due to influences of powerful people/groups on fields of science and technology. Students should be asked to determine likely ‘stakeholders’ (e.g., members of government, companies and activist groups) concerned and not concerned about apparent ‘problems’ and, associated with that, to construct actor network maps to describe the problem(s) in STSE relationships they would like to address. To supplement what they have learned about the STSE relationship of their interest, students should then be asked to design and conduct one or more empirical inquiries. An ‘empirical’ inquiry is one in which investigators base conclusions — at least in part — on experiences with physical phenomena (including energy). There is considerable disagreement, however, how investigators carry out such inquiries. Although experimentation is commonly associated with science inquiry, it is common to suggest that investigations into possible problems associated with STSE relationships be carried out as studies, particularly correlational studies — in which investigators study natural changes in possible independent and dependent variables, such as amount of nicotine (in cigarettes) consumed and cancer rates (Bencze, 1996). Using findings from their secondary (Internet searches) and primary (e.g., studies) research, students should then be encouraged to negotiate conclusions and plans of action (e.g., from Figure 10) to address problems they identify.

Because students, perhaps ironically, rarely have chances to self-direct research in science classes, which would help them to develop expertise, confidence and motivation for such research, teachers often have to provide students with extra lessons and activities, as part of what may be called a ‘skills’ apprenticeship, to help them develop said expertise, etcetera (Bencze, 2000). A set of sample skills development lessons and activities is provided in Appendix B. Since these were developed in the early 1990s, teachers now could adapt them to include more STSE contexts for the activities. Such apprenticeship lessons and activities can be patterned after the 3-phase apprenticeship in Figure 5, first getting students to reflect on and express their pre-conceived notions about research, then teaching them some alternative approaches prior to helping them through sample small-scale research (and action) projects. In such lessons and activities, again, students could be shown samples of reports of projects conducted by students.

A type of project perhaps not common in science classes that students may appreciate involves attempts to design (and perhaps to implement and field-test) an invention or innovation that takes into consideration, not just its functionality, but also its possible positive impacts on the wellbeing of individuals, societies and/or environments. This seems important, given that many STSE problems appear to be (as discussed above) linked to various consumer products and services. An example of such a project, one involving improvements to a popular cologne used by males, is shown in Figure 14. As noted in the figure, students seemed particularly sensitive, for example, to fair labour practices and ecologically-sustainable packing and shipping of the product.
Students Reflect, II. After apprenticeship lessons and activities like those described above, some — but, perhaps, not all — students may have sufficient expertise, confidence and motivation for self-directing effective research-informed and negotiated action projects to address power-related problems of their interest in STSE relationships. Teachers may choose, therefore, to either provide students with another set of apprenticeship lessons and activities or to ask them to conduct a student-led project to deal with a problem of their concern. To help with this decision and, as well, to prepare students for self-directed projects, teachers can encourage students to first return to the “Students Reflect” phase of the apprenticeship (Figure 5). Such reflections are related to the concept of metacognition; that is, thinking about and using characteristics of the nature of learning (Brown, 1987). Encouraging students to — as illustrated in Figure 15 — reflect on and perhaps apply characteristics of the nature of STSE relationships, secondary and primary research and personal and social actions while they are engaged in such RiNA projects and after apprenticeship lessons and activities can increase their expertise, confidence and motivation for such projects (Bencze & Krstovic, accepted). Because, as discussed earlier, students cannot discover all aspects of the nature of STSE and RiNA projects, however, teachers should include in apprenticeship lessons and activities mentions of some such characteristics. Based on discussions above, for example, it may be particularly important for teachers to share with students the idea that effective actions should be networked; that is, single actions, like a poster, can be enhanced by sharing it via social media, such as Twitter, Instagram, YouTube and Facebook.

Finally, after the teacher feels that most — if not all — students are adequately prepared, s/he may choose to give students an assignment — with a range of deadlines for parts of the project — asking them to self-direct RiNA projects to address power-related problems of interest to them in STSE relationships.
Figure 15: Reflection and Acting on Characteristics of the Nature of STSE & RINA.

References


