Environment: Re-negotiating the E in STEM Education

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ABSTRACT

There is little debate that protecting eco-systems and sustaining the environment is important, critical even, now and in the future. From an educational perspective, there is an imperative to provide authentic, ecology-based learning experience for all students. In the Australian Curriculum, Environmental Sustainability is a cross-curricula priority. More specifically, there are also outcomes in the Australian Curriculum Science in the sub-strands, Science as a Human Endeavour and Science Understanding (Biological sciences) that focus on the environment: caretaking, respect, and an awareness of the complex connectedness of biotic and abiotic factors. Seemingly Science, Technology, Engineering, and Mathematics (STEM) education has concurrently risen as the new panacea to address economic and employment issues globally. This paper posits that STEM education could be re-imagined by addressing the E as "eco-thinking", and that this could provide a more cogent and inclusive approach to addressing environmental issues. Integrated and authentic STEM education could not only provide a space to investigate environmental issues but also offer a frame to image and implement solutions or resolutions. In this paper we explore this notion and consider how STEM education could look as ST(Environment)M in elementary schools, either within classrooms or elsewhere in the school.

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BACKGROUND

Since the acronym STEM (Science, Technology, Engineering, and Mathematics) was first coined in the late 1990s in the United States by the National Science Foundation, the ensuing political reactionism of the US in regards to global superiority has not abated (Blackley & Howell, 2015). Businesses in the United States have voiced concern over the current and future supply and availability of domestic workers in STEM fields, and experts are concerned that the demand for STEM labour will only increase with time (Beede, Julian, Langdon, McKittrick, Khan, & Doms, 2013). This becomes even more of an issue as the US National Research Council (2011) revealed that more than half of the per capita growth income in the 21st century may be attributed to advances in science and technology in the United States. In Europe, one of the most influential documents is *Horizon 2020* that makes predictions about the future and the technologies that will be influential (European Union, 2015). It outlines in its *Science with and for Society* program that the way forward is to build capacity and develop innovative ways of connecting science to society. It seeks to make science more attractive and accessible (particularly to young people), increase society's appetite for innovation, and open up further research and innovation activities.

The emergence of STEM in the late 1990s heralded the beginning of a new age in education: *geo-political rationalisation* (Blackley & Howell, 2015). This term refers to the driving of educational policies of individual countries by politicians seeking to justify expenditure and agendas. This was led, and is still be driven by, the US, in a frenzied "nation-centric" (Steele, Brew, & Beatty, 2012) reaction to the Global Financial Crisis and consistently poor rankings in international assessments of student achievement such as the Program for International Student Assessment (PISA) and the Trends in Mathematics and Science Study (TIMSS). The latest PISA data (OECD, 2012) positions the United States 27th in mathematics and 20th in science amongst the 34 OECD countries; with 25% of students tested not reaching the levels 2 baseline proficiency level. Furthermore the trend data show no significant changes in the average performance of US 15-year-old students in the mathematics and science over time (Author 1 & Author 2, 2015). This is of considerable concern given the focus of time and money on programs for improvement in student learning outcomes in mathematics and science. The latest TIMSS 2011 (Mullis, Martin, Foy, & Arora, 2012) positioned the United States 11th in Year 4 mathematics, 9th in Year 8 mathematics, 7th in Year 4 science, and 10th in Year 8 science. Whilst the positions may be acceptable at face value, geo-politically they are not, given that the consistent top scores for both assessments are either historical economic rivals (such as Japan) or emerging and strengthening economies such as Korea and Chinese-Taipei.

Australia performed on a par with the US in both mathematics and science, and the mathematics score was not significantly difference to the 1995 score. One-third of Year 8 Australian students did not reach the Intermediate international benchmark (the minimum proficient standard) in mathematics and science (Thompson, Hillman, & Wernet, 2011). The Chief Scientist voiced his concerns over the lack of progress in STEM education in Australia, and he argued that a growth in STEM innovation is the way forward to secure a strong economy with highly capable workers for the future (Chubb, 2015). He urged Australia to increase the number of STEM graduates to drive innovation and economic growth. His message is clear and has considerable support; in the current world climate

STEM innovations are considered to be key to the economic future and there funds, time and energy need to be put into improving STEM education (European Union, 2015; Hackling, Murcia, West, & Anderson, 2014). Fifteen years since its inception, billions of dollars in global expenditure, and periodic frenzied resurgences of interest in STEM programs have not eventuated in the desired increase in students choosing STEM subjects in senior secondary schooling or the expected increase in STEM graduates from tertiary institutions eventuated (Burke & Baker McNeill, 2011). We suspect that the problem lies in the E of STEM.

Originally the E in STEM stood for "engineering"; however without a shared understanding of or agreement on what was actually meant by "engineering", particularly in a school context, that part of the acronym has continued to be problematic. Politicians, businesses, and those teaching and researching in STEM fields in universities have had a vested interest in the E being developed in schools by classroom teachers (Blackley & Howell, 2015). Yet, to date, the take-up of authentic STEM education in schools has been sporadic with isolated pockets of successful practice. We suggest that there are two driving reasons for this: first, "engineering" is not a subject area in the elementary school curriculum, and second, pre-service teachers are not trained in the engineering discipline (Blackley & Howell, 2015). Globally, the other three components of STEM education (science, technology, and mathematics) have curriculum documents and constitute elements of initial teacher education programs. Perhaps this even begs the question: *Why keep chasing the elusive engineering aspect*? What if the E in STEM was re-negotiated as "Environmental considerations"?

ENVIRONMENTAL CONSIDERATIONS

In the context of this paper, "environmental" refers to "ecology" and associated terms, such as ecosystem, ecotype, nature, and natural habitat. The ecology being referred to is more than a "narrow (anthropocentric) science that mainly addressed pollution or other environmental problems that threatened the affluent in society" (Smith & Gough, 2015, p. 39). Rather it is about embracing a life-style and identity that protects the earth. Naess (1973) coined this as *deep ecology*, the main principles of which are connectedness to nature, bio-spherical egalitarianism, wilderness preservation, population management, biodiversity, and reduction of resource use. When *environmental* is combined with *considerations* the connotation is to ponder, consider, hypothesize, evaluate, debate, justify, and reconsider local and global ecological issues in an endeavor to ethically enact authentic change. The ecological issues, such as climate change, loss of biodiversity, nitrogen deposition, and release of toxic chemicals, facing the world are pushing the planet in "directions never before experienced in human history" (Hobbs, Hallet, Ehrlich, & Mooney, 2011, p. 444). So it is timely that, whilst STEM education continues to attract publicity and considerable funding, an environmental and ethical approach is taken via the promotion of E for Environmental considerations.

ENVIRONMENTAL EDUCATION

Environmental education has been a part of the curriculum in Western education systems for decades, yet there seems to be a persistence of dominant environmental paradigms that tend to be anthropocentric or egocentric (Kushmerick, Young, & Stein, 2007; Stevenson, 2007). First world countries are generally perceived to value consumerism, which is central to their economic systems. However consumerist societies, underpinned by egocentric values, are not sustainable. These values motivate the decisions each person makes regarding their personal resource consumption, waste disposal, and acquiescence of contra-ecological practices of corporations. Legislative and technological attempts to address environmental issues will not work without addressing personal values related to the environment and a sense of global or collective responsibility (Kushmerick, et al., 2007). We believe that this could be achieved by promoting integrated STEM education with a focus on environmental considerations, beginning in elementary school.

Despite roughly 30 years of rhetoric about environmental and sustainability education, Western education systems tend to reinforce *competition and consumption* rather than *care and conservation* (Sterling, 2001). The guiding principles of environmental education, outlined as far back as the Tbilisi Declaration (1977), focus on learning that is the result of the "reorientation and dovetailing of different disciplines and educational experiences which facilitate an integrated perception of the problems of the environment" (Recommendation 2). Ideally students work independently and collaboratively towards the resolution of current, local, and global environmental problems.

The Australian Curriculum has *Sustainability* as one of its cross-curriculum priorities - that is one of the core foci that overarches all aspects of the curriculum. Sustainability is defined as:

- understanding the ways social, economic and environmental systems interact to support and maintain human life;
- appreciating and respecting the diversity of views and values that influence sustainable development; and
- participating critically and acting creatively in determining more sustainable ways of living.

Through the priority of *Sustainability*, students develop the knowledge, skills, dispositions, and world-views necessary to contribute to more sustainable engagement with the earth (ACARA, n.d). It enables individuals and communities to reflect on ways of interpreting and engaging with the environment, and is *futures-oriented*, focusing on protecting environments and creating a more ecologically and socially just world through informed action. Consideration of environmental, social, cultural and economic systems and their interdependence is required to enact more sustainable patterns of living (ACARA, n.d).

The Australian Curriculum Science begins targeting environmental considerations as early as Year 1, in the strand "Science as a Human Endeavour", in which a content descriptor states: *People use science in their daily lives, including when caring for their environment and living things (ACSHE022).* In the Year 7 content descriptors for "Science as a Human Endeavour" the curriculum input is even more explicit: *Science and technology contribute to finding solutions to a range of contemporary issues; these solutions may impact on other areas of society and involve ethical considerations (ACSHE120).* These and other content descriptors pertaining to the environment should provide a strong impetus for developing an awareness, understanding, and resolution of environmental issues but it is often undertaken in an incidental or fragmented manner, therefore a more comprehensive approach needs be taken.

Re-negotiating the E for *Environmental considerations* in STEM education lends itself to: a focus on understanding important concepts, theories, and methods (not only in the discipline of science, but also geographical, historical, and socio-cultural); the authentic and direct involvement of students in a locale or habitat (ie., a beach, forest, stream or park) to develop an awareness of and concern for the environment and to think about ways in which that environment can be nurtured; the "promotion of a willingness and ability to adopt lifestyles that are compatible with the wise use of environmental resources" (Department of the Environment and Heritage, 2005, p. 6.).

Of note here is that this approach is not solely focused upon problem or issue identification; it also encompasses problem resolution based upon ethical considerations. Such an environmental problem-resolution approach should take into consideration the students' "cognitive and experiential development" (Stevenson, 2007, p. 146) so that engagement with the problem is feasible and is supported by parallel learning in traditional curriculum areas such as science. It is important to note the terminology used here: problem *resolution* rather than problem *solution.* In this context the "resolution" could be propositional rather than actionable, multi-faceted rather than singular, and logistically viable. By their very nature, environmental problems require an interdisciplinary or integrated approach, and as such make an ideal alternative to the traditional E in STEM (Blackley & Sheffield, 2015).

ETHICS EDUCATION

Ethics can be defined as the considered and rigorous interrogation of our beliefs about right/wrong and good/bad. To behave in an ethical manner, in an environmental or ecological context, requires a consideration of one's currently held values and honest reflection on the impact of one's actions upon the environment or ecosystem. To contemplate and evaluate and then to not act to better the situation is *unethical.* Environmental considerations are necessarily carried out through an ethical lens, and in the context of STEM education, it can be viewed as grappling with some of the most complex challenges facing human beings such as: *How do we meet our energy needs and desires today without compromising those of future generations?* There is an ever-increasing tension between the cost, benefit, and ecological impact of technological, scientific, and medical advances, and global citizens need to balance considerations of productivity, sustainability, and availability. "Many of the most important ethical predicaments the world community is facing today arise in connection with science, in scientific research and in the development and applications of new technologies" (UNESCO, 2005, p.3).

As politicians seek to increase the number of people working in STEM areas and students opting for STEM subjects, it is vital that educators convey the importance of ethics (Burgess, 2012). We suggest that ethics, as a component of environmental considerations, could be incorporated into STEM education through the use of well-formulated questions and discussion. Examples of the kinds of questions that could be asked of students that will undoubtedly trigger discussions are:

1. What materials and resources will be needed for the construction, operation and maintenance of the technology, machine or process? When discussing the materials factors of durability, cost, accessibility, sustainability, and disposability need to be considered. Resources could encompass the energy requirements for construction and operation.
2. Who will use this technology, machine or process, and how will they be impacted physically, emotionally, and financially?
3. Other than the people using this technology, machine or process, who else may be affected by it? What is the social and economic impact?
4. What else may be affected? (urban environment and natural environment)
5. What will be done with this technology or machine when is it superseded or no longer used by anyone? (Blackley & Sheffield, 2015).

Questions of this nature strongly reflect the ethical framework called *Consequentialism* (McKim, 2010), and classroom discourse would be shaped as the teacher and students consider and discuss scenarios and viable solutions or resolutions. Consequentialism directs attention from the facts and procedures of traditionally taught science, technology and mathematics, to the interconnected nature of our world. As Steele, Brew, and Beatty (2012, p. 129) conclude: "STEM disciplines provide an important canon of knowledge and skills but STEM without ethical grounding, remains self-serving and hegemonic". Teaching STEM education through an ethics lens could prove to be problematic for many science educators for a number of complex reasons: (1) it can challenge a teacher's identity and socio-cultural beliefs, and through this their pedagogical practices (Kim, 2005); (2) the ethics focus takes science teaching and learning away from the norm of memorising content knowledge and following recipe laboratory activities, into the realms of social, environmental, and ethical issues and actions (Steele, 2011); and (3) even when teachers feel confident and motivated to teach from an ethics perspective, they frequently come up against implementation obstacles in their schools (Pedretti, Bencze, Hewitt, Romkey, & Jivraj, 2008).

ENACTING ST(ENVIRONMENTAL)M EDUCATION IN SCHOOLS

Ideally ST(Environmental)M education in a school context would be based upon a local ecological issue or problem, for which a resolution could be created by students, based on their science knowledge, numeracy skills, and accessible technology, as an *intervention*. Interventions take the form of manipulating the living and/or non-living components of an ecosystem, and can vary in intensity and duration (Hobbs et al., 2011). The intent of these "direct action" interventions is either to maintain an ecosystem in a current desirable state or to move the state of an ecosystem from undesirable to desirable; both of which require ethical considerations. At the local level, which is most likely accessible by schools, actions such as fencing off an area of native vegetation for regeneration (even, roping off areas of lawn in the school yard that have been damaged or destroyed by foot traffic) and looking at creating a new path or a way of encouraging the local community to make changes, removing problem weed species, or planting native plants to control erosion would constitute manageable interventions. These are examples of *actionable* resolutions of ecological problems at the local level. Just as worthy are *propositional* resolution to larger-scale ecological problems that impact upon regions, states or countries. Examples of these include, reducing pollutant inflow into water systems, reinstatement of historic fire regimes, and reinstatement of flow regimes in creeks and rivers.

The environmental considerations involved in interventions should be made explicit in the activities carried out by students, and could be framed around questions such as: *What is the root cause of this problem? How could this be resolved? What impact would the intervention have on human and non-human members of the ecosystem? Is the intervention sustainable?* The development of viable resolutions to ecological problems rests upon students accessing scientific knowledge and procedures – whether part of current or past curriculum or needing to be researched beyond the curriculum; *just-in-time* knowledge rather than the *just-in-case* teaching that is so prevalent in schools. This positions students as researchers and supports their personal locus of control in their learning. This approach also supports the development of 21st century learning skills, in particular, communication, collaboration, creativity, and problem solving, as students work to create and implement interventions (Ministerial Council on Education Employment Training and Youth Affairs, 2008).

With the ability of information to flow so rapidly through the Internet and particularly through social media, problems can be shared and potential solutions curated and then applied if viable. In this context the T for technology in STEM education focuses on the flow of information, *Information Technology,* where students can use the connectedness of the global Internet to identify a reported problem, curate data and evidence, use their science and mathematics knowledge to reason the issue and analyse data, and connect, synchronously and asynchronously, with other communities to seek out specific solutions or adapt solutions to meet the identified context.

For example, when considering how to reduce the pollution in their local waterways, students could be directed to "Seabin" (www.seabinproject.com). The solution presented on this site was created by a pair of Australian surfers to clean the solid non-biodegradable rubbish from partially enclosed water areas such as marinas and waterways. This simple yet elegant idea is just one possible solution to a large-scale problem of solid non-biodegradable waste in water systems that leads to significant problems for marine life (education.nationalgeographic.org/encyclopedia/great-pacific-garbage-patch/).
Students could begin by investigating the problem of plastic waste, and research the damage inflicted on the wild life in a particular area. This could include an examination of the ethics of using plastic bags, and the use of mathematics to sample and scale the area impacted. This could prompt a clean-up by students in their local community or an investigation into solutions being enacted in other places such as the Seabin.

Other examples of this type of digitally-connected collaborative problem solving could result in solutions or resolutions to some of the serious health problems being faced in under-developed countries that are caused by the use of materials or processes necessary for survival. Twenty per cent of the world's population does not have access to electricity, and so many families resort to using kerosene lamps in their homes (http://gravitylight.org/the-challenge). These kerosene lamps, which are essentially recycled bottles filled with kerosene and a wick placed inside, present four keys problems: fumes, cost, burns, and environmental impact. The World Bank estimates 780 million women and children breathe kerosene fumes which is equivalent to inhaling 40 cigarettes a day. The cost of kerosene is a poverty trap; amongst the poorest populations it uses up to 30% of their income. In India alone 1.5 million people suffer severe burns each year, primarily due to overturned kerosene lamps. They also cause fires that spread rapidly across slums and refugee camps. Collectively, kerosene lamps cause 3% of the worlds CO_2 emissions and are a significant source of black carbon, with even more intense local warming impact (http://gravitylight.org/the-challenge).

A solution to this problem could be the replacement of the kerosene lamps with "GravityLights", which converts potential energy to kinetic energy that in turn generates electricity. The GravityLight is installed to provide a 1.8m-drop of a 12kg weight. This weight is lifted using a pulley, and on release starts falling very slowly (about 1mm / second). This movement powers a drive sprocket, which rotates very slowly with high torque. A polymer gear-train running through the GravityLight turns this input into a high speed, low torque output that drives a DC generator at thousands of rotations per minute. This generates just under a tenth of a watt to power an LED light bulb. Given the ever-increasing efficiency of LEDs, this produces a light over 5 times brighter than a typical open-wick kerosene lamp. Once the weighted bag reaches the floor, which depends on how high it was installed, it is simply lifted to repeat the process. There is only the initial outlay of the GravityLight mechanism for safe, clean, free light generation. Problems such as these can be investigated using an inquiry process, with students drawing upon their science knowledge (S) to observe and make sense of their observations, their mathematics knowledge (M) to record and analyse their data, and their technology skills (T) to identify, collect and curate their research, and then to present their findings.

We posit that in this context, the M for mathematics in STEM education emerges as *scientific numeracy*: a collection of mathematical skills and procedures that would be used as *tools* at some point within creation or implementation of an intervention. These include: measuring (choosing the unit, instrument, degree of accuracy, and attribute); recording data; displaying data; calculating statistics (descriptive and inferential); and modelling. At times various digital tools and programs could do many of these procedures more rapidly and accurately than they could be done manually. The skill in integrating scientific numeracy into STEM education lies in the educator's ability to dissolve the subject silo and make clear the affordances of the mathematics to undertake the intervention.

Not all ST(Environmental)M education in schools needs to be based upon ecological interventions. One very basic approach, that can be as complex or simple as desired, is the planning, construction, and maintenance of a vegetable garden in the school grounds. Guided by a managerial plan, the vegetable garden scenario has the potential to promote positive environment attitudes and high levels of environmental locus of control with the students. The creation of a garden and the act of gardening can enable students to learn about the environment and gain first-hand experience of ecological processes (Aguilar, Waliczek, & Zajicek, 2008), whilst engaging students in authentic science, technology, and scientific numeracy. Increase the complexity of the scenario by considering aspects such as soil ph levels, the mineral and trace element requirements of various crops, water management, and composting, and the ST & M components are boosted enormously.

IMPLICATIONS

This paper has essentially been an exploration of what the E in STEM could signify, if not "engineering". It seeks to view the many variations of E as having intrinsic meaning and giving authentic purpose to STEM education. Is it that Ecology/environment gives meaning to STEM education or is it that STEM education provides an epistemological framework to address environmental issues? Integrated STEM education can provide a meaningful place for "Environmental considerations" in the curriculum - not being relegated to the end of term or "clean-up" day, and so help students to interrogate problems thoroughly and to identify and propose possible solutions, empowering them to move from eco-*worriers* to eco-*warriors*.

Whether the E in STEM is considered as enquiry, ethics, environment or engineering, the need for teacher support (professional development and readily accessible resources) to incorporate this dimension into their approach to STEM education is consistently evident. In regards to professional development, teachers should be encouraged to reflect on what concepts can be learned or reinforced through a specific activity or project; what concepts and skills students are actually learning, and which aspects of the activity are most effective in this learning; and to consider how to transfer their learning to their classroom, and whether there might be opportunities to connect and reinforce learning from other content areas (Custer & Daugherty, 2009). There are also significant implications for initial teacher education programs – how can STEM education be accommodated in an authentic and robust manner when subject areas are taught as separate entities? There is an opportunity to reconceptualise initial teacher education courses so that they better reflect the connected nature of integrated STEM education, and provide scope for The Arts and English to become significant adjuncts in the pursuit of STEM.

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