Visions for Sustainability

*Vision without action is useless.
But action without vision
is directionless and feeble.
Vision is absolutely necessary
to guide and motivate.
(Donella Meadows)*

*Interactions between different logical levels
produce phenomena unseen at either level.
(Gregory Bateson)*

No. 9

June 21, 2018 **21 giugno 2018**

Contents:

Visions for Sustainability, Volume 09
Published online, ISSN 2384-8677
http://www.ojs.unito.it/index.php/visions

Visions for Sustainability

Direttore Responsabile: Luca Biamonte
Proprietario: IRIS – Istituto Ricerche interdisciplinari sulla Sostenibilità
Editore: IRIS – Istituto Ricerche interdisciplinari sulla Sostenibilità ISSN: 2384-8677

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www.iris.sostenibilita.net

Visions for Sustainability is an indexed scientific journal published in open access by the Interdisciplinary Research Institute on Sustainability (IRIS). The journal promotes a debate on how the concept of sustainability can be addressed and applied in existing and foreseeable societies worldwide. Particular emphasis is placed on facilitating communication between researchers of different disciplines, supporting educational projects and examining the role of contemporary science in dealing with issues related to sustainability. Papers are welcome from researchers and scholars of natural, political, social and other sciences as well as philosophical and humanistic disciplines, and in particular from anyone wishing to make a contribution which combines multiple viewpoints. The aim is to host as wide a range as possible of multidisciplinary, interdisciplinary and transdisciplinary perspectives on sustainability. Discussions or comments on articles which have previously appeared in the journal are also welcome. All submissions will be refereed before publication.

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VISIONS EDITORIAL DOI: 10.13135/2384-8677/2766

Opening Visions for Science Education Futures

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ISSN 2384-8677 **DOI:** http://dx.doi.org/10.13135/2384-8677/2766
Published online: June 08, 2018
Citation: Colucci-Gray, L., Camino, E., Dodman, M., (2018). Science Education Futures. *Visions for Sustainability,* 9: 03-09.

Competing Interests: The authors have declared that no competing interests exist.
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Perspective*: Educational visions*
Fields*: Earth life support systems, Human, social and natural sciences*
Issues*: Science education*

In the current knowledge-economy era, governed by evidence-driven decisions, benchmarking and targets, together with the possibility of large-scale monitoring through the availability of Big Data, important and critical questions arise about the nature and production of scientific knowledge. Who is involved in setting the criteria for its validation, in what contexts and for what purposes? Scientific debate progresses through the accumulation of evidence and logical argumentation, but at the same time through justifications, which carry biases, assumptions and views of the world which are often left undisclosed. Such is the argument put forward by Isabelle Stengers in a book only recently published in English. As a philosopher, she argues, her task is not only that of dealing with and describing the 'probable', that is, what may be reasonably accounted for in the domain of scientific research and praxis, but also 'to activate the possible' (Stengers, 2017), that is, to think situations by taking account of the vast and broad sphere of the 'unknowns'.

As Stengers demonstrates, the linear approach to knowledge production, from the validation of direct links between variables to the commissioning of research directed towards products and outcomes, is founded upon two central assumptions. Firstly, a linear concept of time, whereby the image of the ticking clock, the urgency and speed of knowledge production is linked to the idea that all people on the Planet have a common history or a common future. However, that is certainly not the case in an increasingly unequal and inequitable society. Secondly, the presumed objectivity of a scientific statement automatically provides a certain immunity, for 'objectivity' may be a proxy for 'acceptability', 'safety' or even 'desirability' of particular research and enterprise activities.

From a knowledge-economy perspective, the world can be approached from afar as a place for interventions introduced as if purporting to provide generalized benefit. These are the basis of the university-industry partnerships: the offer of secure grounds which will be validated and defended in the name of science. In contrast, the lives of people on the ground are far more complex, shaped by structures and history, and enacted through a myriad of subjective and contextualized experiences. In this space there is no single future but many, possible futures which may be desired, feared or even dreamt of. This awareness runs counter to the expectation of 'knowledge speaking truth to power'; rather, it calls for wider conceptions of inquiry, to include posing and wrestling with questions which may well not be directly related to a specific focus, or which may not be wholly answerable, either now or later. So we ask: what is the role of education, and science education in particular, vis à vis ideas of time and the future?

This special issue of *Visions for Sustainability* brings together a number of international contributors who all attended the 12th European Science Education Research Association Conference held at Dublin City University in August 2017. The title of the conference, "Research, practice and collaboration in science education" aimed at stimulating educational researchers to look beyond traditional contexts for science education research and practice, from formal to non-formal and informal agencies, designed and circumstantial learning opportunities, and to expand horizons for science education. Here we offer a selection of papers which explicitly deal with visions for the future. Our desire is to engage in debate about questions concerning the futures of the many populations, human and non-human, inhabiting the Earth, and our ability as human beings to think creatively about the future so as to encourage more sustainable points of view, approaches and trajectories.

Accelerating transformations…

Humanity's current perceived global reality is largely described and measured through the eyes of science. Science is a highly variegated field that has in recent decades acquired an increasing ability to measure a vast number of phenomena and processes, in particular thanks to powerful computing machines. There are now essentially incontrovertible data on the human trespassing of the biophysical boundaries of the Planet, the growth and spread of critical environmental conditions (reduction of soil available for farming; pollution of ocean water and freshwater systems; impoverished air quality in urban settings) and the hazardous transformations many ecosystems are undergoing. In 2007 the number of people living in cities went past that of those who live in rural areas, and the percentage of urban dwellers is continuing to rise. Data for 2018 (World Bank Group, 2018) put the figure at 54% and the forecast is that this will reach 70% by 2050 (UNESCO, 2016). As a result, an ever-greater number of children will be born and grow up in cities, thereby risking having little or no contact with Nature. Within a very short time-span, we have seen the expansion of information technology networks, an ever more tightly-knit web of communication which is now covering the entire Planet. Such digital networks both connect and alter the physical and mental activities of a vast part of humanity.

Environmental transformations, urbanization and digitalization are all phenomena related to what are commonly considered to be scientific 'progress' and technological 'innovation'. Both progress and innovation are signifiers which express ideas that occupy a central place in the collective imaginary. These words have arguably shaped and driven research and development projects, spurred on economic investments and propelled the use of energy and resources over the past two centuries, with irreversible transformations of the world as outcomes we have only recently begun to understand. Yet this imaginary is still evident and dominant today, whereby ideas of wellbeing and development continue to be largely associated with a need for economic growth. Techno-science, the building of knowledge aimed at generating immediate gains measurable in material terms, is seen as the engine of growth. This view of science has also long permeated the world of education. Children and young people are encouraged to opt for scientific study in the belief that the competences acquired will help them build successful careers and contribute to improving the state of the world and promoting the wellbeing of all.

… and reflections on the educational implications

Trusting techno-science as the vehicle for 'improving' the world we live in depends on the belief that scientific knowledge is in itself neutral and objective, and that it is up to people to make good or bad use of it. Such a belief ignores the way in which the production of scientific knowledge depends on many factors that are related to a range of questions. Which problems are being considered worthy of investigation and resolution? Who is able to or interested in financing the research? Which political powers decide whether to promote one strand of research over another? Who is in charge of monitoring the validity of the experiments conducted and the results that are being communicated? Who is responsible for ensuring that a regulatory framework exists to assess risks and uncertainties associated with the introduction of new technologies on the market?

The realization that research for military purposes receives larger funding than research serving civil or educational purposes, that research expenditures are higher for the larger multinational companies, that the negative impacts of presumed 'innovations' only come to light after often irreparable disasters, provides potent indicators of the influence of power relationships over the construction and application of knowledge. Hence, talking about science in an educational context requires new perspectives and new goals, in order to develop young people's desire both to access and to do scientific research, together with the reflective and reflexive abilities required for posing questions concerning the what, the why and the how of scientific knowledge, and addressing the need to define the roles and responsibilities of civil society in order to decide if and how to participate actively or to delegate this role to the 'experts'.

Overcoming growing alienation …

Given the relationship of interdependence between every human and non-human entity and the environment in which it exists, the radical change of scenarios we have observed both in the natural systems and human relationships, in particular since the middle of the twentieth century, poses crucial questions about the transformations occurring in children and young people. The apparent ease with which they learn new ways of acting, communicating, thinking and feeling emotions, simply by being immersed in the digital infosphere, raises questions for us about the consequences of losing other ways of being and doing the same things, typical of those who - until a few decades ago – were immersed in the biosphere.

This lack of contact with Nature, its inhabitants and rhythms, its variety and unpredictability, constitutes a sharp and highly significant discontinuity for a species like ours which has gradually developed, over a very long period of time, adaptation strategies which are extraordinarily diversified in order to respond to a variety of natural environments. The digital sphere, while enabling the transfer of an enormous amount of data and information, is still largely a structurally-uniform system when compared to the creativity and diversity expressed by the biosphere. Moreover, while natural processes are spontaneously evolutionary and auto-poietic, the digital sphere is controlled (and thus amenable to manipulation) by a handful of centers of power and it is dependent upon enormous flows of energy, in the absence of which it immediately switches off. Hence, it is extremely vulnerable to perturbations when compared to the resilience and adaptability of natural systems. Such dependence and vulnerability are inevitably passed on to those members of the infosphere who are unable to develop adequate independence and autonomy.

A science education which looks to the future must necessarily start from our present condition and work towards a culture which encompasses new digital resources while maintaining awareness that the roots of humanity, and thus its evolution and survival, are steeped in the web of life (Capra, 1997):

> *Digital literacy (scientific thinking, problem solving, computing abilities, coding) and programming of computers represent new languages with which we need to familiarize ourselves so that we do not become passive subjects of the digital sphere. However, this process needs to go hand in hand with a 'digital wisdom', that is, a responsible and conscious take on one's digital identity, an adequate monitoring of personal data, a right balance between one's life online and offline, so to avoid dependency on the web* (Patrignani, 2017).

Helping young people to exploit in a responsible way the opportunities offered by the infosphere and manage their relationships within the digital domain is a necessary part of the whole educational process. Today it is essential for science education to contribute to this, but also give particular attention to, and if necessary rebuild, those relationships with the natural environment that are increasingly being interrupted or lost. Central to this enterprise is the establishment of empathetic contact or 'affiliation', as expressed by Wilson's biophilia hypothesis – stemming from a spontaneous process of learning, developing from the moment of birth, involving all the senses through which we can receive input, and mediating the construction of the neuronal network and the motor system of every human being.

… and responses from science education research

In light of such a complex scenario, the responses from science education research are multiple and varied. Most commonly, prevailing dominant narratives are transferred across the different levels of education through curriculum choices, assessment and selection procedures and the preparation and support available to teachers (Ryder, 2015). From the perspective of sustainability education there are both opportunities and tensions involved in promoting inter and trans-disciplinary work, requiring pedagogical models which value dialogue across disciplines and partnerships between different stakeholders working across formal, non-formal and informal learning environments. The five papers included in this issue are drawn from a range of educational contexts across five countries. Each paper offers a particular perspective on the future and the opportunities offered by science education.

In the paper by Branchetti et al., "The I SEE project: An approach to futurize STEM education", the authors discuss an approach seeking to 'futurize' science education by introducing pedagogies designed to encourage pupils to 'imagine' the future through 'future-scaffolding skills' such as strategic thinking and planning, risk taking, thinking beyond the realm of possibilities, managing uncertainty, creative thinking, modelling and argumentation. In the context of secondary school education in Italy, still largely characterized by transmissive models of teaching and learning, the authors argue that science education should be seen as a means to encourage the participation and involvement of the pupils, to engage their points of view and ideas, develop their talents and build a community of learners – including the teachers and the researchers – working together on a common task. Within this perspective, a critical aspect concerns the ability to promote and maintain a focus on sustainability. What disciplines are involved and how can they feed into and out of each other? To what extent are conventional views and *expectations* of science and technology being discussed and/or challenged?

Within the context of higher education in Austria, Ilse Bartosch presents a study on "Learning about energy: A real-life approach challenging the present culture of science & engineering". The author discusses the opportunities involved in STEM education to engage with real-life, applied contexts, thus embracing *design* as a pedagogical disposition for addressing sustainability issues. She underlines the influence of political and economic structures and the need to call into question established mainstream ideas about STEM and to engage creatively with experiences able to bring forth new ways of thinking. Students are part of a community of practice developing dialogical and collaborative practices. Such community can be seen as having emotional, biological and ecological dimensions giving rise to an expansion of the realm of experience which entails a shift of perspective from being detached from the environment to being part of it (Zweers, 2000).

The two papers from Portugal by Monica Baptista and Pedro Reis, and Australia, by Paige et al., both illustrate the value of projects involving primary children taking action in relation to environmental issues and developing first hand knowledge of the world around them.

In "Let's save the bees! An environmental activism initiative in elementary school", Baptista and Reis place emphasis on the importance of becoming scientifically informed and scientifically literate through direct experience. Such a position is well-documented in the literature through the rise and development of citizen science approaches at different levels of education. The study points to the opportunities to develop citizens who are knowledgeable about their own environment and are thus able to contribute to research on conservation. We note here how citizen science approaches are now extremely diversified in the ways they promote engagement with scientific research as well as inter-generational learning in the community. The involvement of technology in such initiatives has been key to their expansion, by enabling large collection of data and extending to a variety of users. Both articles bring to mind the reflections expressed by Hannah Arendt in relation to the question of 'style'. According to Arendt (1994), the way in which we think and seek to understand the world is intertwined with the ways in which we allow our different *experiences* to surface. Hence, there are important considerations to be made about the ways in which science education interrogates the quality and processes of inclusion and participation of other people, views and modes of knowing and relating to the world.

In "Futures in Primary Science Education – connecting students to place and eco justice" Paige et al. address this point by recognizing that students' views on science and technology are embedded in a broader social context. Hence their visions of the future offer an insight both into their hopes and fears, and are likely to have important implications for them personally and for society. There is also compelling evidence from psychology that our expectations for the future not only affect how we see reality but also contributes to building reality itself. Hence views of the future and citizens' knowledge are not to be reduced solely to its scientific components. Such recognition opens the way to a greater array of approaches in science education which may engage students' cognitive as well as practical skills, as a way of giving meaning to one's aspirations and abilities in relation to desired futures, and not simply ones that are predicted or feared.

In "Science Education Futures: Science Education as if the Whole Earth Mattered", Donald Gray takes inspiration from eco-psychology in order to articulate a framework for a science education which seeks to facilitate a dialogue across different disciplinary fields in order to encourage an all-encompassing vision of sustainability. It is argued that the starting point for this process is primarily experiential and contextual: "*if the self is expanded to include the natural world, behavior leading to destruction of this world will be experienced as self-destruction*" (Roszak et al., 1995, p.12). Such a vision entails a change of perspective, one which both acknowledges the ecological boundaries of the biosphere (Rockström et al., 2009) and engages the creative and imaginative faculties of human beings. By extension, this leads to an education which goes beyond the acquisition of scientific knowledge and skills to develop a wide range of interrelated abilities: affective, empathetic, linguistic, physical and relational.

A science education seeking to promote community and the active participation of pupils, teachers and researchers can thus be interpreted 'ecologically' as a process which enable us to participate in the self-ordering of nature, instead of acting, and thereby interfering with it, as if from outside, as is the common point of view of the technologies of control. Yet, "such a mode of participation is not at all self-evident or 'natural' (Zweers, 2000, p.153). Rather, it is an existential process of self-realization in relation with others. We conclude here with the Heideggerian idea of being human as 'dwelling', that is, a form of attending to, cultivating and being in the environment:

> *Being-in-the-world means to live among things with which one is ordinarily and proximally familiar, to dwell in places that afford possibilities for being and involvement with others, to see one's self thrown and projected (a potentiality to be), and to stay in a place that one cultivates by making space for things, projects, and beings and safeguarding them or showing care toward them. These are the structural features of being-in-the-world in its average everydayness, that is, the conditions that are necessary for the enjoyment of being in the normal course of things* (French, 2015, p. 352).

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ORIGINAL PAPER DOI: 10.13135/2384-8677/2770

The I SEE project: An approach to *futurize* STEM education

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Abstract
In the world where young people feel that the future is no longer a promise but a threat, and science and technology are sources of fears and global problems, a challenging task for education is to support students in imagining a future for the world and for themselves. The aim of the EU-funded project "I SEE" is to create an approach in science education that addresses the problems posed by global unsustainability, the uncertainty of the future, social liquidity and the irrelevance of STEM education for young people. This way, we believe, STEM education can support young people in projecting themselves into the future as agents and active persons, citizens and professionals, and open their minds to future possibilities. In this paper we propose a teaching and learning approach for futurizing science education, and describe how that approach was used to develop the first I SEE module implemented in summer school in June 2017 with students from three countries. In sum, the I SEE teaching and learning approach consists of three stages and learning outcomes connected to each of them: encountering the focal issue; engaging with the interaction between science ideas and future dimensions, and synthesizing the ideas and putting them into practice. The middle stage of the model is the main part, involving future-oriented practices that turn knowledge into future- scaffolding skills. We describe four kinds of such future-oriented practices: a) activities to flesh out the future-oriented structure of scientific discourse, language and concepts; b) activities inspired by futures studies or by the working life and societal matters; c) exposure activities to enlarge the imagination about possible future STEM careers; and d) action competence activities. We conclude the paper by reflecting on our experiences of the implementation of the climate change module with upper secondary school students.

Key words: futures studies, STEM, upper secondary, action competence, climate change education, future-scaffolding skills

ISSN 2384-8677 **DOI:** http://dx.doi.org/10.13135/2384-8677/2770
Article history: Submitted: February 06, 2018. Accepted May 08, 2018
Published online: June 04, 2018
Citation: Branchetti, L., Cutler, M., Laherto, A., Levrini, O. Palmgren, E.K., Tasquier, G., Wilson, C. (2018). The I SEE project: An approach to *futurize* STEM education. *Visions for Sustainability,* 9: 10-26.

Competing Interests: The authors have declared that no competing interests exist.
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Perspective: *Educational visions*
Fields: *Earth Life Support Systems*
Issues: *STEM*

The future as an educational issue

The current unsustainability of systems vital to earth's functioning, both natural and social, has important implications for education, and has elicited responses from different fields including environmental education, education for sustainable development, post-normal science and futures studies, among others. The uncertainty of the future of our planet that this 'systemic global dysfunction' represents necessarily casts into question the grounds on which education is based, its values and purpose (Lotz-Sisitka, Wals, Kronlid, & McGarry, 2015). If the role of education is to prepare learners for their future, how can education prepare learners for an uncertain future? In light of the challenge to existence these global crises pose, the role of education becomes preparation for uncertainty itself. We synthesized this goal with the term "futurize", that is the counterpart of the notion of "de-futurizing", introduced the first time by Bergmann (1992) to describe a special feature of political discourses: to reduce people's anxiety and fears, the future is often deprived of some of its main features, like uncertainty, possibility, and impossibility to determine what will happen once and for all. On the contrary, several experts in futures studies have suggested that the unprecedented levels of uncertainty of the contemporary world highlight the need for preparing people to be surprised (e.g. Anderson, 2010; Rickards, Ison, Fünfgeld & Wiseman, 2014). As science educators, we set out on this collaboration to discover how science education could respond to the call of the future, developing a pedagogy that acknowledges the tension young learners feel for the future and addresses the personal, social and professional irrelevance of much of current science education practice. We asked ourselves, how can we "futurize" science education?

The future is by definition uncertain, and crises have threatened the future before. However, the nature of current global systemic dysfunction is so ubiquitous that young people feel not only that the future is no longer a promise but a threat, but also that science and technology, far from saving the world, are sources themselves of fears and global problems (Benasayag & Schmidt, 2006). Furthermore, contemporary society is marked by such accelerated, constant change and social fluidity that our sense of ontological security is compromised (Giddens, 1991). This liquidity (Bauman, 2001) is a source of anxiety and frenetic standstill (Rosa, 2013), which is further exacerbated by economic and social crises that limit young people's educational and professional possibilities. Indeed, the European Parliament Flash Eurobarometer showed that young people feel marginalized or excluded from economic and social life by these crises and that their country's education and training system is not well adapted to the world of work (EP EB395, 2014; Eurobarometer, 2015). In this environment, the daunting task for education is to support students in imagining a future for the world and for themselves. Science education, which must play a critical role in understanding and addressing the global crises, also has the task of overcoming the barrier of student lack of interest in and bias against STEM subjects (Tytler, 2014; EC/EACEA/Eurydice, 2012).

Science education does not currently address these issues fully or holistically, and this challenge is the premise for the I SEE project (**I**nclusive **S**TEM **E**ducation to **E**nhance the capacity to aspire and imagine future careers; https://iseeproject.eu): to create an approach in science education that addresses head-on the problems posed by global unsustainability, the uncertainty of the future, social liquidity and the irrelevance of STEM education for young people and their future. The scale and scope of the challenge requires deep innovation in pedagogies. It requires STEM education to stretch itself outside its traditional bounds and acknowledge students' fraught relationship with the future and with science and technology. Educators may take on new roles to help students to cope with their anxieties about the future of the world and their lives. Such a pedagogical approach will necessarily be reflexive about its purpose and values. It will involve facilitating students in gaining competence to understand the post-normal complexity of science (e.g. Turnpenny, 2012) and the complex systems that are highly significant for their futures. Thus it also becomes relevant for students in multiple ways: in their personal, societal and professional lives, now and in future (Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013). STEM education can then support young people in projecting themselves into the future as agents and active persons, citizens and professionals, and open their minds to possibilities, both for the world and for themselves.

After a contextualization of the project, this paper presents the approach we used to futurize STEM education. We firstly describe the design process we followed and, secondly, the result of our design: the structure and the learning outcomes of the module we designed and implemented in an international summer school. The model of an I SEE module is an outcome of the project and, here, it represents the original part of the paper whose goal is not to present the first empirical results but to position the I SEE design approach within the literature. Comments about our experience and our implementation will close the paper.

Futures Studies, STEM and the search for strategies to "futurize" STEM education

In order to futurize STEM education, relevant references for our project are the methods and concepts developed in the field of *Futures studies* (FS in the following). FS is an interdisciplinary field that was born in the 1950s after the World Wars, when groups of policymakers, conditioned by the threat of an atomic war, began to investigate the relation between present and future events. The main goal of this field is to help people to build future scenarios in order to suggest actions in the present, looking at several stakeholders. A turning point was, in 1968, the foundation of the Club of Rome, that pursued the aim to analyze changes in society and establish limits to growth in all fields (economy, industry, technology, etc.), so as to make human life sustainable (Meadows et al., 1972). In the last 60 years FS has become an important field of investigation and many techniques and approaches to the construction of future scenarios have been developed; some ideas and methods are inspired also by science and mathematics (Bell, 2003).

While in the last decades FS has expanded and involved more and more professionals and institutes, experts argue there is a worrying lack of attention to this issue in education (Bell, Preface to Hicks, 2006)[1]. Hicks (2006), talking about future as the missing dimension in education, proposed reflections on the topic and activities to foster FS attitudes at school. Among several possibilities, to face the problem from an educational point of view, we decided to rely on one of the perspectives proposed by Bell (2003), according to whom the futurists' main goal is to teach people that the future is an open horizon, a dimension of freedom that could be creatively explored through the development of skills. Visions of the future can be constructed and they can support possible ways of acting creatively and consciously in the present with one's eye on the horizon. In this general frame, STEM can play a role in conceptualizing the difference among different approaches to the construction of scenarios. For instance, a scientific approach allows us to clarify the meaning of the key concept of *foresight* that starts by imagining possible futures and, through *back-casting* activities, returns to the present to design possible actions that can foster the achievement of a desirable scenario, unlike forecasting, which is based on the elaboration of futures scenarios moving from the present to the future (Börjeson, Hoöjer, Dreborg, Ekvall & Finnveden, 2006). The main difference lies in the assumption of a deterministic or a complex relationship between present and future(s), moving only forward or also backward, from possible futures to the present. A crucial point is that there are several ways to deal with the future(s) that are grounded also in different scientific paradigms and imply different approaches to the construction and analysis of future scenarios (Levrini, Tasquier & Branchetti, under review). In our project we value in particular the distinction made between

[1] In STEM education an interesting approach grounded in FS is developed by Paige and Lloyd (2016).

possible, plausible and preferable futures and the concepts of *foresight* or *anticipation* (Voros, 2003), as we will show in section "Future-oriented practices" below. The intrinsic link with scientific concepts opens up a great opportunity for science educators to get inspiration from the field of FS in terms of key ideas and techniques to "play" with future scenarios in a productive way, but also to face this challenge stressing the important role played by science in formulating and approaching the problem of future(s).

The I SEE project

Purpose

The project is formed by a strategic partnership among three secondary schools, two universities, an environmental NGO, a teachers' association and a private foundation coming from four European countries (Italy, Finland, Iceland and the United Kingdom).

The goal of the project is to design innovative approaches and teaching modules to foster students' capacities to imagine the future and aspire to STEM careers. The goal is not only to develop professional skills but also to foster students' identities as capable persons and citizens in a global, fragile and changing world. To this end, we have recognized specific skills that should be developed through science education in school and out-of-school contexts. Particularly, the project aims to outline a STEM education approach centered on the concept of what we call *future-scaffolding skills*; that is, skills that render science learning relevant – personally, socially, professionally and scientifically – and enhance students' capacity to aspire, envisage themselves as agents of change, and push their imagination towards future careers in STEM. This concept is quite new and we started to develop it in a preliminary study that originated the I SEE project (Levrini et al., under review). On the basis of this preliminary study, future-scaffolding skills were defined so as to include, for example, *strategic thinking and planning, risk taking, thinking beyond the realm of possibilities, managing uncertainty, creative thinking, modelling and argumentation.*

In order to develop future-scaffolding skills within STEM education, the partnership develops innovative teaching-learning modules on cross-cutting fields, including climate change, artificial intelligence and quantum computing, which are likely to be relevant in students' futures, both at the personal, vocational and societal level (Stuckey et al., 2013). The partnership is composed of a multidisciplinary research group in STEM education and the activities are designed within collaborations between researchers and teachers in science (physics, chemistry, geology, computer science, etc.) and mathematics.

Modules build on the action competence approach in which students become more conscious of the decisions and actions they take (Jensen & Schnack, 1997). The approach has been used particularly to develop democratic education and environmental and sustainability education pedagogies but it has not yet been widely incorporated into science education (Mogensen & Schnack, 2010). One case of use of the action competence approach in science education, in which students were given the opportunity to identify a local issue and define what and how to investigate to address the issue, found that it afforded multiple modes of participation to students, so had the unexpected benefit of supporting diverse student abilities and interests, particularly with respect to culturally-related differences (Roth & Lee, 2004). This project will explore this potential further to see what action competence can contribute to creating science education that has inclusion and cultural diversity built-in into its design. Action competence will be moreover combined with "exposure", i.e. the notion that to be able to choose an alternative future and become an agent of it, an individual has to be exposed to it (Elder & Luscher, 1995).

Outputs

Operationally, the I SEE project produces five outputs that are briefly introduced in the following.

(1) *The I SEE start-up module* is a set of materials and a manual for teachers and students in upper secondary school (ages 16-19) for implementing an innovative teaching-learning sequence in the classroom and in out-of-school contexts. This

first teaching module, developed in close collaboration by all partners, dealt with the topic of climate change. The module consisted of a unified set of activities aimed at developing students' conceptual and epistemological knowledge and skills, future-scaffolding skills, and action competence and agency. Together these activities formed an intensive, week-long program of student group work, exercises, plenary lectures, a panel discussion and students' presentations. The module was implemented in an international summer school in June 2017 in Bologna, Italy, with a culturally diverse group of 24 Finnish, Icelandic and Italian upper secondary school students and their teachers.

(2) *The three implemented I SEE modules* follow the same aims, target group, structure and approaches as the first start-up module. The modules are based on the start-up module format and the results and experiences gained from its implementation. The three I SEE modules cover three cross-cutting and contemporary fields: climate change and carbon sequestration, artificial intelligence, and quantum computing and the development of ICT. The duration of the modules when implemented is 10-20 hours, just as for the start-up module. The modules contain lesson plans and materials for teachers' use as well as materials for students' guided and autonomous work. Instructions and tools for student evaluation are provided too. The final form of the three I SEE modules are refined through cross implementations and feedback in upper secondary schools in Finland, Iceland and Italy.

(3) *The I SEE module guide* provides a model and instructions for developing further I SEE modules. The guide is composed of a collection of design principles, commented examples and recommendations for implementations. Principles, examples and recommendations will characterize a module which is recognizable as an I SEE module. The guide is targeted both at teachers and researchers in science, technology and mathematics education. The guide has a function of being a dissemination tool because it is set up as an instrument specifically targeted at teachers and educators that is able to trace back to the realized project, the results of the implementation and the materials produced.

(4) *Case studies* aim to evaluate the most ambitious part of project: the potential of the I SEE modules to enhance students' capacity to aspire to and to imagine their future through inclusive activities in science education. In order to evaluate such a potential some studies on focal students or on focal collective dynamics will be carried out. The set of case studies will be developed to highlight:

- if and how the module impacts: i) students' imagination toward the future and ii) students' imagination about STEM careers;
- the progressive development of new STEM skills;
- the level and quality of inclusiveness created among students with different cultural backgrounds;
- the conditions that foster or hinder the effectiveness of the I SEE modules.

The case studies will be carried out through the analysis of both quantitative and qualitative data. Instruments and data sources include questionnaires, individual interviews, collective discussions, tutorials, audio/video records, specific grids and board diaries for observations. The specific tools for data collection will be chosen and designed to cover both individual development and collective dynamics. Data was collected during the implementation of the start-up module in 2017, and in 2018 more data will be collected when implementing the three modules. The analysis of the case studies translates into finding a way to not only explain what happens in the implementation of an I SEE module, but also what conditions are needed to overcome obstacles and maximize the probabilities of repeating successful experiences in different contexts.

(5) *Recommendations for crossing the barriers between schools and society* will be targeted at educational institutions (schools, science centres, educational centres, universities, research institutions, companies with an educational division) that are committed to addressing the skill-gap problem (EC/EACEA/Eurydice, 2012) by designing and offering stages and/or school-job market

collaborative experiences. The recommendations will be the result of a meta-analysis of the implementations carried out during the project and will be prepared in order to contribute to:
(i) making science teaching relevant from a scientific, professional, social and personal point of view and effective for supporting students to "see" their future and to take accountability for it;
(ii) enhancing the capacity of schools, universities, educational centres, NGOs and entrepreneurs to create local, regional and national forms of collaboration aimed at: (i) influencing the way science is taught in schools, (ii) fostering students' capacity to aspire and to imagine their future, and (iii) attracting, orienting and preparing students for future STEM careers, adhering to the values embedded in the EU's concept of Responsible Research and Innovation (European Commission, 2012).

Methodology

The project employs a comprehensive, holistic approach to address the complex issues in question. Improving science teaching is a wide and multifaceted process that has to take into account multiple dimensions: the disciplinary and epistemological ones, but also the identity, societal and vocational dimensions. Instead of a reductionist approach aimed at addressing one dimension at a time, we searched for a comprehensive central idea that could orient the production of multidimensional modules. It is the key-idea of future-scaffolding skills per se that is expected to enable science education to pursue a multi-dimensional goal: making science teaching relevant from a scientific, professional, social and personal point of view and effective for supporting diverse groups of students to imagine their futures and to exercise their agency.

As a methodological framework the I SEE project uses design-based research (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003; Plomp & Nieveen, 2013), involving an iterative process of designing, testing, and revising the modules, according to back and forth dynamics between theoretical hypotheses and empirical results. This process informs the methodology of the modules' production such that it will not follow a linear process (preparation, implementation and evaluation) but a back and forth, multiple round, dynamic process of reflection, revision and refinement. Unlike action-research, the design-based research methodology has an explicit theoretical orientation (Cobb et al., 2003; diSessa & Cobb, 2004) that enriches the goal to design and realize good practices with the purpose of explaining why a classroom practice is more or less successful. For this purpose, specific data are collected during the implementations and are analyzed through qualitative methods that include researchers' triangulation, practice reflexivity, as well as member-checking (with all the participants of the study, that is teachers, students, researchers) (Anfara, Brown & Mangione, 2002). These methods are particularly suitable to highlight not only what happens in a specific teaching/learning experience but also to provide an interpretation of why, when and how it happened (Plomp & Nieveen, 2013). The theoretical orientation of the design-based methods aims to maximize the materials' transferability in different contexts. Case studies will provide criteria to distinguish, in the complexity of a classroom environment, what is relevant from what can be considered negligible details.

The I SEE teaching and learning approach

Structural reference: A model for Socio-Scientific Issues

Our approach to futurize STEM education aims to incorporate future thinking to the societal, vocational and personal relevance of science, as well as its conceptual and epistemological value. The importance of exploiting the societal relevance of scientific contents in science teaching is, within STEM education, strongly stressed by the research on socio-scientific issues (SSI) and the teaching and learning approaches based on it. The I SEE approach draws from the ideas and structure of a recent conceptualization of the SSI approach by Sadler, Foulk and Friedrichsen (2017) (cfr. Figure 1).

Here we first present the key ideas of that model, and then introduce our model for futurizing science education.
First of all, the SSI approach is characterized by the choice of topics, socio-scientific issues that scholars think should be introduced and addressed in science teaching. SSIs are defined as controversial, ill-structured problems for which there is not a univocal, correct answer, and solutions are uncertain and complex. At a minimum, they have to incorporate two main elements: substantive connections to science ideas and principles, and social significance (Sadler, 2009). Examples of SSI include genetic engineering, climate change, animal testing for medical purposes, oil drilling in national parks, and "fat taxes" on unhealthy foods.
Secondly, the approach proposed by Sadler et al. (2017) to SSI defines the main lines of the teaching and learning model (SSI-TL model) in terms of the phases along which students are guided to work with the SSI. The SSI-TL model includes three phases (cfr. Figure 1): encountering the focal issue; engaging with science ideas, science practices and socio-scientific reasoning practices; and synthesizing key ideas and practices (Sadler et al., 2017). Throughout the teaching/learning process, students are encouraged to progressively develop their own positions on the SSI. To achieve this goal, they are guided to develop scientific knowledge as well as to consider social, political, economic, ethical, and moral aspects of the problem (Sadler, 2009). They should have opportunities to reflect on and refine their own beliefs and perspectives.
Empirical results have shown that SSI are effective contexts for the development of knowledge and processes contributing to scientific literacy, including evidence-based argumentation, consensus building, moral reasoning, and understanding and application of science content knowledge (Sadler, 2009; Zeidler & Sadler, 2011).

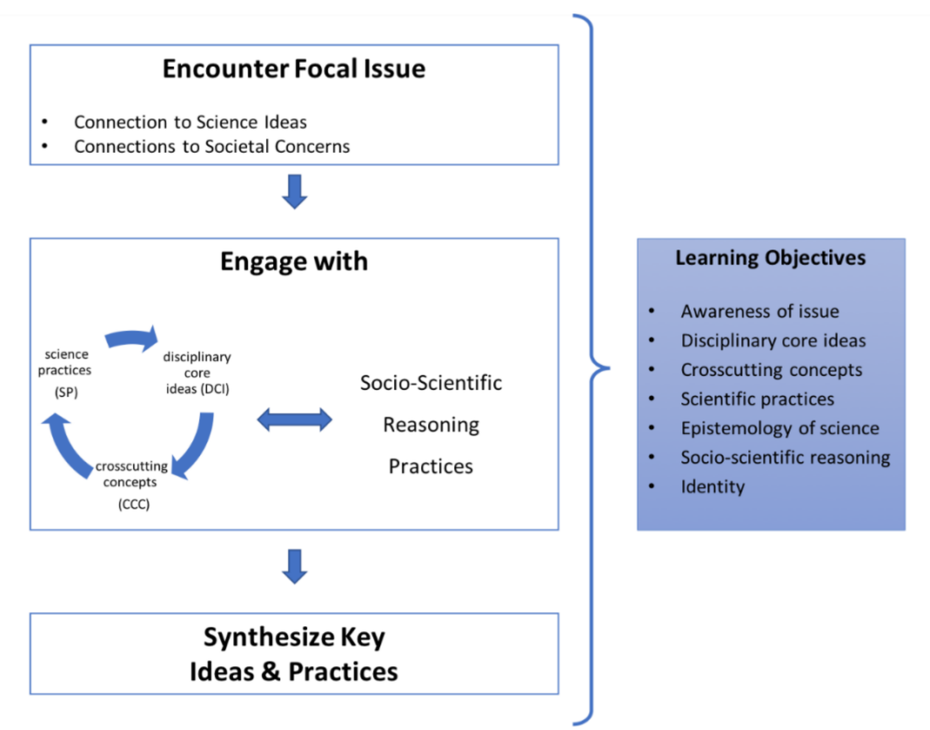

Figure 1. Graphic representation of the SSI Teaching and Learning model (Sadler et al., 2017)

The I SEE model to futurize STEM education

The I SEE model suggested here takes its point of departure from the SSI-TL model. Inspired by the SSI-TL model, our approach also suggests integrating science contents and their social relevance in STEM education. Moreover, our approach is also characterized by the choice of special topics and by a multiple phase teaching-learning model. Thereby, like in the SSI-TL model, the I SEE teaching model includes three main phases and identification of possible learning outcomes. The three main phases are (cfr. Figure 2):

1. encountering the focal issue;
2. engaging with the interaction between science ideas and future (main body of the module)
3. synthesizing the ideas and putting them into practice.

As far as the choice of topics is concerned, in our model focal scientific issues have to be *future-relevant*. This is distinct from the SSI-TL model in that topics not only include scientific contents and scientific practices (reasoning, arguing, explaining, etc.) but also are likely to be significant in students' future. They may, for example, represent a societal challenge or prospect that is controversial because of its implications for future societies, the environment, or working life. Such topics may be so-called *wicked problems* (Head, 2014; Turnpenny, 2012), which are not likely to be solved in the near future because of their complexity, or involve rapidly evolving technologies with great expectations. Examples of future-relevant STEM topics include climate change, artificial intelligence, nanoscience and nanomaterials, big data, and quantum computing. After encountering the focal issue, teaching activities are carried out to enable students to develop scientific and transversal future-scaffolding skills which allow them to engage with the future implications of the issue.

Despite the structural symmetry between the SSI-TL model and the I SEE model, there certainly are differences in the contents. Besides the distinctive focus on future in the choice of topics and of the activities, the I SEE model is independent of the U.S. curricula which are the main reference for SSI-TL model, as the emphasis on disciplinary core ideas, cross-cutting concepts, and scientific practices shows (Figure 1).

In the following sections we present each of the elements of the I SEE model (Figure 2) by discussing their essential features. We illustrate the ideas and discuss how they were operationalized when implementing the I SEE start-up module in the summer school in Bologna in June 2017.

Encountering the focal issue

The module begins with students encountering the focal issues (the upper block in Figure 2). This first experience aims to develop a preliminary level of awareness of the ways in which conceptual and epistemological scientific knowledge, the specific language, the methodological and the pedagogical approaches will interweave in the module. At this point, students are also introduced to social issues and problematic aspects of the topic. The focal issues are scrutinized in the context of post-normal science, recognizing the scientific uncertainties and the variety of stakeholders, interests and expertise influencing the problem, knowledge-making and decision processes (cf. Head, 2014; Turnpenny, 2012). Particularly, in the I SEE approach, the focal issues are characterized by the connections to STEM and future.

In the first start-up module implemented during the summer school of the project, two plenary lectures by Carlo Cacciamani (climatologist) and Peter Bishop (futurist) were expected to enable the students to build a global picture of, respectively, climate change and futures studies and begin to see the interconnection between science and future.

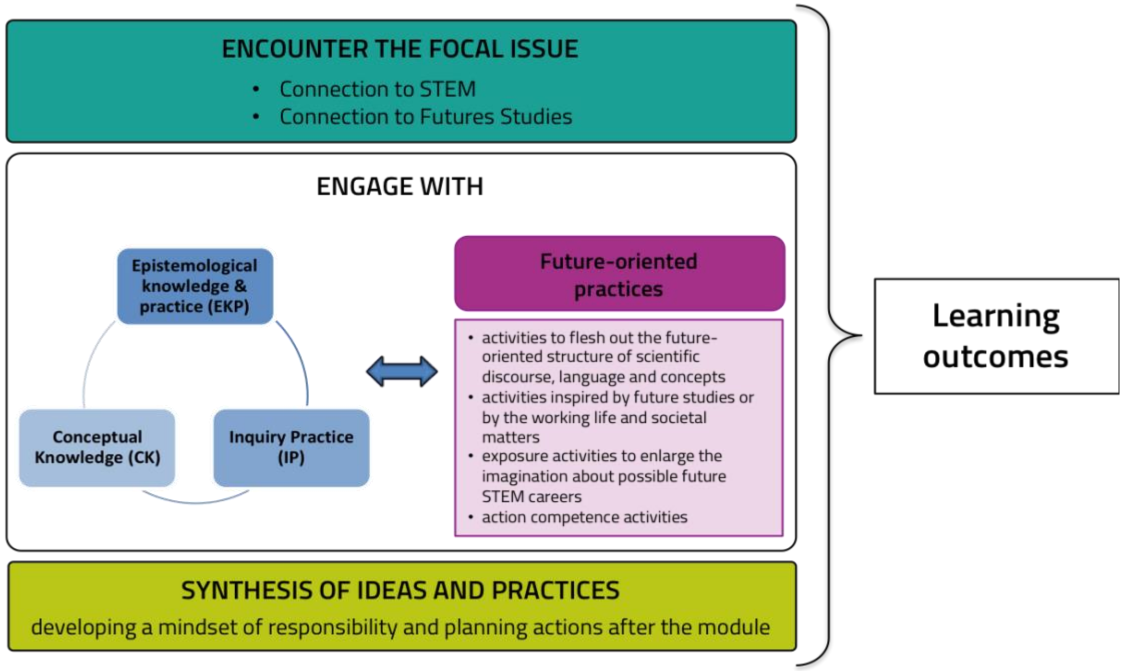

Figure 2. Main structure for I SEE model inspired by the SSI-TL model

In his lecture, Prof. Cacciamani stressed the implications of climate change and its societal dimension. In particular, he pointed out the main bodies of evidence that lead scientists to argue that we are facing significant changes in climate. The crucial point of the lecture was to give a big, complex picture from a multi-dimensional perspective and to introduce some fundamental ideas (like the notions of climate systems and feedback, the notion of scenario and IPCC graphs, the concepts of mitigation and adaptation, etc.) on which the conceptual and epistemological inquiry-oriented activities of the second phase are developed. Symmetrically, Prof. Bishop introduced fundamental concepts on which the future-oriented activities of the second phase are developed, in particular the distinction among possible, plausible and preferable futures (Voros, 2003) and the concept of *foresight* or *anticipation* that, unlike forecasting (which goes from the present to the future), starts by imagining possible futures and, through *back-casting* activities, returns to the present in order to design possible actions that can foster the achievement of a desirable scenario.

Engaging with the interaction between science ideas and future

The central block in Figure 2 presents the elements of the topic that students engage with in the module. The first part of the central block is the circle that links, in a circular dynamic, the three dimensions of science that are expected to give students a sense of disciplinary authenticity (Kapon, Laherto, Levrini, accepted):

i) *conceptual knowledge (CK)* – this dimension refers to the disciplinary content knowledge. CK is dealt with in the module according to the principles of educational reconstruction (Duit, 2007) implying that scientific contents are reconstructed for education through the analysis of scientific content structure, empirical research results on students' learning in the topic, as well as the main school-context constraints. In our case, special attention is also paid to the "critical details" needed to foster meaningful learning and consistence between local issues and the global rationale (Viennot, 2006);

ii) *epistemological knowledge & practice (EKP)* – this dimension refers to epistemic practice such as modelling, arguing, and explaining. This dimension has been proven to be fundamental for deep and meaningful learning (Chinn, 2018; Tasquier, Levrini & Dillon, 2016). Furthermore in many complex and future-relevant topics (like in the case of climate change) students have to be guided to grasp the shift in the epistemological paradigm (from the deterministic paradigm to the perspective of complex systems);
iii) *inquiry practice (IP)* – refers to inquiry skills such as posing questions, formulating hypotheses, designing inquiry, triggering peer-to-peer interaction, recognizing modelling as a process of isolating a particular phenomenon, and moving from models to experiments and vice versa.

In the I SEE summer school, the circular dynamics among the three dimensions were implemented through lab activities where students were guided to develop and practice scientific, conceptual and epistemological, and inquiry skills. Such skills included: modelling phenomena, testing hypotheses, making predictions, observing, planning, interpreting graphs and executing controlled experiments and measurements, analyzing data, communicating findings to peer groups, and forming arguments on the basis of empirical findings from the research evidence base.

Since the topic of the first I SEE module was climate change, the epistemic and inquiry skills were developed on the specific concepts and models that concern the greenhouse effect and that are needed to grasp its global implications. The following topics were covered: the process of interaction between matter and radiation; the energy balance mechanism explaining why changes in the composition of the atmosphere can cause changes to the Earth's surface temperature; the concept of anthropogenic greenhouse gases and their relation to global warming; the concepts of positive feedback needed to explain phenomena (e.g. melting of glaciers); and the space and time scales of climate modelling. Climate modelling implies a systemic, global approach that includes a new way of looking at possible future scenarios, from predictive to probabilistic and projective models. Active learning was stimulated through student-centered activities, group work, and the teacher's higher order type questions. Students were encouraged to consider their own role and significance to the phenomena, for example, in the activity where they calculated their own carbon footprints.

Future-oriented practices

The second part of the central block (Figure 2) concerns future-oriented practices.

The I SEE approach foresees at least four types of future-oriented practices that can be developed with the aim of turning knowledge into future-scaffolding skills and competences:

a) activities to flesh out the future-oriented structure of scientific discourse, language and concepts;
b) activities inspired by future studies or by the working life and societal matters;
c) exposure activities to enlarge the imagination about possible future STEM careers;
d) action competence activities.

The first type of activities (a) aims to highlight that the concept of future is intrinsic to the nature of science, being the goal of prediction at the core of scientific modelling. Even if it is very seldom emphasized in science teaching, future is absorbed and integrated into the epistemological structure of science and is closely linked to its models of causal explanation, which are gradually elaborated to make predictions (Barelli, 2017). Science has developed many temporal patterns and epistemological models of causal explanation, from linear up to probabilistic models elaborated within modern science (like for example the science of complex systems which are applicable to many STEM topics from the analysis of ecosystems, climatology and geophysics, to computer science). These fields can offer powerful concepts (like *space of possibilities, future scenarios, projection instead of deterministic prediction, uncertainty, sensitive dependence to initial condition, feedback and* *circular causality*) suitable for problematizing linear causality and that can be developed into skills for thinking and talking about the future (Barelli, Branchetti, Tasquier, Albertazzi & Levrini, 2018; Levrini et al., under review; Tasquier, Branchetti & Levrini, under review).

On the basis of these remarks, the I SEE approach includes the design of activities aimed to: i) flesh out the temporal patterns and the structures of causal reasoning elaborated within science; ii) turn basic concepts - like linear or circular causality, feedback, sensitive dependence on initial conditions - into skills to analyze texts where topics based on complex dynamics are described. In the case of the first I SEE module, in the summer school after an interactive lecture aimed to introduce the perspective of complexity and its basic concepts, the students were directly involved in the analysis of a text on biofuel. More specifically, they were asked both to point out the causal reasoning behind the argumentation, and the positive and negative feedback loops.

In our language, this type of activity is expected to develop "future-scaffolding scientific skills", that is skills that come from science and can support students to talk and to think about the future.

The second type of activities (b) are built to infuse science education with the perspective of Futures Studies (FS), which is a complex interdisciplinary field developed by a community of sociologists, philosophers, as well as academics in STEM, economics, politics and the entrepreneurial realm.

Drawing upon the science of complex systems, FS problematize the common belief that futures are only matters of making predictions, and stress them as ways to open up possibilities and solutions. One of the main ideas is that, since accurate predictions are not necessary and not possible (due to scientific constraints), it is socially, economically and personally important to develop skills for thinking about possibilities and ways to realize possible futures rather than predicting exactly what will happen. In this possibility perspective, the existence of a plurality of futures is crucial, and 'scenario' becomes a keyword. Scenario-building (or planning) is a tool for generating narratives about multiple futures, and has been used extensively in FS especially in the contexts of wicked problems such as climate change (Rickards et al., 2014).

Within the I SEE approach, we found particularly illuminating the distinction, made within FS, among possible, plausible, probable and preferable futures. The relationship among them is often represented with a 'futures cone' (Hancock & Bezold, 1994), elaborated by Voros (2003) (Figure 3).

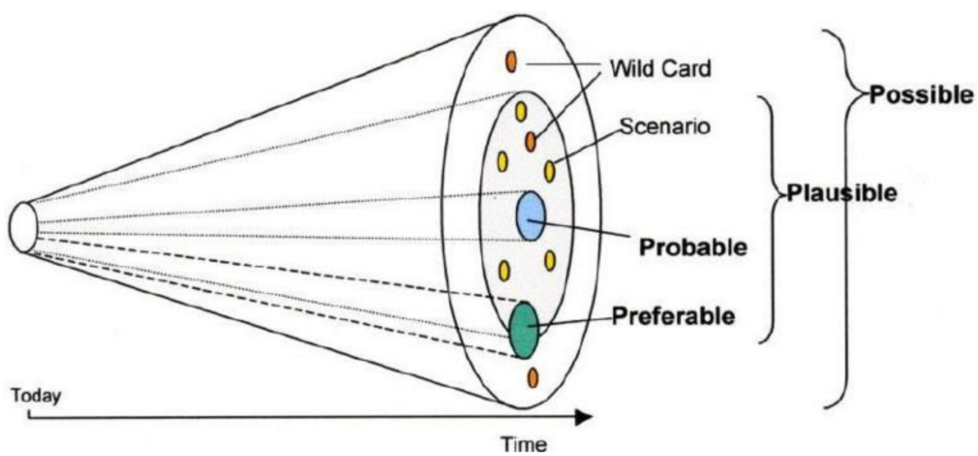

Figure 3. The futures cone by Voros (http://www.nesta.org.uk/blog/accuracy-and-ambition-why-do-we-try-predict-future) [Image credit: Ironing drone by Max Cougar Oswald & Nihir on the Noun Project via Creative Commons]

The I SEE approach gives a special emphasis to preferable (also called desirable) scenarios (Figure 3). While plausible and probable futures are largely concerned with informational or cognitive knowledge, preferable (or desirable) scenarios are concerned with people's wishes or aspirations. In other words, these futures are largely emotional and ethical rather than cognitive, and are thus more subjective than the other future types. To think in terms of preferable futures, students have to cope with their current values and desires, their identities, their competences and their cultural points of view, and to imagine a preferred scenario in which they would like to live. Within the summer school, the cone was introduced by Prof. Bishop in his plenary lecture and, during the core part of module, students were engaged in discussion and comparison of possible future scenarios for an imaginary city that depended on the different possible decisions of the city's mayor. The different possible decisions, as commonly happens, were not values-neutral and the students had to consider the complexity of the current situation where technological, social, and cultural progress have to cope with the big issue of climate change. The students were not only requested to point out the values that underpin the different models of development and different future scenarios, but also to discuss in groups about their "ideal city to live in 2030."

The exposure activities (c) are part of the approach with the aim of enlarging students' imagination about possible future STEM careers. Particularly, activities of this type are based on the idea that an individual, in order to be able to choose among alternative futures, has to be exposed to the sense of them. The exposure activities make STEM careers more attractive because, we conjecture, they will not only help students directly experience the acquisition of authentic professional competences but they will also support students to cope rationally, emotionally, creatively and responsively with their future. In the summer school the exposure activities consisted of a panel discussion with experts from various climate-related fields. The experts discussed their career paths, the choices they have made, their professional ambitions and other driving factors. After the panel discussion they stayed available for personal communication with the students.

Later in the summer school, the students carried out a final project in part of which they had to imagine themselves in a professional role in the future, which was meant to reinforce the imagining they had already begun in the exposure panel.

Finally, **action competence activities (d)** are thought to trigger awareness of the plurality of perspectives at stake in decision-making processes, and so support students in expanding their ethical consideration as they go forward making intentional decisions and taking deliberate actions. The action competence approach can be practiced in education by presenting students with the task to collectively decide on an issue, determine how to investigate it and address it. This affords multiple modes of participation to students and supports diverse student abilities and interests, particularly with respect to culturally-related differences. Such activities have the feature of activating a back-and-forth dynamic between present and future.

Action competence activities in the summer school included the final project described below in the following section.

Types b, c and d activities are expected to develop what we called future-scaffolding transversal skills, that is skills that do not have a scientific origin but that can be developed also within science classes with the aim of enabling students to project themselves into the future.

Synthesis of Ideas and Practices

The final phase of the module calls for students to synthesize ideas and practices they have encountered and engaged with throughout the whole pathway. After the experience of the previous activities, the students are ready for the more creative part of the module. First, working individually, they identify issues relevant to the topic and of interest to them. They then are grouped by common interests and guided through a process including analysis, evaluation, and planning around the issue. In this activity they take responsibility for their future and plan an action able to realize their desirable future. This is an important moment of synthesis and of cross-checking of values, since they have to choose what they can negotiate and what is not possible to be negotiated. This is also a moment in which, knowledge and practices acquired along the whole sequence begin to transform into skills in action. Students are challenged to find their active role in the complex interaction between individuals and nature.

In particular, the students in the summer school were required to project themselves into a desirable future in 2030. They were asked to plan and tell their success story – in the form of back-casting activity during their final presentations -- of how they managed to solve a critical problem (in this case about climate change) by using a leverage point to change the system. They were required to work together by grouping themselves according to shared values. Each student took a role in the change they had chosen for themselves, and the groups presented to their peers their future scenarios as a narrative of the past from the perspective of the year 2030 "in character" in their imagined roles.

This part of the model is very demanding on students' imagination but also on their critical thinking and analytical skills. It serves as a challenging and empowering comprehensive activity as well as a springboard for other modules of other topics, or indeed many other kinds of learning activities that build on future imagination and systems thinking.

The synthesis of ideas is not only bound up to the end of the module but it is expected that the students, inspired by the I SEE experience, can continue developing a mindset of responsibility and planning actions after the module.

Learning outcomes

The I SEE teaching and learning approach aims at action competence (Mogensen & Schnack, 2010) and transformative learning (Dirkx, Mezirow & Cranton 2006) rather than plain cognitive learning outcomes. Since the project's aims are to develop future-scaffolding skills and to foster students' personal, societal and vocational agency and identity, the primary outcomes strived for are competences and the ability to put those competences into action. Transformative learning typically aims to develop reflective and critical thinking, holistic and systemic understanding, and transferring that understanding into action (Dirkx et al., 2006; Sterling, 2010). In the I SEE approach the development of such competence and agency entails learning aims at three levels, corresponding to the types of activities presented above: conceptual and epistemological knowledge, future-scaffolding skills, and action competence. In the following, some learning outcomes are specified for each level in regard to the climate change module.

First, learning outcomes related to *conceptual and epistemological knowledge* involved that students learn to model the greenhouse effect as a scientific phenomenon. To achieve this understanding, students learn or revise the physical concepts of, for example, radiation, heat, temperature, and interaction between matter and electromagnetic radiation. Besides the conceptual knowledge, the students should learn scientific epistemology and lab working skills, such as testing hypotheses, making predictions, observing, planning, and executing controlled experiments, and communicating findings to peer groups.

Learning outcomes concerning *future-scaffolding skills* involved that students get acquainted with basic concepts of science of complex systems (e.g. sensitive dependence on initial conditions, circular causality, positive and negative feedback loops) and become familiar with one of the main tools of the science of complex systems, the simulation. Students learned that approaching science phenomena that involve citizenship issues (e.g. climate change) implies a change in the epistemological way of looking at the phenomena itself: they learn, for example, that climate is a complex system and that the interpretation of phenomena related to it implies new types of explanation, modelling and argumentation. They also learn that approaching and tackling the effects of climate change implies a change in the ways we live in everyday life and we, collectively, make decisions. They become also personally committed to outline a desirable scenario and/or to point out a desirable objective to be reached in the future. Learning outcomes concerning *action competence* and agency include the ability to critique and revise their own future visions in the light of new knowledge and perspectives. Students become able to define, map and analyze a climate change problem of their choice, and to articulate a strategy to achieve a desirable solution for the problem, based on its systemic context.

Our experience and future directions

In this paper we have proposed a teaching and learning approach for futurizing science education, and described how that approach was used to develop the first I SEE module implemented in a summer school in June 2017 with students from three countries. In sum, the I SEE teaching and learning approach consists of three stages and learning outcomes connected to each of them: encountering the focal issue; engaging with the interaction between science ideas and future dimensions, and synthesizing the ideas and putting them into practice. The middle stage of the model is the main part, involving future-oriented practices that turn knowledge into future-scaffolding skills. We have suggested and described four kind of such future-oriented practices: a) activities to flesh out the future-oriented structure of scientific discourse, language and concepts; b) activities inspired by future studies or by the working life and societal matters; c) exposure activities to enlarge the imagination about possible future STEM careers; and d) action competence activities.

We conclude the paper with some experiences from the first implementation of the I SEE module. During the implementation in the summer school, many data were gathered. The data collection aimed to evaluate the potential of the modules to enhance students' capacity to aspire and to imagine their future through inclusive activities in science education. To cover both individual development and collective dynamics, we used a variety of data sources (e.g. focus groups, individual interviews, questionnaires, audio/video-recording of several discussions and activities).

The students' reactions that emerged from the focus groups and the individual interviews during the summer school imply that the activities of the module had a positive impact on students' perceptions of the future and sense of agency, on the personal experience of cultural diversities as well as on the capability to imagine future careers. To understand how the module brought about these outcomes, we have started a detailed analysis of students' discourse in the audio-recordings. We have already recognized systematic shifts and reactions within their discourse, and perceived some new vocabulary that became part of their way of thinking about the future. The results of this analysis will provide means to connect the outcomes to the future-scaffolding skills which were taught in the module. According to the preliminary analysis, many students abandoned their fear-inducing deterministic future views and started to talk about future scenarios, referring to a variety of possible, probable, plausible and desirable futures. They also showed vocabulary pertaining to complex systems and reasoned in terms of circular causality. Such findings from the discourse analysis help us understand which future-scaffolding skills were learned during the module and how they may contribute to students' thinking. The next steps of the analysis will be to match against the whole corpus of data in a systematic way in order to investigate the relationship between reactions and shifts in personal perspectives and the triggering of some particular skills.

As an overall reflection, it must be noticed that the group of students cannot be considered as representative. Indeed, these students were already somewhat interested in STEM and/or in climate change, and therefore no sweeping generalizations can be made about the influence of the module on students in general. In the further stages of the project, the developed approaches will be tested with larger and more diverse groups of students. Another challenge will be to match the modules with the curricular constraints of different countries. This requires a careful analysis to grasp the essence of the module. After that, we will render the materials and the activities adaptable to different contexts and practicable also by teachers who did not participate in the project.

Preliminary results of the first module implementation led us to reflect on the design process of our first I SEE module on climate change and to flesh out the essence of our approach and the skeleton of our model. Indeed, the trials currently ongoing of the new modules on quantum computing, carbon sequestration and artificial intelligence retain the structure and elements of the I SEE module as presented in this paper. They are being carried out in upper secondary schools in Italy, Finland and Iceland and will give valuable insight as to what the impacts of the I SEE model on teaching approaches and learning outcomes in science classes are and thus how widely applicable the model could be for accomplishing its goal of preparing learners for the uncertain futures. Together with the data from the summer school, the data from these trials will aid us in answering the question we posed to ourselves, how can we futurize science education?

Acknowledgement

This article is an outcome of the I SEE project (www.iseeproject.eu). The project has been funded within the framework of the Erasmus+ Programme (Grant Agreement n°2016-1- IT02-KA201- 024373).

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ORIGINAL PAPER

DOI: 10.13135/2384-8677/2771

Learning about energy. A real-life approach challenging the present culture of science & engineering

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Abstract.
There is an increasing number of publications in various fields of research suggesting that a purely technocratic approach cannot mitigate the current environmental crisis caused by climate change. This goes hand in hand with the criticism expressed by science educators that classroom teaching on energy is mainly based on the conceptual knowledge perspective of science education, which is considered inappropriate for empowering young people to fight in the best interests of the biosphere. Based on the experiences gathered in the R&E project "SOLARbrunn – heading for a future with the sun" the paper highlights some facets of STEM education which seem to be indispensable for empowering young people to contribute to sustainable development. In an interdisciplinary research setting modelled upon Zeidler's conceptual framework for socio-scientific issues, students at a Secondary Technical and Vocational School in a small Austrian town worked out suggestions for converting a local kindergarten into a 'green building'. In the course of the project, the traditional view of engineering - constructing technological solutions based on the rigorous mathematical processing of data acquired by diligent measurement – was challenged. When dealing with real world cases where everyday routines are important for planning, implementing and adjusting technical systems, the limitations of the technocratic approach to sustainable development becomes evident. Sustainable development is less a question of enhanced technology; it is rather a question of improving socio-technical practices by means of interactive efforts on the part of various players.

Key words. sustainable development, situated learning, socio-scientific issues, culture of STEM, socio-technical systems, green building

ISSN 2384-8677 **DOI:** http://dx.doi.org/10.13135/2384-8677/2771
Article history: Submitted January 31, 2018. Accepted May 07, 2018
Published online: June 04, 2018
Citation: Bartosch, I. (2018). Learning about energy. A real-life approach challenging the present culture of science & engineering. *Visions for Sustainability,* 9: 27-40.

Competing Interests: The author has declared that no competing interests exist.
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Perspective: *Educational visions*

Fields: *Earth Life Support Systems, Economy and Technology*

Issues: *Energy*

Introduction

Energy is not only one of the most important concepts in science; it is also an issue of great economic and political significance in modern society. The supply of renewable energy and the efficient use of energy are seen as key steps towards finding solutions to the current environmental crises brought about by climate change. However, classroom teaching on energy is still mainly defined from a conceptual knowledge perspective of science education and does not pay attention to the complex and multi-faceted environmental and societal challenges that face us today. This is particularly due to the so-called "economic imperative" that dominates science education today (cf. Donovan, Mateos, Osborne, & Bisaccio, 2014). The justification of STEM education by the "economic imperative" is based on a number of macroeconomic studies which link the achievement of students in maths and science (e.g. PISA) with the growth of gross domestic product (GDP) (e.g. Hanushek & Woessmann, 2012). From this perspective, the primary goal of STEM education is to produce students who will pursue STEM careers and therefore help maintain continuous economic growth, enabling economies to compete effectively on the global market.

However, these ideas are misleading for various reasons:

(1) They ignore the fact that, in the long term, the impact of economic growth puts limits on biodiversity and has a negative effect on ecosystems, and therefore also limits the potential for future economic growth.

(2) They rather reinforce the status quo as technological solutions primarily concern the symptoms and not the causes of the problem.

(3) They delegate the solutions for environmental problems to experts, thus disempowering citizens.

(4) They fail to take account of the fact that both the environment and technology are social constructs and are thus inextricably linked up with economic resources and power.

Therefore the "economic imperative" of the STEM pipeline "falls short of empowering students to assess, preserve, and restore ecosystems in order to reduce ecological degradation and increase economic welfare" (Donovan et al., 2014, p.1).

Reducing the emission of greenhouse gases necessitates a substantial redirection of energy systems towards greater sustainability. For this purpose the European Union's Energy Strategy targets an increase in the share of renewable energy supplies to a level of at least 20% by 2020 (and 27% by 2030) and an increase in energy savings of 20% or more by 2020 (and 27% by 2030) compared with the business-as-usual scenario of energy consumption[1]. One important response would be to intensify research and innovation; another would be to translate these objectives into concrete decisions, investments and practices, not only at a national but also at a regional level. Sustainable development therefore compels engineers to reflect on the ecological, economic and social impacts of new technologies on today's and tomorrow's societies when constructing technological devices. However, sustainable development also compels citizens and politicians to actively participate in societal discussions and reach informed decisions, on a personal as well as on a political level, in order to initiate a transformation of our society into a more sustainable one. As sustainable development cannot be accomplished without questioning western lifestyle with its dominant patterns of production and consumption, the discussions about concretizing objectives, formulating priorities and developing strategies are highly controversial.

The literature highlights the fact that education and, in particular, a change in (young) people's awareness is of particular importance for achieving the ambitious goals of sustainable development. Participating in controversial discussions and decision-making processes in this context demands skills and abilities such as "acquisition and assessment of information, the capacity for communication and cooperation,

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https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2020-energy-strategy
https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

and foresighted planning in linked systems" (de Haan, 2006, p. 21). STEM approaches in the context of sustainable development must therefore not only contribute to students' personal intellectual knowledge but also to their ethical development. For this purpose a number of science educators (Hodson, 2003; Sakschewski, Eggert, Schneider & Bögeholz, 2014) have suggested "functionalizing" scientific literacy into an issue-based curriculum. In such a curriculum "social, economic, political, and ethical issues are taken into consideration and are closely linked to STEM learning. In this way, it is hoped we can empower young people and prepare them for socio-political action 'in the best interest of the biosphere'" (Hodson, 2003, p. 645).

This paper takes up these considerations and investigates how a teaching-for-sustainability approach can be integrated into the curriculum of a secondary technical and vocational school. It focuses on the sustainable supply and use of energy in a public building as about one third of the energy required by the European Union is used in the private and service sectors. Energy efficiency and renewable energy supplies as well as their economic viability play a decisive role in the education of future engineers. In addition, investigating energy use in a public building includes considerations of the health and everyday practices of the users. Furthermore, sustainable design is not only a configuration of technical structures in response to a situationally specific analysis of an environmental challenge in a more or less successful way. It is rather "a social expression of competing ecological values" (Guy & Moore, 2005, p. 9), a result of competing discourses, framed by dynamic social, technical and political contexts. Therefore, investigating the energy use in a public building and proposing measures for transforming it into a sustainable building demands an arena for meaningful discussion and critical reflection between the various stakeholders in order to figure out how their different interests affect the conceptualization of sustainable design. Thus, according to Guy and Moore (2005, p. 9), a sustainable building is not a result of best technological practise vis-à-vis accepted environmental standards; it is rather "an assembly of ideologies, calculations, dreams, political compromises and so on".

Theoretical Background

Teaching for Sustainability

Since the concept of Sustainable Development was introduced by the United Nations (1987) in the so-called Brundtland paper, there have been a number of world congresses for elaborating what measures can be taken on an individual as well as on a societal level for developing answers to and strategies for the world's environmental and social problems. Amongst these congresses, the Rio conference in 1992 highlighted the vital importance of education as achieving sustainable development requires a global change in mindsets, beliefs and behaviours. Despite all these efforts and although sustainable development is accepted as a normative framework for politics, the economy and education worldwide, the concept remains elusive and its implementation challenging. In this paper we will rely on the widely accepted three-pillar model, which suggests that sustainable development can be achieved by balancing economic development, social equity and environmental protection. Referring to the three-pillar model, sustainable engineering can be understood as design under ecological, economic and social constraints. Thus, teaching for sustainability must deal with impacts on ecology, economy and society on local, regional and global levels (de Haan, 2006).

Framing learning about energy as a Socio-scientific Issue (SSI)

The above-mentioned ideas suggest that orienting learning about energy towards Education for Sustainable Development[2]

2 The term Education for Sustainable Development is applied by the United Nations organizations, such as UNESCO https://en.unesco.org/themes/education-sustainable-development or UNECE (https://www.unece.org/env/esd.html), for describing the practice of teaching for sustainability. While the translation 'Bildung für Nachhhaltige Entwicklung' is also frequently used

requires an interdisciplinary context that is broader than the usual conceptual and technological approach. For this purpose science education research proposes framing teaching about energy as a socio-scientific issue (SSI). Although the domain of SSI is related to the science-technology-society (STS) movement, SSI remodels the STS approach by adding considerations about the ethical dimensions of science as well as the students' emotional development and their ethical/moral reasoning (Zeidler Sadler, Simmons & Howes, 2005, p. 360). While STS has been defined as a context for science education (Yager, 1996), the SSI approach is a pedagogical strategy which explicitly focusses on the empowerment of students by helping them to reflect "how science based issues and the decisions made are concerning them" (ibid.). Thus, considering how controversial scientific issues and dilemmas affect the intellectual growth of individuals in both personal and societal domains is the key concern of SSI education. SSI issues therefore have their basis in science; possible solutions, however, involve ecological, societal and ethical considerations (cf. Oulton, Dillon & Grace, 2004; Sadler, 2004; Sakschewski, Eggert, Schneider & Bögeholz, 2014). Related problems like energy storage technologies, the construction of off-shore wind power systems, a reduction in private traffic or the specific design of energy-efficient buildings are often ill-structured, their solutions multifaceted (cf. Sadler, 2009, p. 11). Because of the social significance of SSI, scientific data underdetermines strategies of resolution. Besides, these problems are not only complex challenges for science and engineering, they are also ethically and politically complex for individuals and different groups within society who have competing perspectives and priorities that generate both interest and controversy. For instance, the energy performance of energy-efficient buildings is not only determined by the technological components used in construction but also by the interplay of the specific devices installed (e.g. the heating and ventilation systems) and the way occupants become acquainted with and are supported in their use of such devices (cf. Rohracher, 2005, p. 208). Consequently, the real-world performance of clear-cut technological solutions designed by experts in the lab is highly dependent on contextual factors.

Although there is broad agreement within the science education community that the implementation of SSI is fundamental in today's science education classrooms, the implementation of SSI in STEM curriculums and everyday classroom practice faces some difficulties, especially in physics and engineering (Sakschewski et al., 2014, p. 2293). The reasons are manifold: disciplinary purity or rigour (Hodson, 2003, p. 660), the challenges of teaching the complex concept of energy (Driver & Millar, 1985), and the perception of physics and engineering as 'hard' science disciplines which exclude 'softer' socio scientific orientations (Zeidler, et al., 2005, p. 360). Yet, if we acknowledge the necessity of sustainable development, we need both groups: citizens who are able to discuss and critically judge energy-related decisions but also scientists and engineers who are able to include the socio scientific perspective in research and innovation. As SSIs support the development of reasoning skills and the appreciation of the merit of evidence in everyday decision making, opening STEM education to SSI is important in academic and vocational education alike.

In order to implement socio scientific issues in science education practice and research, Zeidler et al. (2005) have proposed a framework which links science education research with sociological, psychological and developmental factors. This framework can be thought of as entry points in a science curriculum which contributes "to a student's personal intellectual development and in turn, helps to influence teaching in science education to promote functional scientific literacy" (ibid. p. 361).

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by German-speaking educators, the equivalent term 'teaching for sustainability' will be utilized in the article as it is the current terminology in the English-speaking world.

The conceptual model of Zeidler et al. is based upon the analysis of a huge amount of science education research literature regarding SSI and it identifies four areas of pedagogical importance central to teaching SSI:
(1) nature of science issues
(2) classroom discourse issues
(3) cultural issues
(4) case-based issues.
Controversial socio-scientific issues provide an environment where students become engaged in discourse and reflection. Being exposed to or challenged by the arguments of others in classroom peer discussions provides a rich opportunity to analyse the quality of claims, warrants, evidence and assumptions among competing positions. Moreover, epistemological stances regarding the nature of science (NOS) influence how students evaluate scientific data. Therefore, explicit instruction in NOS and careful evaluation of evidence regarding SSI is of crucial importance as it helps students evaluate any kinds of claims, scientific or otherwise.
As 21st century science classrooms are highly pluralistic and sociologically diverse, students approach controversial issues from a variety of everyday experiences, worldviews and sets of values. Encouraging the expression of these diverse perspectives is an important feature of SSI learning environments as they require identifying and critically examining one's own interests and desires as well as the ability to understand another person's cultural context. The variety of cultural values, desires and interests opens rich opportunities for classroom argumentation and discourse. To make themselves open to various solutions to a problem, students have to have an understanding of their peers' worlds; they have to connect with them intellectually and emotionally. This supports empathy and ambiguity tolerance.

Situated Learning as a theoretical lens

When viewing learning about SSI through the theoretical lens of situated learning, the specific social and cultural environment of the learning process becomes significant. According to Lave and Wenger (1991) these environments, which

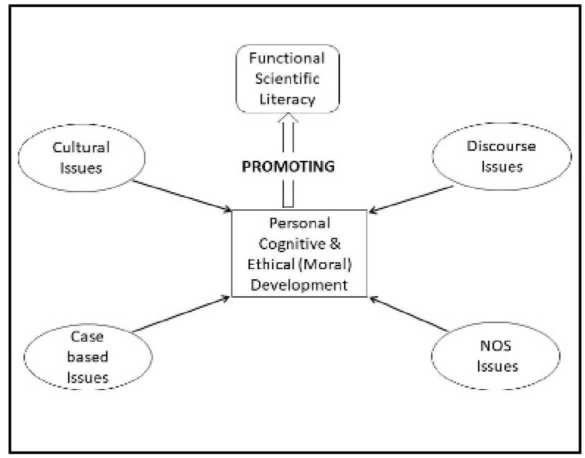

Figure 1: Framework for teaching socio-scientific issues (Zeidler, Sadler, Simmons & Howes, 2003, p.361)

they called "communities of practice", are formed by those who participate in the learning process, the available ideas, tools and resources as well as the cultural norms, both tacit and explicitly stated, which guide interaction and communication. Consequently, learning cannot be considered an isolated process that occurs in the minds of individuals; learning rather requires an understanding of how to function within the specific community of practice.
If learning is not only viewed as a cognitive but also as a social activity, the process of learning goes beyond acquiring facts, concepts and skills; it is "more basically a process of coming to be, of forging identities in activity in the world" (Lave, 1992, p. 3). Hence, when students participate in a community's projects, they appropriate specific facets of its culture. As student develop a growing understanding of the specific culture, they are then able to engage in more elaborate discourses and activities. Learning, as understood by Lave and Wenger, is therefore rather enculturation into a specific culture. As a result of this integration into a new culture, apprentices gradually gain new ways of behaving and acquiring new best practice methods. According to Gee (2000) this goes hand in hand with the integration of new facets of identity. Thus, education understood as enculturation into a specific community of practice "must strive to open new dimensions for negotiation of self" (Wenger, 1998, p. 263).
The culture of STEM classrooms is established by the specific routines carried out, the

(implicit) rules followed and the aims shared by teachers and students. Although there are significant differences between the culture of STEM classrooms and the culture of academic STEM disciplines, they are intrinsically linked to each other. They share a focus on specific phenomena; the scientific ideas taught at school, though simplified and abstracted from the context, are the same as those derived and used in research. Usually a wide array of equipment and tools is found in STEM classrooms which are very similar to the ones used in STEM research, albeit used in a different way from their original intent. Moreover, there are certain habits, rules and modes of discourse and enactment that are thought of as distinguishing a STEM person from others that reveal themselves during school science learning. Students who can identify with these rules and habits are recognized as STEM persons by their teachers and their peers.

From the perspective of situated learning, the fact that the transfer of tools and concepts strips "these resources of their cultural significance" (Sadler, 2009, p. 9) leads to a dichotomy as the aims of STEM education (understanding well-established concepts and formalism) and STEM research (creating new understandings of the natural world by using scientific formalism and practices to answer, ask and solve new questions and problems) are completely different.

There are some initiatives to bridge the gap between the two cultures by providing learners with authentic research experiences: e.g. Research and Education collaboration projects where students collect data which is incorporated into scientists' work or extracurricular programmes where students work as research apprentices. Although these programmes are successful to some extent, they are also criticized as they may alienate "many students who lack the interest and motivation to cross 'cultural borders' into professional science" (Sadler, 2009, p. 11 referring to Aikenhead, 1996).

Sadler (ibid.) therefore proposes to establish "science as it is practiced in the living experiences of engaged citizens", which can offer an alternative to the dissatisfying dichotomy between the two cultures – the one of the science classroom and the one of the science community. The basis for developing this different kind of community of practice in STEM classrooms is the implementation of socio-scientific issues in STEM learning environments. Establishing such communities of practice plays an important role in teaching for sustainability. Because of the social significance of these problems, their exploration requires not only a negotiation of scientific concepts, principles and practices, but also of interests and values. These aspects are a prerequisite for raising students' awareness, which is an important feature of education for sustainable development.

The importance of the gender lens

There are several reasons why the gender aspect was important in the project: The field of science and engineering is gender-biased. There is an imbalance in the participation of men and women worldwide and, what is even more important, scientific knowledge, like other forms of knowledge, is culturally embedded and therefore reflects the gender (and racial) ideologies of societies. Although environmental issues were originally considered a 'soft' science and political issue, "the growing attention to climate change has been accompanied by a relocation of the centre of environmental debate and action to […] the scientific and policymaking institutions" (MacGregor, 2010, p. 230). Hand in hand with the change in the perception of environmental problems, sustainable development has been redefined as an exclusively techno-scientific problem which requires technical solutions. As a consequence, ecological problems related to climate change have become "hardened" and have brought "men to the fore as policy experts, scientists, political advocates, entrepreneurs, commentators and celebrities" (ibid.). What is more, these discourses have led to a 'masculinization' of environmental politics. Besides, these approaches are responding to the symptoms rather than working towards a sustainable global development, as already mentioned. Therefore it is important to focus on the cultural and symbolic dimensions of processes through the gender lens, thus unveiling the hidden (masculine) norms and power relations which shape the discourses of sustainable development.

This paper investigates how dealing with a socio-scientific issue in the context of sustainable development interacts with the culture of a secondary technical and vocational school. In particular, we wanted to find out how a real-life approach can contribute to a more inclusive perspective on energy teaching and, at the same time, raise awareness of the limitations of a purely technocratic approach to ameliorating the environmental crisis.

The project SOLARbrunn – heading for a future with the sun

The collaborative Research & Education project, "SOLARbrunn − heading for a future with the sun", was modelled on the conceptual framework for socio-scientific issues elaborated by Zeidler et al. (2005). The specific case we want to look at involved a kindergarten building in Hollabrunn, a small town in Lower Austria. This was a real-life situation which students at the local Secondary Technical and Vocational School (HTL – Höhere Technische Lehranstalt) investigated in their diploma theses, part of their school leaving examinations. They were supervised by their teachers, student teachers majoring in physics and an interdisciplinary team of scientists (a physicist, a science educator and a social anthropologist). They had to find research-based suggestions to convert the kindergarten into a 'green building'[3] which should reflect the needs and expectations of the kindergarten's staff and children. As the main objective of SOLARbrunn was to reconstruct scientific/engineering knowledge against the background of sustainable development for solving local problems, the students and their teachers conducted the research process themselves while the scientists assisted and facilitated the process. This stands in contrast to the usual practice of research and education projects, where students collect data which are incorporated into the scientists' research. Instead of producing knowledge to be objectively validated by scientific discourse, the SOLARbrunn project intended to produce what Bammé (2005) calls "socially robust knowledge", i.e. knowledge which is integrated into the local living environment of the municipality of Hollabrunn. SOLARbrunn therefore does not only have to consider scientific aspects but also economic and social ones as well as aspects of power. To cover all these facets in a creative way, the project made use of a complex stakeholder process where the above-mentioned research team (HTL students and their teachers, scientists and student teachers majoring in physics) formed a community of practice together with members of the town's municipal government and the staff of the kindergarten. The advantage of this strenuous, time-consuming, contradictory and sometimes highly emotional process was the production of knowledge that the community can rely on in further energy management and construction projects. In addition, this could be an impetus for the organizational development of the HTL establishing itself as a key player for promoting sustainable development in the region.

Thirteen students in all from the different departments at the HTL took part in the research process. The students volunteered to participate in the project by choosing to write their thesis there. The specific objectives were created collaboratively by the research team and the HTL teachers and were aligned with the various vocational focuses. The final formulation of the research questions for the diploma theses was the result of a stakeholder process which the HTL students participated in. The electronics students worked on climate monitoring and designed a 'CO_2-signal light' for collecting comfort data (CO_2, humidity, temperature) remotely. The students in mechanical engineering developed ideas for adapting the

3 Green Building is a systematic approach to designing and constructing houses which embraces the complex and diverse needs of the occupants and users and at the same time fosters sustainable use of energy and natural resources (Johnston & Gibson, 2008).

regulation of the ventilation and enhanced shading systems based on an analysis of the comfort data collected. Based on an energy consumption analysis, the students from the department of electrical engineering developed suggestions for sustainable energy management and investigated the potential for installing a photovoltaic plant. The students from the industrial engineering department were responsible for project management, communication and investment calculation but they also collected the necessary social data regarding the particular needs of the kindergarten's staff and presented them in a 3D-visualization of the kindergarten building. Thus, they took the lead in the project.

A key aspect of the project was that the 'learning environment' was an 'ill-structured' real-life-case, i.e. the energy management of a recently built public kindergarten in a small Austrian town. This, however, implies that learning about sustainable use of energy transgresses the intimacy of the classroom. Problems 'out there' are not clear-cut assignments and although theoretical knowledge and engineering skills are good guides, decisions in the research and development process have to consider social, political and economic interests as well as the values of the stakeholders involved. In short, sustainable technological solutions have to be created under ecological and social as well as economic and legal/political constraints.

Research Design

The specific goal was to find out to what extent the collaboration with researchers and the focus on teaching for sustainability affected the process of the students writing their diploma theses. Moreover, we were interested in learning how the specific setting affected traditional perspectives on teaching STEM.

At the beginning of the research process, a 4-R analysis[4] was conducted to clarify the roles played by the different stakeholders and the relationship between them. To provide a "thick" description of the ongoing processes in accordance with Geertz (1973, p. 10), a vast amount of data was collected. There were 24 departmental meetings altogether which were audio-recorded and fully transcribed. Additionally, the students, their teachers, student teachers and members of the scientific team as well as the school's headmaster, the heads of the four departments and the local environmental councillor (who was also a teacher at the school) met at three interdepartmental meetings. These meetings were documented by minutes. Moreover video-records were taken which were partly transcribed. At the interdepartmental level there were four more meetings attended by the teachers, the local environmental councillor and the scientific team which were documented by minutes. Most of them also were audio protocolled and partly transcribed. Furthermore, the scientific team, one teacher from the HTL's project team and the HTL's headmaster met the head of the kindergarten and 2-3 members of the town council at four stakeholder meetings. These meetings were documented by minutes. Another important database is the five diploma theses the students wrote as part of their school-leaving examinations[5].

At the end of the project the four main teachers were interviewed, as were 11 of the 13 students[6]. We were interested in the motivation behind participating in the project and the role that sustainable development and research played in the diploma thesis process. The interviews were audiotaped and fully transcribed.

The methods for subsequent analysis were chosen depending on the character of the document. A deductive path content analysis (Mayring, 2003) and a key incident analysis (Kroon & Sturm, 2000) were used for highly structured documents like the minutes or the diploma thesis. For the rather low-structured

4 http://www.policy-powertools.org/Tools/Understanding/docs/four_Rs_tool_english.pdf

5 At the HTL the diploma theses are written in teams of two or three students.

6 Two of the students graduated one year earlier. As they only participated in part of the process, we did not interview them.

documents like the transcriptions of audio protocols or the interviews we followed a rather inductive path involving an applied discourse analysis based on the documentary method elaborated on by Ralf Bohnsack (1998). Thus we tried to reconstruct elements of the engineering culture which guided teaching and learning.

Results

The 4-R analyses revealed the crucial role of the head of the kindergarten: although not directly involved in the research process, she was the gatekeeper for data collection. Furthermore, the town that was responsible for running the maintenance of the kindergarten had to be considered as an important project partner as they had the necessary resources as well as the legal power to implement the proposed refurbishing measures.

The first draft of the investigation plan, as elaborated by the students together with their teachers, just involved the collection of technical data. However, the minutes provide evidence that it soon became clear that collecting technical data would not suffice to transform the kindergarten into a green building:

> Mr. E. (teacher industrial engineering department): *"I was informed by a colleague … about platforms which help to connect specific investments and their benefits – a lot of Excel sheets. … I am pursuing that track – automatizing as much as possible. But in the end everything is different … . We don't need these investments and how they affect energy consumption or things like that, we have to follow the social track!"* [Audio protocol departmental meeting 100615, Ll05-115[7]].

In order to interpret the measurements, social data about the everyday routines at the kindergarten also had to be collected. The students from the industrial engineering department designed a questionnaire for this purpose aided by their teacher, the student teachers and the social anthropologist. In accordance with the request of the kindergarten director, Mr. E., the HTL students' teacher, conducted the interviews with the kindergarten staff. The analysis of the interviews was of key importance for the whole research process as it helped to focus the research questions and steer the whole process. In the course of the project, it became clear that all of the students had to collect social data in addition to the technical ones. They could count on the help of their colleagues from the industrial engineering department, but they had to draw up drafts of the questionnaires and do interviews themselves. Yet, the idea of collecting 'soft' social data did not appeal to all of the participating teachers and students: As mentioned earlier, the electronic engineering students developed an indoor environmental comfort data recording device with signal lights, which could be used for aligning the settings of the ventilation system with the comfort data, especially the concentration of CO_2. In one of the meetings they expressed their disappointment that they had not got any feedback. However, as the students had just installed the device without explaining how it worked, it was not surprising that the kindergarten staff did not understand its functionality. Although it was clear that non-experts could not interpret the signals of a device whose operation mode they did not understand, the teacher did not ask the students to explain the device to the staff.

> Mr. C. (teacher electronics department): *"Do you want to make me a sociologist? … Electronic engineers do not bother about the user, they only build devices! … This is the reason why we decided that the industrial engineers deal with the sociological components".*
>
> Mr. M. (teacher mechanical engineering department): *"Well I am a mechanical engineer and these steps were also quite new for me, but to tell you the truth, we gained useful information for the analysis."*
>
> Mr. C.: *"I only took two 'skilled engineers'[8] to do this job – they are not interested in working with people. I can't make them be that, I would lose face in front of the boys. This was not part of the agreement for the*

7 All quotes were translated by the author.

8 orig.: Vollbluttechniker – literally translated: "thoroughbred engineers".

> *diploma thesis"* [Audio protocol 261115, L65-238 excerpt].

In the end, the 'skilled engineers' gave a short demonstration to the staff of the kindergarten on how to use the device.

In their diploma theses all of the students followed the standards of scientific publications and developed data-based suggestions for optimizing the indoor environmental comfort of the kindergarten building which had been built to low energy standards. At the time the building was constructed, the legal regulations aimed primarily at lowering energy consumption but did not reflect the users' comfort. Therefore, the results of the investigation clearly confirmed that the temperature was too high (primarily on the top floor) due to solar radiation and a lack of adequate shading. Additionally the humidity was rather low (10-20%) during the heating period due to the construction and settings of the ventilation system.

The interviews, however, provided evidence that the students struggled with the long-term process of defining an approach to the problem.

> "*At the beginning, after our first meeting we had to bring some suggestions for optimization. Well, we thought of very different things than we proposed in the end. … The vision we had in the beginning changed ten times. But I would not say that the idea in the beginning was good and the end bad, definitely not!"* [Int.StudME2, L166-173].

Another problem that was raised frequently in the interviews was the regularity of the meetings and the problems of communication between the departments:

> *"It took some time, I think until the second meeting, until we found out to whom the tasks were assigned and only then were we able to find a way to deal with the tasks. And then we launched the WhatsApp group … but in the beginning … everyone was working more as an individual than as part of a team"* [Int. StudIE1, L45-109].

While some of the students felt that "*the time invested* [in regular discourse] *was not supportive in making progress in the completion of diploma theses"* [Int. StudEl2, L85], for others it was motivating that *"there was always someone who was interested in our progress"* [Int. StudME1, L76]; this helped them to move forward and to improve.

However, the students were convinced that their research was not very scientific because genuine research has to discover something new. Moreover, collecting social data and carrying out economic calculations were not seen as 'genuine engineering'.

> *"It was not extremely scientific. It was a mere evaluation of a certain view on the problem and providing some suggestions for improvement. Genuine scientific work would not contain anything social; it would only promote technology. Actually I have never done that"* [Int. StudEE4, 4:36-4:50min].

As the following quotes show, some of the teachers conceptualize research in a similar way:

> *"Well, that was handicraft! They have recorded graphs; they have interpreted them, if one takes that as research, then one can say yes. But, where is the research? Where are the analyses of measurement results? It is a thin line between research and the daily role of an engineer"* [Int. TeachIE, L474-478].
>
> *"What's all this about research, I need equipment, I need an electron microscope, and I don't know what else! In the area in which we work – research means 10 million Euro and half of an enterprise behind me. As a social anthropologist this looks probably quite different"* [Int. TeachEl, L645-649].

Discussion

In a traditional view of engineering, the engineer's job is measuring and constructing technological solutions based on the rigorous mathematical processing of data. They usually work in the laboratory where they design and refine solutions to a given problem. The guidelines for a diploma thesis at Higher Colleges of Engineering in Austria reflect these characteristics of the engineer's job description: The assignment should comprise a problem for which a solution is found using substantial theoretical and practical knowledge and state-of-the-art technology. It may encompass situations which are not predictable and this will demand creative approaches.[9] Therefore, taking ecological demands or economic and legal constraints into consideration could be an important factor for design decisions. Although the user as a theoretical construct influences innovation, real-life contact with prospective users is usually not seen as an important part of the development process. A discussion regarding the social impact of technological systems and devices now and in the future is not a compulsory part of the engineering curriculum.

These principles guide engineering education and practice and are widely shared by teachers, students and departmental heads, not only in the Secondary Technical and Vocational School which participated in this project. These principles also guided the construction of the kindergarten building: Every facility was state of the art; the calculated energy parameters gave the building a low-energy status as defined by the legal regulations. However, to transform a low-energy building into a 'green building' or sustainable building "a careful understanding of relationships and patterns of interaction among those involved in the design, production and use of buildings" (Rohracher, 2005, p. 202) is necessary. The performance of energy-efficient buildings is an open-ended process and depends largely on pre-existing experiences and the social learning processes between providers (architect, municipality, engineers and construction companies), maintenance staff and users. This shifts the focus of the issues to be dealt with, in the context of the diploma thesis, from a purely engineering approach to a more inclusive approach, which reflects the sociocultural conditions of the use of technology.

Modelling the greening of the kindergarten building as a sociotechnical problem influenced the diploma thesis process significantly: The students did not construct devices, as is frequently done in the scope of a thesis. Instead, they proposed suggestions for ameliorating the users' indoor environmental comfort and the building's energy efficiency based upon rigorous measurements. However, communication with the users, the municipality, the maintenance staff and the other students involved in the project was of key importance for the research process.

Therefore, the research practiced in SOLARbrunn was not sophisticated cutting-edge technical research; it was rather applied research based on the actual experiences of engineers who are employed in small companies or are working as freelancers. Out in the field, engineers have to solve problems which are ill-structured at first sight, and they have to negotiate with their clients over needs and problems. They also have to adapt technological solutions and devices to the requirements of the users, and they have to instruct them how to use these devices. This approach caused some problems and questioned the commonly held beliefs of all project partners, the participants from the HTL as well as the head of the kindergarten, who was convinced at the beginning of the project that her voice was not important as she does not understand anything about technology.

The HTL project participants' feelings about some aspects of the project were particularly ambivalent, notably due to the high frequency of the meetings, the need to coordinate measurement designs, and most of all the need to combine technical and sociological research. On the positive side, the importance of the results for everyday life and the municipality as well as collaboration with the university were highly welcomed. The students learned a lot, but did they learn the right things, the right things for a 'skilled" engineer'? Was it genuine research that was carried out? For some of the teachers and department heads, it was not the 'lighthouse project' they had hoped for; they had difficulty assessing the students' successes and evaluating the merits of their work.

The project and the problems that it encountered raised points that questioned deeply held beliefs. It motivated teachers to think about future diploma thesis projects

9 www.htl.at/fileadmin/news/downloads/Diplomarbeit_Durchfuehrungsbestimmungen_HTL.pdf

which would be better adapted to the particular problems of the region and the future job prospects of those students who will not go on to study at technical universities or universities of applied sciences but who also want to start working in the region's SME's. A line of conflict ran between the "two cultures" which Charles P. Snow (1959) described, between arts and the social sciences on the one side and science and engineering on the other side; between positivism and interpretivism. These conflicting paradigms are deeply rooted in the beliefs of the project's participants, thus making sustainable technological development difficult. A cultural perspective which establishes a sharp line between methodical and discursive practices as used in the natural and social sciences generates a hierarchy, not only between academic disciplines but also between experts and non-experts. It narrows the view on 'genuine research', which is perceived as an elitist and expensive endeavour, thus impeding the participation of citizens in solving social problems related to climate change.
Yet, in the pragmatic approach of some of the engineers, the synthesis between the scientific and the social data is seen as quite a useful strategy for technological development. Questions about the role of social skills and the use of sociological methods were discussed. The teachers had to admit that they adhere to a hybrid engineering culture which neither mirrors the culture of engineering work in the field nor the culture of high-end basic and applied research. Moreover, the headmaster acknowledged the merits of emphasizing the three-pillar concept of sustainable development as a goal for school development.
Although a single project would not change what is a well-established educational structure with an excellent national and international reputation and a very specific culture, it can be seen as a considerable disturbance of the 'business as usual' approach and there is some hope that it has initiated a mental shift in some of the teachers and the students involved.

Conclusions

The most obvious finding which emerged from this analysis is in line with the analysis given by Donovan et al.: The objectives targeted and the practices developed at a HTL reflect to a high degree the "imperative perspective". In spite of the schools' success at placing graduates in the labour market, they often lack the required social skills for promoting sustainable development.
As the social and technical aspects of sociotechnical systems in general and low-energy houses in particular are inseparably interwoven, optimizing these systems is "only to a minor extent the search for enhanced technical solutions. What is much more challenging is the social embedding and the socially interactive process of designing, constructing and using" (e.g. Rohracher, 2001, p. 137) these buildings/technologies. Therefore sustainable development needs the interactive effort of various players to improve sociotechnical practices. In order to find resolutions to societal problems like climate change, experts and non-experts have to establish learning communities where the interests, attitudes, habits, values and perspectives of non-experts have the same status as those of the researchers and experts. Both sides have to develop a common understanding of the research problems but at the same time recognize that they have different interests and therefore have different perspectives on the specific research process. For a successful process, it is therefore important that a mutual understanding of interests and attitudes is negotiated in regular reflective meetings.
This study also suggests that to successfully integrate aspects of sustainable development into STEM education, a critical reflection of the culture of science and engineering plays a crucial role. The teaching-for-sustainability approach challenges the narrow image of engineering as a hard-science approach as well as the prototype of the 'skilled engineer'. As the dichotomy between 'hard' and 'soft' approaches also establishes a hierarchy between STEM experts and non-experts,

reconsidering the culture of science and engineering also challenges the power relations/gender relations between engineering experts and laypeople. It therefore has the potential to initiate an organizational process that aims for a more realistic, more inclusive and less male stereotyped orientation in engineering.

A holistic approach to engineering comprising sustainable development shifts the emphasis away from constructing and building devices and more towards planning and adjusting sociotechnical systems built upon research-based analysis. It widens the possibilities of engineering activities and therefore has the potential to motivate a broader spectrum of young people to take up a career in engineering.

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Contributions and acknowledgements

The research was conducted in cooperation with Viktor Schlosser (University of Vienna, Faculty of Physics) and Anna Streissler (FORUM Environmental Education, Umweltdach-verband, Austria) and the students and teachers of the HTL-Hollabrunn.

Funding

The project "SOLARbrunn – heading to the future with the sun" was funded by Sparkling Science, an initiative of the Austrian Federal Ministry of Science, Research and Economy, which fosters collaborations between Research and Education.

ORIGINAL PAPER DOI: 10.13135/2384-8677/2772

Let's save the bees! An environmental activism initiative in elementary school.

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Abstract.
Science education research emphasizes the need to engage students in socio-scientific issues, empowering them to act in a substantiated manner. This study aims to understand the potential of a collective action initiative, focused on the decreasing honey production issue, and on the students' empowerment for action. A qualitative research methodology was used with an interpretative stance. The participants were 26 3rd grade students and their teacher. Data was collected from the students written documents, and through an interview with the teacher. Results show that students' engagement in collective action focused on the decreasing honey production issue, required them to mobilize their scientific knowledge to support their actions, as well as the development of several other competences. Students also became aware of the importance, for every citizen, to substantiate their knowledge in order to act, that acting is crucial to overcome issues that may persist and impact future generations, and that only by engaging in action can change take place. Another highlight was the students' strong engagement in collective action, allowing them to raise awareness this issue in their local community.

Key words. activism, collective action, science education, scientific literacy, socio-scientific issues.

ISSN 2384-8677 **DOI:** http://dx.doi.org/10.13135/2384-8677/2772
Article history: Submitted February 12, 2018. Accepted May 07, 2018
Published online: June 04, 2018
Citation: Baptista, M., Reis, P., de Andrade, V. (2018). Let's save the bees! An environmental activism initiative in elementary school. *Visions for Sustainability,* 9: 41-48.

Competing Interests: The authors have declared that no competing interests exist.
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Perspective: *Educational visions*

Fields: *Earth Life Support Systems*

Issues: *Honey Production, Collective Action*

This paper was developed within the scope of the contract UID/CED/ 04107/2016 to UIDEF – Unidade de Investigação e Desenvolvimento em Educação e Formação, funded by the Fundação para a Ciência e a Tecnologia, SA.

Introduction

Recognizing the importance of science in our lives, several authors emphasize the need for students to develop a scientific attitude, meaning, to critically analyse the produced knowledge, distinguishing between scientific knowledge and common-sense knowledge, appreciating different assertions, critically analysing their limits and potentialities, among other aspects (e.g., Lederman, 2006). This implies that students develop not only scientific knowledge (i.e., concepts, facts, relevant theories that constitute an entire body of fundamental knowledge), but also knowledge about science (i.e., the way that this activity works, how knowledge is constructed, and the nature of this knowledge) allowing them to develop a critical perspective about what is being presented and about which they have to take a stance (Schwartz, Lederman & Crawford, 2004). Moreover, science education must go beyond the learning of knowledge and scientific skills, to focus on problem solving, and on the ability to negotiate solutions through open and critical dialogue, giving students the opportunity to actively participate in society. In order to achieve these goals, it is essential to engage students in solving social problems with a scientific and technological nature, giving a useful and concrete meaning to science, allowing them to better understand the society they live in, and how science can contribute to environmental sustainability and social justice (Hodson, 2003). Thus, there is a need to educate students for informed action, i.e. to prepare students for action and engaging in problem solving activities. In fact, the earlier students become involved in collective action, the better prepared they are for exercising their citizenship rights in a participatory democracy. Education must be an active and critical lifelong enterprise, transcending the boundaries of classrooms and schools (Hodson, 2003).

To encourage citizens to understand science and to promote informed action, it is important to bring together public and scientists, involving the citizens in science as researchers (Kruger & Shannon 2000), i.e., citizen science involves citizens in academic research, bringing together non-academic community with scientists. For citizens, citizen science provides an opportunity to contribute to scientific understanding and decisions. For scientists, is an opportunity to collect information that would be impossible to gather for different reasons, such as time and resources' limitations (Tulloch et al., 2013). Educating citizens in this type of context can contribute to solve society's issues – such as poverty, injustice, terrorism, wars – as well as environmental ones – such as the ozone hole, global warming, decreasing biodiversity, among others (Bencze, 2011). This is a crucial point, given the nature of social and environmental problems currently facing society, demanding responsible and engaged citizens to actively exercise their citizenship (Bencze & Sperling, 2012). Finding an adequate solution to these issues requires thinking about sustainability education with the idea of engaging and transforming something that is ours, taking on our responsibility for the world and for others, taking into account the future of society, i.e. the coming generations (Earth Council, 2000). Thus, sustainable development presumes an improvement of the quality of life for all individuals, aiming to give each of them greater control over their destiny (UNESCO, 2005). Sustainable development can only be achieved with the strong engagement and awareness of all. This requires the development of citizen's critical awareness, allowing them to learn about and be alerted to reality, prompting them to feel engaged with it, and to assume their role as an integral part of this reality (UN, 2013).

Sustainability education is about more than developing critical awareness; it aims to create in the citizen a will to transform and to be transformed, i.e. the will to engage and act (Jurgensen, 2003). This action on social and socio-scientific issues, such as the sustainability of the Earth, requires informed, competent and empowered citizenship. The engagement in collective activism initiatives allows students to develop the skills and attitudes necessary for its liberation from the hegemonic control of experts and businesses. Participation in activism drives students to perceive their power to intervene. Realizing that they are agents for change, they are capable of demanding and exercising participatory and informed citizenship, also demanding social and ethical justice in the interactions between science, technology, society and the environment (Reis, 2013). In order for students to be/become citizens with full rights, collective action on socio-scientific issues must be experienced in schools (Hodson, 2014; Reis, 2014).

Taking into account these issues, in this study we developed an initiative, related to a local problem (selected by the students according to what they considered more relevant), dealing with the decrease in honey production in rural areas, engaging the students in collective action. The main goal of this study is to learn about the potential of collective action, related to the reduction of bees and honey production, for students' learning and engagement. This study is part of a wider project, "We Act – Promoting Collective Activism on Socio-Scientific Issues" (Marques & Reis, 2017; Reis, 2014) aiming at the development, implementation and study of materials, methodologies and approaches that support teachers and students in carrying out informed and negotiated actions on socio-environmental and socio-scientific issues.

Method

The research design for this study is grounded in qualitative methods (Bogdan & Biklen, 1994) with an interpretative nature (Erickson, 1986). The participants were an elementary school teacher and 26 students from 3rd grade, with ages between 8 and 10. Students came from a rural setting, in inland Portugal, where agriculture is the main source of subsistence. It is a region with high honey production. Most parents have low academic qualifications, corresponding to basic education and, in most cases only elementary education. The teacher has a degree in Elementary School Teaching. She's 51 years old and has 26 years of professional experience.

During two months, students were engaged in collective action activities related to the problem "What is happening to bees?". Before starting the problem solving, the teacher asked the students to discuss what they already knew about the bees and to bring to the classroom stories related with bees (the importance of bees in their life and for their families). In a preliminary phase, this discussion was important for students' engagement in the issue.

In order for students to develop scientifically grounded actions their tasks were organized into several phases. In the first phase, the local problem was contextualized with a dialogue between two friends, Rosa and Benjamim, and their uncle Sérgio. The two friends called their uncle to inform him that they were going to be spending part of their summer holidays in his house, and to ask him to make Benjamin's favourite honey and ginger cookies. Faced with this request, the uncle answered that he could not make the cookies because in that year there hadn't been any honey production. He added that the bees were dying. From this dialogue, students identified the problem and explored it, using mainstream media as a source. After this phase, in order to better understand the issue, students participated in a role-play activity, focused on a local concern: "The president of your municipality is worried about this issue and has decided to hold a meeting with all concerned parties, to arrive at a proposal that they could send to the Ministry of Environment."

After this, students were organized into groups, and each group selected a role to play during the meeting, namely: pesticide industry representative; agricultural company representative; scientist; beekeepers' association representative; and environmental association representative. Before taking part in the discussion, students had to prepare arguments to support their role. After the discussion, they helped the President writing the letter to the Ministry of Environment with their main concerns and the final conclusions reached by all participants. They reached a consensus and wrote the letter given that they had played roles with potentially contrasting perspectives. As a way to reach out to the local community, i.e. to develop collective action, students undertook two initiatives: (i) wrote a manifesto (figure 1) and asked the local population to subscribe it, and (ii) created slogans that would draw attention to this problem. The arguments used by students were focused in the use of pesticides. This fact is related with the information that was provided in the task (essentially directed to pesticides), conditioning their point of view.

students' classroom written records. The interview and written documents provided the data for the researchers to analyse and give meaning to the process (Bogdan & Biklen, 1994). For the analysis of data related to the potential of this particular collective action for the participants, in the teacher's perspective, we used the categories "framework for collective action" and "engaging in collective action".

Manifesto

Why are bees dying? The 3rd grade students investigated about this question and found out that the main reason for this problem is that human beings are using pesticides in agriculture. These toxic substances cause bees to become disoriented, having difficulties to find their hives. They get lost and end up dying. All people have to protect bees. Bees are very important. They pollinate, carrying pollen from one flower to another and allowing fruit production. So if we want to continue to produce and eat fruit we have to take care of the bees. Bees also produce honey that we all consume, for example, in tea or cakes. In our village a lot of honey is produced and sold to other people, being a form of subsistence. So, what can we all do? We can avoid the use of pesticides or, in the case we cannot stop using them, we can choose those who are not harmful to the bees. Let's not forget that bees are our friends!

Subscribe with us this manifest and defend the bees, saying no to the use of pesticides.

Figure 1 – Manifesto prepared by students for community action

As usual in this type of document, the manifesto constituted a declaration of principles and intentions, which sought to: a) alert to the bee's disappearance problem; b) publicly expose some of the local agricultural practices as a possible cause of the problem; and c) summon the community for a particular action – in this case, changing behaviours. The manifesto, proposed by the students and subscribed by the population, worked as a commitment to change agricultural practices, harmful to the ecosystem, and for the adoption of more environmental and sustainable methodologies. The proposals presented resulted from the students' knowledge of the agricultural practices used by their families and from the investigations they carried out, allowing them to: a) recognize the inadequacy of these practices; and b) learn about environmentally sustainable alternative practices.

Data about this process was collected through an interview with the teacher, at the end of the school year, and by the analysis of

Results

Framework for collective action

Before starting the problem solving, the students had opportunity to discuss what they already known about bees and the importance of bees for their life and their families, as well as, they had opportunity to tell stories related bee stings and honey production. This was an important moment to engage students in the project. It was a trigger for the problem solving, allowing teacher to realize what their students already known about the issue. Honey production in the region is high and it is one of the ways of the families subsist. The students have a big proximity to the bees and they help their parents to take care of the hives and on the crest of the honey, such as the teacher said: "they are used to bees, they are not afraid."

In addition, from the teacher's perspective, students efforts to answer the problem: "what is happening to the bees?", helped them to sustain their collective action, taking form in two initiatives, as mentioned in the interviews:

"it was important the initial work of identifying the problem, reading the news, realizing that they should prepare for the discussion (…) it was important because it helped them to understand that they can act if they know how, they developed new knowledge". According to her, this initial activity, before the collective action phase, is crucial to raise students' realization that each citizen should be aware and informed to make competent decisions related to their life on Earth, and to the consequences of human activities for the future of the ecosystem. In her words:

> "*Playing different parts allowed students to get ready, allowing people to learn, taking into account different points of view. They realize that there are different points of view, but at the same time it is necessary to intervene because it is an issue that can affect their future, how do I explain this? If it's affecting the bees, if it's an environments problem, I as a student have to do something, because if I don't, what will happen to the bees? The production of honey will reduce and so will the bees, and in the future, I might not have any more honey. On the other hand, the disappearance of bees affects the whole ecosystem because it prevents plants reproduction. Therefore, it affects the future of all living creatures. This was important for the students*" (Interview).

In the teachers' words it becomes clear that students thought about the future, i.e., as citizens, if they didn't act, the problem could persist and affect the whole ecosystem and future generations. It is also visible in the interview that, from the teacher's perspective, students recognized the need to safeguard environmental, social and economic issues. As illustrated in the following example,

> *"I think it warned students that the use of pesticides is an environmental problem and that there is a need to intervene because it can affect beekeepers and farmers themselves by causing the bees to disappear. It was important for students to think about this before writing a manifesto for the population and slogans"* (Interview).

In the previous excerpt, it is clear that the cause of death identified by the students was the use of pesticides. However, the teacher could have promoted a moment of deeper discussion. For example, teacher should have encouraged students to discuss other causes for bees' death. In addition, the activity that students developed has focused on searching information.

Examples related to the beekeeper's profession, or the importance of producing honey for the region can be found in the students' written records:

> *"So, in our county bees are dying, just like in the rest of the world, and the production of honey is decreasing which affects the survival of some beekeepers"* (Group 1).
>
> *"This harms bees and kills them, if we continue like this one of these days we'll no longer have honey to eat"* (Group 2).

The idea presented by group 1 shows that students are aware that this problem can affect the beekeeper profession, and therefore have a local social impact.

From the teacher's perspective, this initiative facilitated the development of knowledge and skills for action. This way, students acquired scientific concepts related to the importance of bees for the pollination of flowers, and used this knowledge to support their action. In addition, it allowed them to develop other skills such as reasoning, communication and attitudes, as mentioned in the interview:

> *"Acquiring scientific knowledge was an important part. In order to solve the problem, it is necessary to know what bees are, what's their importance. We have to take into consideration questions related to pollination. I remember that the students asked me: Teacher, can bees really do this? They were amazed at their ability to transfer pollen from one flower to another. So, what did they learn? Scientific knowledge and other things. As they themselves say, to argue, to defend ideas, to respect their peers, to plan their communication strategy, to think, to write, to read, and also writing skills ... what have they done with all this? They used it in a very interesting way for their collective action, to reach the population"* (Interview).

As we mentioned, the students were motivated to solve the problem. For this, it was important to explore the previous concepts, before the students started the task. This engagement was crucial for the project's development and for the knowledge mobilization by students as described by the teacher in the previous excerpt.

Students' written records allow us to reinforce what the teacher said during the interview. The following example points us in the same direction:

> *"Bees do pollination, honey and help trees produce good fruits. People need to know that bees are dying from pesticides. We have to think, investigate how to solve the problem, and argue and defend our ideas to try to change farmers' behaviours "* (Group 3).

In this example, it is quite clear that students have learned scientific concepts and developed other skills that are fundamental for collective action planning.

Engaging in collective action

From the teacher's perspective, engaging in collective action allowed students to become aware that their local action is important and that as citizens they can induce change, i.e., to engage in actions leading to change in current issues:

> *"Preparing the initiatives and putting them into action was extremely important. By doing this they realized that they could do something, of course for this it is necessary to know what to do, to have knowledge about the subject, and to want to do it. And I heard them saying: "teacher, we did it". This is important, such as other small things, like inviting parents to come to school to see the exhibited slogans, it empowers them and is key to this feeling, i.e., I am aware of what I can do, and that someone hears me because it is important and they hadn't thought about it before"* (Interview).

From the teacher's description it becomes clear that collective action was important for students, leading them to become aware that they can act as citizens. The sentence that the teacher used "teacher, we did it", supports the idea that students know that they can act as citizens, and that their initiatives are heard by the local community, i.e., students realize they can "do it themselves". Through the teacher's answer, we can notice that students' actions related to the slogans led their families to think about the socio-scientific issues being addressed.

According to the teacher, students' engagement in these two initiatives – i.e. writing the manifesto and asking the community to subscribe it; and developing the slogans raising awareness to this issue – was very positive, and the students showed that they enjoyed it, and that it contributed to developing their critical thinking skills. Equally positive, according to the teacher, was the feedback parents and families gave about the initiatives that were carried out:

"Students were very motivated and asked "will people sign it?" and another would answer "yes, my father says he wants to read it", and another "my mother will also sign it". It really motivated students and I realized they were interested. (...) The writing of the manifesto was important because they were discussing what was really crucial to pass on to others, what was essential to say from what they had learned, and what was only accessory ... Parents came to get the kids from school and said that the children were enjoying it and that this type of task adds value to their learning" (Interview).

In the teacher's words, it is clearly visible that it was important for students that their parents signed the manifesto. The parents recognized this aspect as something that their children liked, influencing positively their learning. For the teacher, collecting signatures in the final manifesto within the community was also crucial for students and for the people who signed it. There was a responsibility for action and a realization that action is key. As mentioned,

> *"[families] were also asked to read the manifesto, to see if they agreed, to sign it, and see the slogans. Some of them became aware of what was happening to bees. It was important for everyone, and students saw that they can do things, small initiatives that in a small community can have real consequences (...) The manifesto was signed by families, parents, grandparents, cousins, uncles, and other people as well. In total we had 150 signatures, or close to that, it also gives us the notion that we are responsible"* (Interview).

The example described in the interview shows that students were able to engage in the action several members of the local community, not only family members, but also "other people". The teacher also added that school has a fundamental role in this process, as we can see in the following excerpt:

> *"We are talking about a small county, with a small population. School is very important for students' lives, for their families, and for the whole population in general. There is great*

recognition for school as a source of learning. Activities such as these, alerting the population and taking what the students did outside of the school are valued. This is important for students, these activities increased their motivation, leaving them wanting more, saying "teacher when do we do more?" This also came from their homes "teacher my son wakes up in the morning saying he wants to come earlier". I had comments like this! It's great because it shows that everyone's very engaged" (Interview).

This example reinforces the idea that such initiatives are fundamental to engage students in school, bringing discussion and information to local communities who recognize "school as a source of learning."

Conclusion

Engaging students in solving the problem "What is happening to bees?", relevant in their local context, was fundamental for their engagement in two collective actions. These initiatives, from the teacher's perspective, required students to mobilize scientific knowledge to support their actions and the development of several competences, such as building solid arguments to support their position, present their arguments to others and defend them, and respect for others and their ideas. Another feature highlighted by the teacher was the development of students' critical judgment, especially when they prepared the manifesto to be signed by the community, forcing them to discuss what was fundamental and what was accessory. These competences are undoubtedly essential to actively engage in society, supporting knowledge-based decision-making. Effectively, the OECD (2005) defends that, individuals need to be able to take responsibility for managing their own lives, situate their lives in the broader social context and act autonomously.

In addition, the results of this study allow us to conclude that students became aware that (1) it is important for citizens to have substantiated knowledge in order to act; (2) it is important to act because the problem may persist and impact future generations; (3) only through action can we cause change. In fact, from the teacher's interview, we can understand that students reflected on their role as citizens and recognized that it is important to act as members of their local community. The work that preceded the implementation of the activism initiatives was important for students to feel capable of acting, i.e. it allowed students to prepare their action in a substantiated manner, to feel confident in analysing the problem and in their response to it. This is an important element when educating for sustainability, with the intention of promoting activism (Gray, Colucci-Gray & Camino, 2009; Reis, 2014). In addition, it is possible to mention that students developed the idea that human actions, in this case the use of pesticides, can have negative consequences for society, the environment and even the economy. Another aspect that stands out is the engagement of other community members. It can be noted in the teacher's descriptions that, on the one hand, students realized that they can be agents of change, and that they know how to reach others. This can be seen in the teacher's discourse when she mentions that students say "yes, my father says he wants to read it", and "my mother will also sign it", revealing that these initiatives influenced their families. On the other hand, what parents learned from their children should also be stressed. As the teacher also mentioned, they became aware of what was happening to bees. However, we recognize that the teacher's exploration of the problem could have been deeper. Pesticides are one of the probable causes of death of the bees. One of the reasons that led students to focus on the use of pesticides is related with the task. The roles played by students were directed to the use of pesticides. So, their argumentations and initiatives were related with pesticides. In order to go further, the connection with the University would be important, following citizen science approach (Kruger & Shannon 2000). This interaction could be important in order to get more support for the students claim that pesticides are the main cause of death.

According to the teacher, students' engagement in collective action related to bees was very positive, allowing them to establish relationships between their own life, their local context and science (Lavonen et al., 2005; Trumper 2006). This study showed that, since the first years of schooling, it is possible to engage students in solving problems through collective actions about socially relevant issues. It is vital that, from an early age, every citizen realizes that engaging in action is crucial for democracy, in order to promote the necessary changes required for a fairer world, more protective of the environment, and in which everyone is an active participant. A possible development of the study could be to collect data from the local community (such as parents), allowing to know their perspectives about the collective action initiatives performed by the students.

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ORIGINAL PAPER DOI: 10.13135/2384-8677/2773

Futures in primary science education – connecting students to place and ecojustice

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Abstract.
After providing a background to futures thinking in science, and exploring the literature around transdisciplinary approaches to curriculum, we present a futures pedagogy. We detail case studies from a year-long professional learning action research project during which primary school teachers developed curriculum for the Anthropocene, focusing on the topic of fresh water. Why fresh water? Living in South Australia—the driest state in the driest continent—water is a scarce and precious resource, and our main water supply, the River Murray, is in trouble. Water is an integral part of Earth's ecosystem and plays a vital role in our survival (Flannery, 2010; Laszlo, 2014). Water literacy therefore has a genuine and important place in the school curriculum.

Working with teachers and their students, the Water Literacies Project provided an ideal opportunity to explore a range of pedagogical approaches and practices which connect students to their everyday world, both now and in their possible futures, through place-based learning. We describe the use of futures scenario writing in an issues-based transdisciplinary curriculum unit on the theme of Water, driven by Year 5 teachers and their students from three primary schools: two located on the River Murray and one near metropolitan Adelaide. All three schools focused on a local wetland. The research was informed by teacher interviews, student and teacher journals, student work samples, and teacher presentations at workshops and conferences. We report on two aspects of the project: (1) the implementation of futures pedagogy, including the challenges it presented to the teachers and their students and (2) an emerging analysis of students' views of the future and implications for further work around the futures pedagogical framework. Personal stories in relation to water, prior knowledge on the nature of water, experiential excursions to learn about water ecology and stories that examine the cultural significance of water—locally and not so locally—are featured (Lloyd, 2011; Paige & Lloyd, 2016). The outcome of our project is the development of comprehensive adventurous transdisciplinary units of work around water and connection to local place.

Key words. futures thinking; ecojustice; place-based learning; science learning

ISSN 2384-8677 **DOI:** http://dx.doi.org/10.13135/2384-8677/2773

Article history: Submitted January 30, 2018. Accepted May 04, 2018

Published online: June 04, 2018

Citation: Paige, K., Lloyd, D., Caldwell, D., Comber, B., O'Keeffe, L., Osborne, S. Roetman, P. (2018). Futures in primary science education – connecting students to place and ecojustice. *Visions for Sustainability,* 9:49-59.

Competing Interests: The authors have declared that no competing interests exist.

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***Perspective**: Educational visions*

***Fields**: Earth Life Support Systems*

***Issues**: Water, place, ecojustice*

Background: Science, ecojustice and futures

Our introduction to futures in education, and our later use of this work in science education, originated in 1988 through Australia's *Commission for the Future: Bicentennial Futures Education Project* (Slaughter, 1989) and developed through the application of futures studies in schools and, more recently, a middle school teacher education program (Lloyd 2001; Lloyd et al 2010; Lloyd, 2011; Paige & Lloyd 2016). As science educators in schools and later as lecturers in teacher education, we have integrated futures thinking and action into our courses. This paper brings together key passions of our intellectual work in science education over four decades, where ecojustice and connection to place collide with futures thinking. Ecojustice seeks to preserve and, where appropriate, enhance ecological well-being and the integrity of the ecological commons—the 'properties' of the Earth that sustain all life, including human life, properties called 'ecosystem services' (Costanza et al., 1997; Costanza, 2012) or 'the larger systems of life that we depend upon' (Martusewicz et al., 2010, p. 11). To achieve ecojustice, we need alternatives to the further expansion of capitalist consumer culture, including socioeconomic changes that reduce environmental racism, limit the resource exploitation and cultural colonization of non-Western societies, and renew the cultural and environmental commons (Lowe, 2009; Nelson & Cassell, 2016). This ensures that prospects of future generations are not diminished by the current generations' environmental destruction, and that non-human forms of life be understood as having rights within the larger ecosystems of which they are a part (Bowers, 2006b). Given that we are in an era of extreme environmental, social, and cultural change and uncertainty (Goldie & Betts, 2014; Hajkowicz, 2015; Hansen, 2009; Laszlo, 2001; Nelson & Cassell, 2016; Raskin et al., 2002; Raskin, 2016) there is no more important time to explicitly imagine and plan for liveable futures. We argue that science education must include an explicit connection to students' personal and collective futures using a futures methodology which is inclusive of individual and community, material and cultural needs, and cognizant of planetary boundaries—a safe operating space for humans and all other species (Rockström, 2015; Steffen et al., 2015). This necessitates a transdisciplinary/integral approach to curriculum and pedagogy (Gidley, 2016, 2017; Lloyd, 2007).

Context and world view

The Water Literacies Project used an interdisciplinary or even transdisciplinary approach to learning which aimed to connect primary school students to their environment through the study of a natural waterway in their community. We took a 'Literacies in Place' approach (Comber, Nixon & Reid, 2007) which values 'the interrelationship and cross-fertilisation between the arts and the environment, between feeling and knowing, sensitivity and action, the personal and the lifeworld', achieved 'through the expressive quality of both aesthetic imagination and representation' (p. 156). In effect, this is an integral approach. Wilber (1979, p. 40) observes that 'both modern science and Eastern philosophy view reality not as boundaries and separate things but as a non-dual network of inseparable patterns, a giant atom, a seamless coat of no boundaries' and provides evidence from both science and the spiritual tradition. 'Literacies in Place' education focuses on making connections to the self, to the community and to the natural world through hands-on learning and reflection.

Murphy (2014, p. 78) describes the current 'massive collapse of biodiversity and the ecological destruction' as an 'extraordinary crime against a truly wondrous creation' (see also Kolbert, 2014 for similar comments). Societies are facing an 'inability to relate effectively to the integral functioning of the Earth' (Berry, 2009, p. 35). Consequently, we need a new set of values to inform our actions which can be explored and implemented in our educational institutions and through community conversation. While humans can certainly be destructive and short-sighted, we all also have the capability to be forward-thinking and altruistic (Kolbert 2014).

This flawed worldview, in which earth is fragmented into bits and pieces, can be challenged in a number of ways, and the transdisciplinary Water Literacies Project provides us—teachers, students and communities—with an opportunity to 'allow the world to work on us so that we may change and mature—we are cultivated by that engagement, and then we see the world anew' (Zajonc, 2006, p. 75). Through this project we act individually and collectively to value water as a part of who we are. We are using the term *interdisciplinary* to indicate that many disciplines are used in the study of a problem or theme, and *transdisciplinary* to refer to an approach that uses many disciplines to investigate a problem or need in a particular social setting by drawing on grounded, local knowledge (Balsiger, 2004; Després, Brais & Avellan, 2004).

Justification for including futures pedagogy

There is considerable evidence to suggest that what we think/understand about the future affects all aspects of the self, including our state of well-being (Eckersley, 2002; Frankl, 1964; Goodall, 2003; Hicks, 2002; Hutchinson, 1996; Masini, 2013). Our expectations for the future not only affect how we see reality, but also contribute to reality itself (Alm, 2011; Assadourian, 2017; Lloyd, 2014; Slaughter, 2004). For example, current behaviour and decision-making depends on the image held by an individual or group of individuals where the thinking is more than the cognitive (knowing); it includes other ways of being such as the affective (feeling), the spiritual (connecting) and intentional (doing) (Bowers, 2006a; Wilber, 2006).

According to Bowers (2001), an ecojustice curriculum:

> *encompasses an explicit understanding of relationships and processes, an embodied knowledge of community relationships and the ecology of place, and an awareness of the layered nature of the interdependencies of life-sustaining processes* (p. 152).

From our own research (Paige, Lloyd & Smith, 2016) and from the literature (Gidley, 2016; Hutchinson, 1996), we know that students' views on science and technology are embedded in a broader social context. Their visions of the future offer an insight into their hopes and fears and are likely to have important implications for them personally and collectively. For humans to thrive in the future, we will need to systematically rethink education, helping students to learn the knowledge that is most useful for their survival on a planet that is undergoing rapid ecological changes (Assadourian, 2017; Murphy, 2014; Wijkman & Rockström, 2012). Despite growing scientific consensus of major environmental threats, societies are largely operating on the basis of 'business as usual'; at best attempting to tinker at the margins of the problems. This calls for a radically different type of education that tackles the uncomfortable issues created by human-induced rapid ecological changes, unsustainable human population and economic growth, and that directly challenges the current cultural values that promote this unsustainable living (Assadourian, 2017; Kopnina, 2014; Laszlo, 2014; Raskin et al., 2002; Suzuki, & Taylor, 2009). These areas of unsustainable living which, we argue, come under the umbrella of ecojustice and social justice, are key motivators for the development of futures thinking embedded in an integral/transdisciplinary/place-based pedagogy using a critical praxis framework (Hodson, 2003; Lloyd & Wallace, 2004; Moore & Reid, 1992). Futures scenarios and visioning have proved useful for environmental education because they make participants feel responsible and empowered to take action to reach their vision for a better community by raising their awareness of environmental issues (Velarde, Rao, Evans, Vandenbosch & Prieto, 2007). Our own work with futures has also brought us to this view (Lloyd, 2001; Lloyd, 2014; Paige & Lloyd, 2016).

Action research methodology

For this project, we engaged teachers in long-term professional learning through action research (Grundy, 1994; Kemmis, 2008; Kemmis & McTaggert, 1988). The teachers researched aspects of their own pedagogy as they developed and delivered a unit of work to engage their students with the theme of water.

They then evaluated the success of their units of work by observing student behaviours and actions in coming to understand the environmental and scientific issues around water and acting to defend the integrity of their local wetland.

This was a collaborative process between researchers, teachers and students in which professional learning experiences were delivered to the teachers by the researchers through workshops and on-going conversations. In this pilot study, teachers participated in five one-day workshops throughout the academic year. The workshops included discussion around a critical praxis teaching framework, integral futures scenarios, the meaning of place-based learning, the value of citizen science, and transdisciplinary approaches to learning. During follow-up visits to the three schools, teachers and researchers discussed the teachers' progress as they implemented integral futures thinking with their students as they learnt about and acted to maintain and value their local wetland.

Over four terms, five teachers with their Year 5 classes worked as co-researchers alongside the research team. Each teacher identified aspects of their pedagogical practice on which to focus their action research. They developed comprehensive adventurous transdisciplinary units of work around water which involved the *Science* of water quality (measuring salinity, turbidity, pH), the *Mathematics* of data collection (locating middle of data, mean, mode and median), the *English* of constructing future scenarios and the *Art* of accurately depicting and recording local animal and plant species. The program engaged the teachers to explore pedagogies that connected students to their place.

The futures pedagogy presented to participating teachers lies within an Anticipatory Critical Praxis Pedagogy—an action orientated approach to futures thinking. Moore and Reid (1992) advise that:

especially in moments of significant decision-making, we do call on past experiences both in our own lives and the lives of others to inform them. We try to learn from the past in order not to repeat its failures, and to select courses of action which seem to carry a potential for success. (p. 181)

This innovation focuses on developing a primary curriculum for the Anthropocene (the current era in Earth's history). The curriculum aims to place people within nature rather than distinct from it (Comber, Nixon & Reid, 2007; Corcoran, Weakland & Wals, 2017; Sobel, 2008; Somerville, 2013). It addresses problems of 'separation'; both the separation of people from nature (Louv, 2008; Suzuki, 2010), and the separation of knowledge across disciplines (e.g. arts and science) that is typical of the Australian school curriculum.

The sequence of professional learning workshops conducted over the school year was structured around the following phases:

- Term 1 - Provocation
- Term 2 - Redesigning curriculum and pedagogy
- Term 3 - Enacting the redesigns and collecting student data
- Term 4 - Evaluation and documentation of the data. (Paige, Hattam & Daniels, 2015)

Data collection and findings

We have been informed through teacher interviews, student and teacher journals, student work samples and teacher presentations and reflections at workshops and conferences. After teachers were introduced to the futures approach we asked them a series of questions: *How did you go about introducing futures to your students? How do you think they coped with/managed the focus on futures? What messages from the students stand out?*

The findings are organised around two key themes:

Part A: Engaging students in futures scenarios (illustrated narratives and persuasive text)

Part B: Student examples and emerging themes.

Part A: Engaging students in futures scenarios

The teachers used two strategies to engage their students in imagining possible futures for their wetland: illustrated narrative and persuasive text in response to a stimulus.

Illustrated narrative

One of the teachers, a resident of the area for twenty years, indicated that she could not herself imagine that a wetland was possible, yet one was now established. She encouraged the students to imagine how the wetland could look in 30 years and to write and draw what they envisaged as an illustrated narrative. She says,

We brainstormed what the wetlands could look like in 30 years. This included things like flying cars, robot rubbish collectors, Pokémon hideouts and automated 'just about everything'. This is more of a reflection of the cartoons they watch on Netflix.

However, on further discussion, students started to ask questions about possibilities for the wetland. They started to reflect on what they loved about the area in its present form (the playground, the bridges and waterfalls, birdlife, the lizards, and plants as well as fishing) and then proceeded to think about the future of the wetland. Through guided instruction from the teacher the children generated a creative list of 'I wonder' questions.

I wonder if we could camp there? Could we build a cubby house? Could scientists establish a breeding program? Could we protect the fish by introducing a fishery program? Would camping affect the animals? How could we camp there without destroying the wildlife? Could we have an underground viewing chamber, so we could see the fish and macro-invertebrates? Could we expand the wetlands so that small boats or hovercraft could be used for fishing? Imagine if we could build a restaurant with glass panels so we could see across the wetlands. Is it possible to create an enviro-dome for the birds to protect them from predators?

This imagery allowed students to understand that they can contribute to creating a future for the wetlands.

Persuasive text in response to a stimulus

A second strategy involved a teacher-generated stimulus designed to evoke the futures scenario writing. The teacher wrote a stimulus letter, purportedly from the Local Council, to encourage students to think about why the wetlands were important to them. This letter indicated that the Council planned to fill in the wetland and use the site for housing. The students responded with their own *Save the Wetlands* letters to persuade the Council to reconsider this plan. These persuasive texts demonstrated the students' invested commitment and connections with the wetland as a place of significance and belonging and a part of their community—their future vision for the wetland. The teacher reported that the students became advocates and showed a real understanding of the importance of citizens defending their rights to protect the wetland.

Through their previous involvement in a locally-developed Biodiversity Corridors project students had already been introduced to the history and geography of the wetland. Subsequent lessons focused on water sustainability and water surveys which gave students the chance to build on their knowledge of how water is used, the concept of water harvesting, and sustainable practices. These lessons were complemented with weekly visits to their wetlands during which students developed a keen interest and enthusiasm for investigating the importance of waterways to wildlife and people with the help of 'citizen scientists' and 'citizen science projects'. Students became passionate about the possibility of losing the wetland to housing developers as we illustrate in Part B using examples from their *Save the Wetlands* letters.

Part B: Student examples and emerging themes

An analysis of a selected sample of students' scenarios provides a strong indication of the value of futures work for students' cognitive and socio-emotional development. A more comprehensive analysis of student work samples is planned when further data is collected. We analysed student work using a framework of four dimensions: cognitive learning, ecojustice, social justice, and physical health. Together, these dimensions provide us with insights into the value of the wetland study for students' overall healthy development (see, for example, Louv, 2011). Cognitive learning involves 'knowing about' and is valued in student assessment by the school and education system. However, ecojustice and social justice connect with students' affective and socio-emotional development. Baldwin (2017, p. 143) argues that 'Water and its management … evoke deeply held values and emotions' and are thus related to the affective. Although ecojustice and social justice tend to be less valued than cognitive learning—they relate to students' mental and emotional health. In addition, through their visits to the wetland, students engaged in physical activity which has significant implications for healthy child development. As Louv (2008) observes, 'the quality of exposure to nature affects our health at an almost cellular level' (p. 43).

The development of an ecojustice disposition comes through strongly in the future scenarios.

Both the cognitive (knowing) and the affective (feelings/connection) are clearly evidenced. Students are developing a social conscience and are prepared to be active participants in the current and future management of the wetland. They also see the value of the wetland as a place of learning, relaxing, exercising, meditating—a place of peace and reflection.

Futures scenarios Analysis
Ecojustice (positive student statements) ***I strongly believe the wetland shouldn't turn into houses because we can feed the ducks and the fish, count the ducks, do the testing, play at playground. If it turns into houses and then there will be nothing.*** ***You will kill all the macro invertebrates and where would the ducks live? If you cut the plants/trees down there will be no more oxygen because they clean the air from germs.*** ***The little grass bird wrote down a message 'you have been destroying our homes and eating all our food. You are going to kill us. Our babies will be disturbed and die from fright. We will have to leave and go to a different home. But we like it here! You don't want to leave. It's not fair that you can destroy our homes and we can do nothing much about it". Little grass bird flew through the window and placed the note in front of the fishermen. When the fishermen read it they could understand what the birds were saying and why they attacked them. From that day on the fishermen were careful about the nests and gave equal fish to the birds.*** ***The waterfall gets cleaned out every week and a half and if it doesn't get cleaned out it will not clean any more water because it will be too full.*** ***Okay I think that the next thing that we should do is to go to the things that keep out litter.***
Ecojustice (negative student statements) ***The wet land has gone and that's where the animals lived.*** ***The whole wetland was on fire and burning orange and yellow everywhere.*** ***We walked around the whole wetland, but the water was pretty polluted.*** ***Over the last 20 years there have been campers, bridges and domes built in my home which is wrecking it! I have had enough.*** ***We started complaining about the campers. The geese have lost their home to fishermen and there is barely any fish left. The Pelican complained that the fishermen are disturbing them when they come in their boats and steal their fish.***
Learning: Social justice (Access to the commons) ***Some people do their exercise there and they take the dog for a walk. If you put/build houses there, where would they go?*** ***I went for a walk around my old school… And memories came flooding back to me - my friends, teachers and just people I know but are not really my friends.***
Learning: Cognitive ***Then we arrived at the wetlands. All the students were so excited to see the wetland and meet the wetland's scientist. The scientist worked at the colourful tree house. The scientist told us her name, which was Miss Emily, and she told us lots of facts about the wetland. We enjoyed it.*** ***We went to the wetlands nearby and did testing on Tuesdays and Thursdays.***
Learning: Physical & mental well-being ***I love the wetlands - it's so clean and shimmering in the bright hot sun.***

Supporting observations from a teacher:

Each morning I would be bombarded with ideas, research and questions from students. I introduced a Learning Journal so students could write down their ideas and I would look at them when time permitted. I implemented many of their ideas, so they realised I valued them. I would allow time for students to present their ideas and receive feedback from their peers.

Persuasive text in response to a stimulus

An analysis of a sample of the persuasive texts also provided strong evidence of valuable and deep learning.

Persuasive text in response to a stimulus
Ecojustice ***Firstly, you will kill all the living things in the wetlands that help the environment in all different ways. You are destroying habitats of the birds and any other animals and there would be endangered species of birds or animals in the wetlands. There could also be a rare species of birds and animals and a new species of birds and animals.*** ***The macro invertebrates are dying because the water is polluted.*** ***I am against your decision to take down the wetland and build a house block because there are living creatures and plants that help the environment and will die because of construction.*** ***Where would ducks and fishes lay their eggs?*** ***If there were no more wetland, you mightn't find any new birds and we won't be able to explore the wetland any more.***
Social justice ***Now think of all those families that go to the wetlands they have picnics, a walk around the wetlands, kids play on the playground and people enjoy relaxing and watching ducks and other birds. Just think how disappointed they will be when the next time they go to the wetlands, the wetlands is filled in and houses are being constructed.*** ***If you take down the wetlands our families and ourselves will have nowhere to hangout.*** ***It is a beautiful place where people go and look at the cute little birds and the beautiful stuff, especially old people.*** ***What I am trying to tell you is that room 17 is connected to the wetland.*** ***Where would the kids play?*** ***Where would room 17 have a picnic?***
A learning place ***Room 17 has been going to the wetlands to test the water and learn about birds and macro-invertebrates.*** ***It takes way too long to go to a different wetland for our learning. If we don't go to the wetland that would take away nearly 50% of the learning that we do. Also, we help the NRM and the University as well as our own learning. We help them by collecting water.*** ***How could we do our testing?*** ***We go to the wetlands and collect the rubbish, practice mapping the wetland and drawing birds.***
Recreational ***Now think of all those families that go to the wetlands they have picnics, they walk around the wetlands, kids play on the playground and people enjoy relaxing and watching ducks and other birds.*** ***How could we go for a walk with our class?*** ***There will be no more family walks.***
Physical and mental well -being ***Lots of people go there just to look at the scenery and relax, watch the ducks, walk around the wetland and much more.*** ***We will be sad and mad at the same time.*** ***I go there sometimes for a walk for peace and quiet.*** ***You will take away all the memories we had as kids and we see all the community doing things there as well.*** ***Please don't take our wetlands away.***

A second teacher explained that by the end of the topic students had identified key issues such as pollution, storm water, illegal dumping and water leaks and this was accompanied by a readiness to take action. She explains:

This was due to the lessons on civic responsibility and government to respond to situations identified during wetland visits. By this time in the project the students had had experience in taking action and were familiar with the local and state government bodies that they could approach in protest to this happening. They also knew so much about their wetlands that they could use their knowledge and experience to discuss and argue against the stimulus proposal confidently.

Discussion

When referring to how students managed the focus on futures, one teacher commented that the futures narrative writing allowed students to consider the possibilities of a futures wetland. They were excited and inventive about the possibilities and considerate of the wildlife. For example, a camping narrative from one student was written from the perspective of the ducks and the disturbance to their habitat. The teacher also commented that the persuasive text responses to the stimulus letter was extraordinary. Her words below tell a powerful story of what happens when students are connected to their place:

The stimulus I created incorporated our discoveries; a fly fisherman talked about European Carp in the wetlands, Genius Hour, we learnt not to feed the ducks bread because it makes them ill, we learnt about the cost of maintaining the stormwater drains. I included all of this in the stimulus as evidence to why the wetlands would be redeveloped. I finished reading the letter to the students at 5 minutes to home time. They just sat there and stared. Not a word was spoken. The bell rang. The students kept silently staring. Then one student called out, 'Let's protest!' The break in silence created a storm of questions and ideas. At 5 minutes after home time, I stopped the students and told them the letter was a stimulus to help them write a persuasive text. Relief washed over them, this was the indicator that the students were totally committed to the preservation of the wetlands. The realisation that they play a part in its future.

The students also wanted to inform their community about the importance of looking after the wetlands and worked hard to create brochures to present at the local shopping centre. This was a challenging experience for most of the students, who overcame their shyness in talking to strangers as they shared their knowledge and passion for looking after the wetlands.

The teacher believed that student interest in the project and their futures thinking was tied very strongly to the fact that there were weekly visits to the wetlands and the creation of a sense of belonging to place.

I had many conversations whilst walking with students, many of whom expressed their joy in watching the wetland changes and bird life change through the seasons, asking questions or posing ideas about their questions. Often students' comments dwelt on imagining what the wetlands would look like in a future season or when they were grown up. Some said they hoped that it was going to be a place they could bring their own children to one day. They talked about building glass bridges to walk over the water so you could look into the water and see what was there, building a waterfall that would clean the water like a giant filter, creating tree houses where you could go to watch the birds without disturbing them or that could be like a restaurant where people could eat and enjoy looking at the birds.

In conclusion

Students have identified in their futures writing many of the problems with maintaining and improving their local wetland; their place. They have come to a working understanding of wetland ecosystems and the need to value all of the species that live there including humans, an ecojustice mindset. Our analysis suggests that the issues students feel strongest about are keeping the wetlands healthy and vibrant with abundant flora and fauna for the future generations. What they don't want is the wetlands turning into a drain or housing estate. Their understanding and connection to place resulted in them being able to internalise what the loss would mean to themselves and community. Active citizenship, both local and planetary, was a critical aspect of this transdisciplinary unit of work. There was evidence that teachers valued the development of children's futures thinking and enactment. They listened to the children's visions and supported them to take action to get there.

We conclude using two teacher comments that we think encapsulate the value of the futures work in the Water Literacies Project:

Whilst some of the students struggled to create narratives that captured future scenarios of possibilities for the wetlands most students were able to draw future possibilities with vision and creativity. All of the students were able to discuss its importance to themselves and many could articulate what its loss could mean to themselves and the community in the "save the wetlands" writing.

I think that it is due to the students' connection with their place that made it possible for them to try to imagine the future of the wetlands.

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ORIGINAL PAPER

DOI: 10.13135/2384-8677/2774

Science Education Futures. Science Education as if the Whole Earth Mattered.

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Abstract.

In 1990 a gathering of ecopsychologists took place at the Harvard Centre for Psychology and Social Change to participate in a conference entitled “Psychology as if the Whole Earth Mattered”. They concluded that “if the self is expanded to include the natural world, behavior leading to destruction of this world will be experienced as self-destruction” (Roszak, Gomes, & Kanner, 1995). I take this idea into the realm of science and science education which I suggest requires a reconfiguration and extension of science into a new inter- and trans-disciplinary realm of sustainability science with implications for renewed pedagogies of science in schools and universities. Such a changing perspective requires greater vision, creativity and imaginative approaches to address the problems currently facing the planet and the future of humanity. This paper provides an overview of a journey in science education over the years covering a range of views around science: starting from what we might consider to be the idea of modern science and how that science has been transformed into “big science” and “techno-science”. Further, in the current era of the Anthropocene (Steffen, Crutzen, & McNeill, 2007) it can be argued that such approaches to science need to be reformed to take account of ideas such as post-normal science (Funtowicz & Ravetz, 1994), sustainability science (Clark & Dickson, 2003) and holistic science (Bohm, 1980; Goodwin, 1997). Using the concepts of planetary boundaries (Rockström et al., 2009b) and doughnut economics (Raworth, 2012, 2017) as a framework, consideration is given to what this might mean for science education futures.

Key words. pedagogies of science, techno-science, planetary boundaries, doughnut economics

ISSN 2384-8677 **DOI:** http://dx.doi.org/10.13135/2384-8677/2774

Article history: Submitted March 11, 2018. Accepted May 23, 2018

Published online: June 04, 2018

Citation: Gray, D. (2018). Science Education Futures. Science Education as if the Whole Earth Mattered. *Visions for Sustainability,* 9: 60-76.

Competing Interests: The author has declared that no competing interests exist.

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Perspective*: Educational visions*

Fields*: Earth Life Support Systems, Economy and Technology*

Issues*: Sustainability science*

Introduction: Science, Society and the Age of the Anthropocene

It has become apparent in the closing years of the 20th century and the opening of the 21st, that a crisis in science, encompassing the "roles and social functions of science" (Saltelli & Funtowicz, 2017, p5) has progressed hand in hand with another crisis, that of the overstepping of the 'planetary boundaries', (Rockström et al., 2009a, 2016; Steffen et al., 2015) thereby resulting in an unsafe operating space for humanity. We are now said to be living in the Anthropocene, a term coined by Eugene Stoermer and popularised by Paul Crutzen, put forward to suggest that we have entered a new epoch characterised by the human impact on the planet (Crutzen & Stoermer, 2000). This is an epoch in which human beings and their societies have become a global geophysical force capable of creating global level changes in the biological fabric of the Earth; the stocks and flows of major elements in the planetary machinery such as nitrogen, carbon, phosphorus, and silicon; and the energy balance at the Earth's surface" (Steffen et al., 2007, p614).

Such are these crises that many, very prominent, scientists have passed comment on them. Jane Lubchenco, for example, in her presidential address to the American Association for the Advancement of Science stated:

> *The world at the close of the 20th century is a fundamentally different world from the one in which the current scientific enterprise has developed…" and "…Business as usual will not suffice* (Lubchenco, 1998, p492).

Just a few years later, in the new millennium, Peter Raven, the then president of the AAAS, suggested that "We need new ways of thinking about our place in the world and the ways in which we relate to natural systems in order to be able to develop a sustainable world for our children and grandchildren" (Raven, 2002, p958). More recently, the eminent physicist, Stephen Hawking, suggested in his UK Reith Lecture in 2016, that "most of the threats we face come from the progress we have made in science and technology", (Hawking, 2016, p7). Hawking went on to suggest that we will have to recognize the dangers and control them. However, the Earth is a complex open system and predictability and control in a complex open system is not possible with any certainty (Solé & Goodwin, 2000). This has implications for how we conduct science and how we use the knowledge gained from science. While modern science is held up as the apogee of modern civilization and has achieved a certain hegemony in Western culture, thought and institutional practice, this very hegemony has resulted in the "delusive belief that science and only science could find proper answers to any and all questions that human beings might ponder" (Bauer, 2004, p643).

There are many commentaries from the field of science studies which have sought to articulate the changing nature of science in society. All these perspectives indicate that science has moved away from what might be considered as the more traditional, historical idea of science, what Gibbons et al. (1994) call Mode 1 knowledge production, or Ziman (1996) calls "academic" science. The new forms of knowledge production are much more distributed, interdisciplinary and applied, often with connections to industry and commerce. Such new configurations of science, Mode 2 (Gibbons et al, 1994), post-academic (Ziman, 1996), the Triple Helix of university – industry – government relationships (Etzkowitz & Leydesdorff, 2000; Etzkowitz & Zhou, 2006) have resulted in complex, larger scale and high impact forms of science knowledge production.

Science and Corporate Interests

The term "Big Science" (Weinberg, 1961) refers to the way in which, following the second world war, the scientific enterprise developed a new form of working which required large budgets, often provided by governments and linked to military and energy research, conspicuous staffs, big machines and big laboratories. The number of scientists employed on research projects grew from the small teams in research departments in institutes or universities into several hundred individuals working on big projects, such as those at the CERN particle accelerator in Switzerland. As described by Aranova, Baker, & Oreskes (2010), academic research had increasingly become bonded to big government and big industry. This had transformed science from an individual initiative into a collective enterprise, requiring large interdisciplinary government-funded teams of researchers as a major feature of this novel organizational form of scientific research.

While there has been considerable academic theorisation in the field of science studies, which has often created tension between the idea of the "hard facts" of science and the idea of science knowledge being, at least in part, a socio-cultural construction (Longino, 2002) perhaps some of the ideas about how we are in our current predicament can be extrapolated from examination and compilation of different aspects of these theorisations.

So on the one hand the crisis in science is a result of the institutional entrenchment of the corporate organization of science as it is currently structured, which has given rise to what Bauer (2004) calls *knowledge monopolies* and *research cartels*, controlled and funded by large multinational interests. On the other hand, the crisis is, arguably, also caused by an outmoded way of thinking in science which, while very successful at certain local levels, when applied to global issues and planetary dynamic systems, fails and, in fact, has the potential to cause catastrophic harm to ecosystems and human populations, particularly when tied to corporate global developments.

In summary, what we have in science and technology is a greater and greater alignment between the sciences and industry, often supported by governments. The direction and choices made with respect to the sciences is largely dictated by the needs of industry, with, perhaps, universities taking on an increasing role in commercialisation ventures related to the production of scientific knowledge. Of course, this is an oversimplification but it essentially is the underpinning driving force behind the undertaking of science and the underlying reasons for encouraging what has come to be known as STEM education in schools. With the acronym STEM, a clear indication is given of the applied nature of science education, privileging those subjects which may be associated with economic and industrial ventures (The Scottish Government, 2016). Coincidentally, and almost to prove a point, the title of a seminar organised by Scotland Policy Conferences in 2018 is "Next steps for STEM education and training in Scotland: widening participation, improving delivery and *meeting the needs of business*" (Scotland Policy Conferences, 2018). Thus the way in which science has been conducted in the post-war period has been largely for the benefit of industry and global enterprise, together with resultant social benefits, but at an environmental cost which has been largely ignored. While this form of scientific knowledge production remains the dominant world paradigm, there is little incentive from industry and governments to critically examine the content and purpose of science education. What is important, therefore, is that education needs to focus on questioning this dominant economic world view, replacing it with an ecological world view and a science education which is commensurate with such a world view. Unlike an economic world view, which mentally disconnects human progress and economic growth from the biosphere, an ecological world view recognises that humanity is deeply intertwined with, and is part of, the natural environment, there is no separation (Folke et al., 2011; Zweers, 2000). As such we need to consider what is important now and for the future, and to consider the type of science education, its contents and objectives, required to address these. Later I set out a provisional framework as a foundation for exploration, discussion and development. Before this, however, there is a need to examine the philosophical and practical foundations on which modern science has been built.

The Limits of Reductionism

Perhaps one of the fundamental aspects we must recognise with respect to current, modern, science is the foundation upon which it has been built, the notion of reductionism. Reductionism is, quite simply, the idea that the scientist can focus on the parts of any object, process, or system and by understanding the parts it is possible to assemble the parts to understand the whole. In many spheres this is acceptable and practicable but only if the phenomenon under investigation is a simple, mechanical or closed system. To that degree reductionism has been incredibly successful in producing many of the materials and processes that we take for granted today. However, there is a growing recognition of the limits to reductionism, "…reductionism is inadequate as the primary explanatory framework of science. Progress in understanding natural phenomena … involves grasping relevant aspects of whole systems" (Solé & Goodwin, 2000 p.19). Recognition of the limitations of reductionist science is not new, many scientists have recognised this and have suggested more systemic approaches (e.g. Katagiri, 2003; Lucadou & Kornwachs, 1983; Regenmortel, 2004). However, Bortoft (2012) critiques the claim made by systems thinkers that it is holistic, suggesting "it is in fact much more reductionist in practice than many of the optimistic pronouncements about it would lead us to suppose" (p13). Such a view of supposedly holistic approaches, such as systems biology, are not unique to Bortoft, with other critics also pointing out that systems approaches often fall short. Joyner & Pedersen (2011), for example, while applauding systems biology for recognising the limits of reductionism suggest that it "continues to fail to recognize that a variety of integrating functions between cells, organs, systems, the entire organism and the environment are required to generate a fully functional and highly adaptive animal" (p1020). Bortoft addresses this limitation in systems thinking and offers a different approach to wholeness, which will be considered later.

A Multiplicity of Legitimate Perspectives

A result of the gradual recognition of complexity in Earth systems is that it has led to a realisation that "normal" science (Funtowicz & Ravetz, 1993) cannot be privileged when it comes to decision making in policy processes around socio-environmental issues. Such recognition led to the development of the concept of post-normal science by Funtowicz & Ravetz (1993). In post-normal science the two attributes of systems uncertainties and decision stakes are used to determine the type of science that can be used. When either attribute is high, then the traditional methodologies of modern science are ineffective and, in those circumstances, an 'extended peer community' is required in order to provide greater quality assurance of scientific inputs to the policy process. Such an extended peer community consists of all those with a stake in the issue. In this way post-normal science can provide a path to the democratization of science. Such ideas are rarely, if ever, encountered in a science classroom or science lecture hall.

However, the idea of sustainability science, which seeks to understand the fundamental character of interactions between nature and society, is perhaps starting to become more mainstream. In order to do this, such a science must encompass the interaction of global processes with the ecological and social characteristics of particular places and sectors, and research will have to integrate the effects of key processes across the full range of scales from local to global (Kates et al., 2001). There is clearly an overlap with ideas contained in post-normal science, although the fundamental difference is that post-normal science is predominantly focussed on the processes that science and policy must engage in when dealing with decision making in complex socio-scientific/socio-environmental issues, whereas sustainability science is more focussed on the way in which science itself is conducted when grappling with such issues. As Kates et al., (2001, p641) state:

> *sustainability science that is necessary to address these questions differs to a considerable degree in structure, methods, and content from science as we know it*.

The implications for science education

So, if there is a need for a practicing science that "differs to a considerable degree in structure, methods, and content", to what extent is this being addressed in core science courses in schools, colleges and universities? Certainly there are moves in this area with a number of courses on sustainability science, very often at Masters Level, being provided in higher education institutions around the world.

However, arguably, there is still little indication of these changes occurring at school level or undergraduate science degree courses. Perhaps what is important to note is what Clark (2007, p1737) states with respect to sustainability science as "a field defined by the problems it addresses rather than by the disciplines it employs". From the recent thinking in post-normal and sustainability science, with recognition of complexity and the intractable interconnectedness of socio-environmental systems, I would suggest that there are a number of issues which need to be addressed in science education. One is the "how" of science and another is the "what" of science.

Towards new visions for Science

According to Bortoft (2012) the current predicament we find ourselves in on the planet is largely as a result of our approach to the production of scientific knowledge. This approach is a Newtonian mechanical philosophy and the mathematical physics of nature; and is a Verbal – intellectual (computational, representational) approach which subjugates the sensorial and experiential. It situates science "outside" of Nature; and is built on a foundation of Cartesian dualism. While some alternative approaches to science, such as the sustainability science already mentioned (Kates et al., 2000), which recognise our situatedness in nature, are becoming more mainstream, others such as Goethean and holistic science (Bortoft, 2012; Goodwin, 1997; Seamon, 2005) still remain at the fringes. It can, however, be argued that some of the principles they advocate are important in developing a new sense of connectedness and embeddedness within the natural world, as well as offering more engaging and enactive forms of science education. At the same time, it should be stated that adopting more holistic and phenomenological approaches to science does not mean rejecting in its entirety reductionist approaches. Each have their place. As Maurer (1999) stated with respect to understanding ecological systems:

> *this is not to say that reductionist science cannot help scientists understand ecological systems. I am simply arguing that reductionist science alone will not suffice* (p7).

Reductionist approaches in science are not appropriate for the study of global environmental issues, perhaps an argument to be pursued is the degree to which we require reductionist science at all. Such an acknowledgement recognises the inherent unpredictably of complex open systems and the capacity for such systems to reach a tipping point when they will "flip" into a different configuration. Such a "flip" can be significantly, and possibly dangerously, different from the system it emerges from. The science of complexity has been described by Goodwin (1997) as a holistic science, which seeks to describe the properties of complex wholes. Such an understanding is very different from the Newtonian mechanistic principles on which modern science has been built. We thus see that, in sustainability and holistic science, there is a need to move from a mechanistic to a holistic perspective, which entails a move from seeing phenomena as a simple linear chain of events to a vision of complex, non-linear phenomena, which are inherently uncertain and unpredictable. We also need to recognise that human systems are inextricably bound up within natural systems and human beings are embedded within their environment and not detached and separate from it. Sustainability science, therefore, needs to focus on the dynamic interactions between nature and society "with equal attention to how social change shapes the environment and how environmental change shapes society" (Clark & Dickson, 2003, p.8059). Solutions to such problems need to be ''coproduced'' through close collaboration between scholars and practitioners, in a way similar to the idea of the extended peer community suggested by Funtowicz & Ravetz (1993).

We can thus see that there is a move within the sciences themselves to begin to recognise different ways of approaching knowledge about the world. Ways which recognise that the Earth and the systems upon it do not behave in the way suggested by Newtonian and Cartesian mechanistic science, although their principles may still have some role in future science.

However, it is important to recognise that modern science, as currently practiced is only one way of knowing. The direction taken by modern science was only one possibility, the choices made at the onset of this modernity opened the door into the way that followed, but at the same time it closed the door to other possibilities (Bortoft, 2012). Or, as Hutchins (2010) suggests with reference to Bateson's view that boundaries should not be placed across important communication lines in a network, something which happens often in reductionist science, "Every boundary placement makes some things easy to see, and others impossible to see. The danger of putting boundaries in the wrong place is, as Bateson warned, that doing so will leave important phenomena unexplained, or worse, inexplicable"(p706). What future science must do is to open up the doors to other ways of seeing so we begin to approach knowledge and the production of knowledge in a new way. *"A change in the way of seeing means a change in what is seen"* (Bortoft, 2012, p143). It can also be argued that in order for there to be a change in the way of seeing, scientists must recognise that there is no real separation between themselves and the phenomena that they are investigating. This process, which Goethe called 'delicate empiricism' (Zarte-empirie) is described by Naydler (1996, p71):

> *The Goethean scientist seeks to participate in the objects investigated to such a degree that the mind makes itself one with the object, thereby overcoming the sense of separateness that characterises our normal experience of ourselves in relation to the world.*

Such a recognition begins a transformative process for the scientists involved. Many authors have suggested that Goethe's vision of science offers some prospect for a renewed approach to science (e.g. Amrine, 1998; Bortoft, 2012; Franses & Wride, 2015; Hoffmann, 1998; Seamon, 2005). Goethe suggested that direct experiential contact was the basis for scientific generalization and understanding, but that the experience was only the beginning of a rigorous scientific process.

Science Education

While a crisis in science caused by the close association between corporate business and the scientific community has been posited, at the same time it has also been suggested that there is a crisis in science education which emerges every few years (Aubusson, Panizzon, & Corrigan, 2016; Gilbert, 2016). The claimed crises in science education usually focus on the perceived reduction in young people's science knowledge and interest in science, although the legitimacy of such claims is disputed (Gibbs & Fox, 1999). As suggested earlier, this crisis usually relates to the apparent drop of young people's interest in science subjects, and their continuation into higher education or careers in the sciences. In the UK, for example, the House of Commons Committee report on Science Education (HCSTC, 2002) in 2002 described the science provision as being required to provide a general science education for all but also to inspire and prepare some for science post-16, stating that "it does neither of these well" (p.5) with most science taught at ages 14–16 having "remained largely unchanged for decades" (p. 16). This apparent drop in interest is seen as problematic in policy areas largely because of the perceived importance of science for economic competitiveness, as well as for quality of life (HCSTC, 2002). However, while the crises in science education often focus on young people's performance in science, or their inclination to go further in science and pursue careers in science, the actual science contained within science education is very often not subjected to close scrutiny. What is rarely recognised is the connection between the role that science plays in the economic sphere and the growing impact that this is having on the planet and on human societies. Others, however, have recognised that the way in which science is introduced in schools today is not necessarily conducive to nurturing a way of thinking which recognises the complexity of environmental problems, nor offers a way of thinking which can contribute to dealing with those problems. Ashley (2000), for example queries whether science is an "unreliable friend to environmental education", suggesting that "Almost all pupils…are presented with a view of science that is still largely influenced by logical positivism, reductionism and the 'value-free' thesis. It is, furthermore, a curriculum that is driven primarily by the goal of selection for university entry" (p275). Carter (2005) points out that the complexities of our increasingly globalised world and technoscientific society are not well elaborated in school science education, a point dealt with by Gray & Colucci-Gray (2014). Even Aubusson et al.'s (2016) consideration of science education futures does not deal with this in any depth. However, Gilbert, (2016) does recognise that it is perhaps time to reconsider this, stating, in relation to our fossil-fuel based existence, that "…if we accept that carbonised modernity is coming to an end, then we have to accept that science education as we have known it must be transformed. Substantial rethinking—of its content, its purposes and its relationships—is required." (p.188).

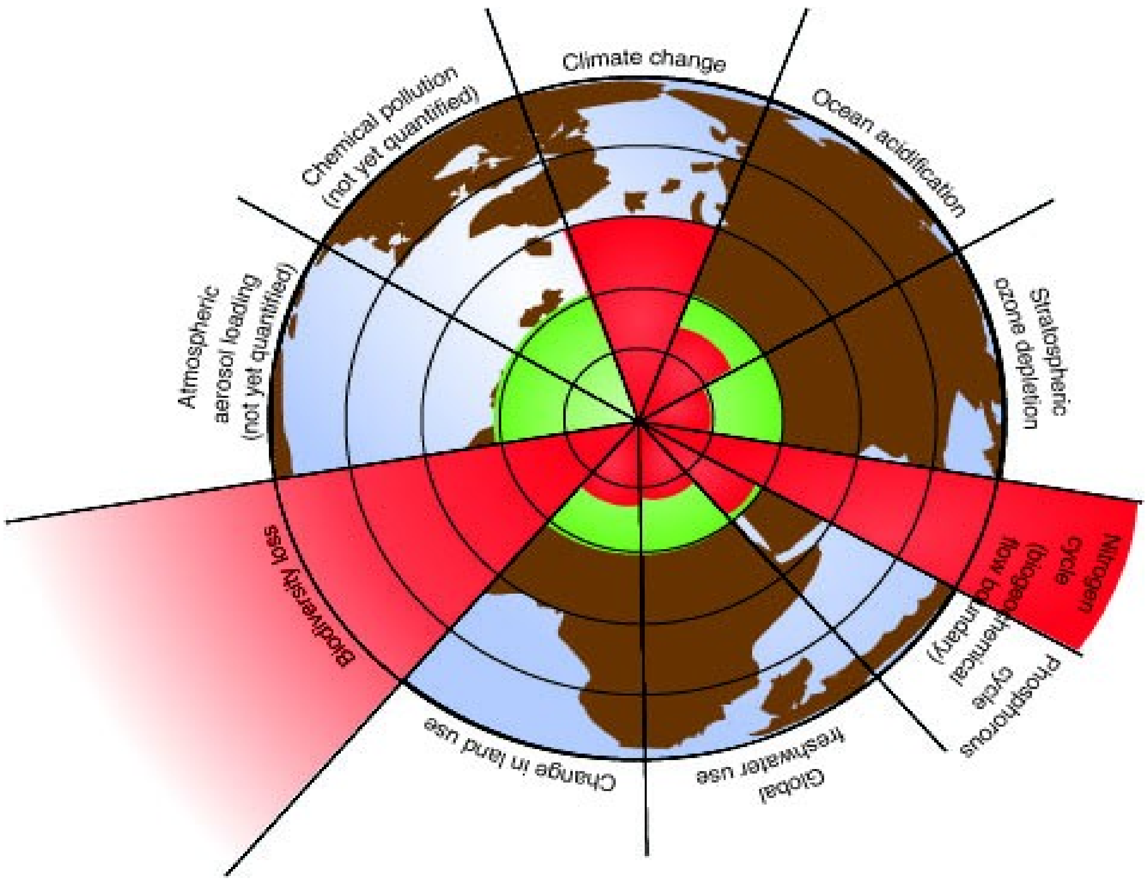
Similarly Osborne's (2007) consideration of science for the twenty-first century, while having much to commend it, and recognising that science education is important in addressing global issues, focuses very largely on classroom based pedagogy and argumentation in science. Much of previous literature in science education still regards science as verymuch a conceptual, "in the head", process and largely ignores recent work on embodied cognition and socio-materiality (Gallagher and Lindgren, 2015), which, it can be argued, may prove to be a critical factor in developing positive environmental attitudes, enhanced learning and engagement with science.

What visions for Science Education Futures?

In the preceding paragraphs some of the current critiques of modern science have been outlined, along with the need to adopt practices in science which acknowledge and integrate other forms of knowledge and other approaches to generating knowledge and understanding of the world around us. Adopting new thinking in science education, which recognises the complex, interdependent nature of the planetary cycles, will help in developing new approaches to addressing problems at the planetary scale. Thus, the following paragraphs will look at what the implications of such recognition might be for a science education futures.

For science education to be relevant and appropriate to current concerns it must do three things. It must cover the science that is necessary to understand current planetary problems, which includes understanding ideas around complexity. It must recognise that science is only one way of gaining knowledge and should be able to engage with other forms of knowledge in dealing with complex problems; it must incorporate current understanding about cognitive process and associated pedagogies to enable learners to effectively engage with and understand the issues and phenomena they are investigating, as well as their own way of investigating, observing and making sense of the inquiry.

With respect to necessary scientific knowledge required to understand issues around the Earth systems, the planetary boundaries model proposed by Rockström et al., (2009) provides a robust framework within which many of the key concepts of science can be explored. This model identifies nine of the planet's bio-physical subsystems or processes which define the safe operating space for humanity with respect to the Earth system. It is important that these boundaries are not transgressed, yet we have already overstepped the safe operating space for three of these boundaries (see Figure 1).



"Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded." (Rockström et al., 2009a, p472)
Credit: Azote Images/Stockholm Resilience Centre

It may be felt that the planetary boundaries model does not cover all the areas of science of interest to the many different disciplines, but it can provide a good working framework for many, if not most areas of science in schools. Many key concepts already dealt with in school science, such as the carbon, nitrogen and water cycles can be reframed in relation to the planetary boundaries model to make these concepts more relevant to young people's lives and to help them in understanding the importance of these systems. There are many such issues that can be covered in this respect, issues such as air quality in cities, plastic in the oceans, the impact of industrial agriculture and meat based nutrition.

If the planetary boundaries model is taken as a starting point, it can then be elaborated in many socio-scientific issues through development and engagement with social sciences using the "doughnut" model first proposed by Raworth (2012) and subsequently further developed and elaborated to the current model in Figure 2.

Figure 2: The Doughnut of social and planetary boundaries (2017)
Source: https://www.kateraworth.com/doughnut/

In this model, the two key features consist of an outer environmental ceiling of nine planetary boundaries, as described above, beyond which lie unacceptable environmental degradation and potential tipping points in Earth systems. We must not surpass this ceiling. The inner social foundation of the model is formed from twelve dimensions derived from internationally agreed minimum social standards, as identified by the world's governments in the Sustainable Development Goals in 2015. It is suggested that society should be structured such that no-one falls below this social foundation. The space between the social and planetary boundaries is an environmentally safe and socially just space in which humanity can thrive.

We need a science education which focuses on relevant science that bridges the knowledge frontiers required by a modern economy, but also primarily provides a foundation for current and future generations to understand the safe operating space required by humanity on a finite planet. Such a science education will also address the socio-environmental problems that the sciences are, at the very least, implicated in and potentially exacerbate. Such a science education is different from the 'Big ideas in science' approach, put forward by Harlen, (2010; 2015), which attempted to set out principles that should underpin the science education of all students throughout their schooling, and takes the position of more openly addressing the earth systems approach but linking in with socio-environmental issues. In this respect it is similar to the politicized, issues-based curriculum proposed by Hodson, (2003) which, he suggests should focus on seven areas of concern: human health; food and agriculture; land, water and mineral resources; energy resources and consumption; industry; information transfer and transportation; ethics and social responsibility.

The doughnut model provides a good basis, I suggest, for considering the content of future science education programmes: a science education that deals with real-life issues, planetary stability and social and environmental justice. However, as well as a model for content, we also need to consider the way in which pedagogies are constructed.

Body, Mind and Nature in Science Education. Renaturing[1] Science Education.

As outlined above there is clear evidence from the literature around science studies and science education, that both leave much to be desired when it comes to engaging with planetary processes and socio-environmental impact of human activities. There is now a growing body of literature which provides further argument for a different approach to science education. The key element of what might be a renewed pedagogy for science education is a much greater understanding of the complex and dynamic interdependence of the body, the mind and the environment.

Much of modern science, and thus modern science education, has been foundational on the idea of the computational model of cognition i.e. that cognition rests entirely in the brain and results from a representation of the external world being present in the working mind. The second aspect is that scientists, and thus students of science, are separate from the external world which can be viewed objectively, from a neutral, value free position. Both of these foundational ideas are now subject to increasing critique emanating from a much great understanding of the relationship, and interdependency of our bodies, minds and the environment in which we are all embedded.

One aspect of this is the way in which our brains, particularly at younger ages, are shaped and moulded by the experiences we have of the world we move around in. With respect to children's development, it is important to acknowledge the changing, and highly urbanised, environment that most youngsters are now growing up in. It is more than ten years since half of the world's population migrated to urban environments with the current figure at 54% (World Bank Group, 2018) and with a projection for that to increase to 70% by 2050 (UNESCO, 2016). This figure has already reached 73% in Europe and is projected to rise to 84% in this period (UN Habitat, 2008). Arguably, one result of this increasing urbanisation is a sense of disconnectedness from the natural world, a distancing from the fabric and energies that actually sustain us on the Earth (Ives et al., 2017; Nisbet, Zelenski, & Murphy, 2009). Thus, as children become less exposed to natural environments, and more exposed to urban life and digital technologies, so their perspectives, values and attitudes toward the natural world will be changed. As Puk (2012, p5) states:

> *The developing mind is being stimulated on a daily basis overwhelmingly by technology, by media, by transportation, by books and by words rather than by wind in the trees, the smell of the earth after a rain, the ever changing movement of water, the sound of silence in quiet meadows and the awe and majesty of ecological systems.*

Such an interdependency between body and mind was noted around a hundred years ago by John Dewey, who recognised the inextricable link between body and mind, using the term "body-mind":

> *The world is subject-matter for knowledge, because mind has developed in that world; a body-mind, whose structures have developed according to the structures of the world in which it exists, will naturally find some of its structures to be concordant and congenial with nature, and some phases of nature with itself* (Dewey, 1925, p225).

Of course, it is clear from Dewey's words that the body-mind does not exist in isolation from the environment it finds itself in, since "mind has developed *in* that world", with the body being the mediator between the external world and the inner mind. This might appear self-evident but has largely been ignored by classroom-based pedagogies during the history of schooling, perhaps more so in many of the sciences which, given that they are essentially concerned with understanding the world and

1 Renature: to restore (a denatured substance) to its former, natural state. In this context we can think of science as the study of *nature*, of understanding the natural world. While essentially this is still a definition of science the use to which science has been put is more for economic gain than for planetary stability. Refocusing on nature may help to restore that balance.

nature, should actually be more engaged with experiences in the world. However, views of cognition have been largely dominated by the computational model of the mind, in which the brain constructs representation of the world inside the head, the body not playing any significant part.

Now, however, progress in neurocognitive sciences, as well as considerable developments in the philosophy and psychology of mind, have led to a much greater understanding of the role of the body in cognition, embodied cognition. Gallagher and Lindgren (2015) explain that cognition, as enactive and embodied, does not take place, as traditional cognitivist views have it, 'in the head' as some form of symbolic representation of an external world, but is rather a dynamic set of interactions between brain and body and between body and environment. While individuals are autonomous autopoietic systems, they are always systems, they are always 'structurally coupled' to their environment (Thompson, 2007) and 'structural coupling' refers to the history of recurrent interactions between two or more systems that leads to structural congruence between them (Maturana, 1975; Maturana & Varela, 1987). In other words, it is the interaction of body-brain-environment as inseparable units, thus the hyphens, which is central to cognition, to knowing. 'They produce each other, and thus are linked by a radical form of co-dependence' (Bocchi & Damiano 2013, p.123). Gallagher & Bower (2014) provide further elaboration of the idea of enactivism, which is an extension of embodied cognition. In enactivism the link between body and mind is further elaborated by the dynamic coupling of the body-mind with the environment. In other words cognition arises through a dynamic interaction between an acting organism and its environment, it does not happen through simple computational representation in the brain. However, as Gallagher and Bower (2014) suggest, an account that focuses only on sensorimotor contingencies falls short due to its neglect of the relevance of the affective domain. These aspects will include "proprioceptive and kinaesthetic aspects—factors that should be of high interest since they derive from movement and contribute to one's practical grasp of sensorimotor contingencies" (p234). Thus, it is not only the sensory-motor interactions with environment that are important in cognition but also the affective dimension, an area that has been largely ignored in science education (Alsop, 2005).

So, we begin to see that there are more recent ideas in cognition that may make a significant contribution to future pedagogies in science education, some of which have made their way into some classrooms already, but what is required is much more research and development in this area. Existing research already suggests that whole-body engagement, framed by enactive metaphors, in other words metaphors that we put into action or that we bring into existence through our action, rather than metaphors which "sit on a page", can improve learning outcomes in science, mathematics, and other subjects (Gallagher and Lindgren, 2015, p391).

Recognising that cognition is firmly linked to our lived experiences and perceptions of the environment in which we move around, leads to the inevitable conclusion that the type of environment we find ourselves in is going to play a significant role in how we see the world around us. So young people growing up in a heavily urbanised city, exposed to primarily digital technologies, smart phones and TV screens, with little access to green space, are going to have a significantly different view of the world from those who have more ready access to natural environments and whose exposure to techno-scientific developments is more controlled.

Greater engagement with natural environments, it can be argued, is thus an essential requisite for all sciences at all stages of education. All the sciences can potentially have a significant impact on the planet, as has already been demonstrated, from chemists and biologist through to engineers and physicists. It is, therefore, essential that all children and young people at all stages of education, are provided with the opportunity to become deeply engaged with the natural environment. It is only through this profound engagement that they will gain a deeper understanding of their place in that natural environment. Referring back to the beginning of this paper, and the need to expand the self to include the natural world, in order to do this we must begin to open our senses to those aspects which current scientific practice shuts down, what the author elsewhere has called "renaturing science" (Gray & Sosu, 2018)

Perhaps one way of doing this is to learn from Goethean science. While Goethe is primarily known for his literary works, he was also intensely engaged in the scientific study of a range of topics such as "plants, colour, clouds, weather, morphology, and geology" (Seamon, 1998, p1) and his approach to science, which was both intuitive *and* rigorously systematic, has been suggested as being "a valuable means for fostering a deeper sense of responsibility and care for the natural world" (Seamon, 2005, p.86), thus linking back to the idea in the opening paragraph, the necessity to nurture a more caring attitude towards the world that we are part of. This is something which, it can be argued, Goethean science attempts to do. Goethe's approach to scientific study is unusual in that it seeks to draw together the intuitive awareness of art with the rigorous observation and thinking in science (Seamon & Zajonc, 1998) and has been described as a phenomenology of nature (Bortoft, 1996). Such an approach is as much about the experiences of the scientists themselves as it is to do with the phenomenon under investigation. As described by Amrine (1998):

> *Goethe's scientific ideal is to allow oneself to be transformed in following the transformation of the phenomenon….the ultimate aim of science is nothing other than the metamorphosis of the scientist. (p.37). Essentially what Goethe did in his approach to science was to put sensory experience first rather than the mathematical modelling* (Bortoft, 2012).

Bortoft (2012) also describes his Goethean approach to science as a dynamic way of thinking, which is neither simply based on a systems approach, which acknowledges the structure of open systems and complexity, nor on the reductionist approach used in modern science which reduces all phenomena to the parts in an attempt to understand the whole. Bortoft uses the hologram as a metaphor where the whole is contained in the parts and the parts make up the whole. In order to truly understand we must find a holistic approach which requires a dynamic way of thinking that is dependent on understanding the relationship amongst the parts, " any entity is only what it is within a network of relations" (Bortoft, 2012) or as Bateson (1972, 2002) suggested "the pattern which connects".

Goethe's emphasis on the phenomenological experience as the starting point for scientific exploration, and intuitive perception, does not diminish the rigorous scientific approach that he used in his method, but it does indicate the unique connection that Goethe sees between science and art and its importance for the study of natural phenomenon:

> *… the link between art and science can provide a key to understanding Goethe's form of 'nature study' as a new ecological discipline in our time* (Hoffman, 1998, p 129).

There is thus a need to consider the contribution that the arts can make to science and science education.

From STEM to STEAM.

It is this link with art which has recently become more prominent, although perhaps for different reasons. The term STEM, originating in the USA, has been used to address concerns about apparent lack of engagement in the sciences and also in relation to the perceived need for global economic competitiveness. In the USA the Committee on Science, Engineering, and Public Policy placed greater emphasis on STEM (Science, Technology, Engineering and Mathematics) as a response to the poor performance of students in Science and Mathematics (NASCSEPP, 2005) . It also specifically linked future national prosperity with having enough STEM graduates to support the STEM workforce and, having enough STEM teachers to teach STEM subjects to the next generation (Colucci-gray et al., 2017). Incorporation of the "A" into STEM to create STEAM, again arose largely from an economic imperative, as a means to engage young people in STEM careers in order to revitalise the US economy, however, it is also suggested that such integration can be used to reconfigure science for a more sustainable future (Colucci-gray et al., 2017). As van Boeckel (2009) states: ""Art, through engaging the senses, can be a unique catalyst in developing a "sense of wonder" about nature." (p1) and "Through art, we can see and approach the outside world afresh. Art can hit us unexpectedly, catch us off-guard, and sometimes provoke us. This estrangement or defamiliarization is an important quality of art." (p2). Thus, there is an important quality to art which requires us to look afresh at the world and can move us to see things in a different way, which is complementary to the scientific way of looking at things. Hoffmann (1998), in elaborating the unity of science and art in Goethe's work as a new ecological discipline, argues that "*both* science and art are necessary to obtain a full picture of reality" (p167). There is not space enough here to elaborate on the many dimensions of STEAM, which is a contested and not clearly defined concept. However, the recent work by Colucci-gray et al. (2017) provides a significant contribution to elaboration and discussion in this area, as well as opening up avenues for further research in science education.

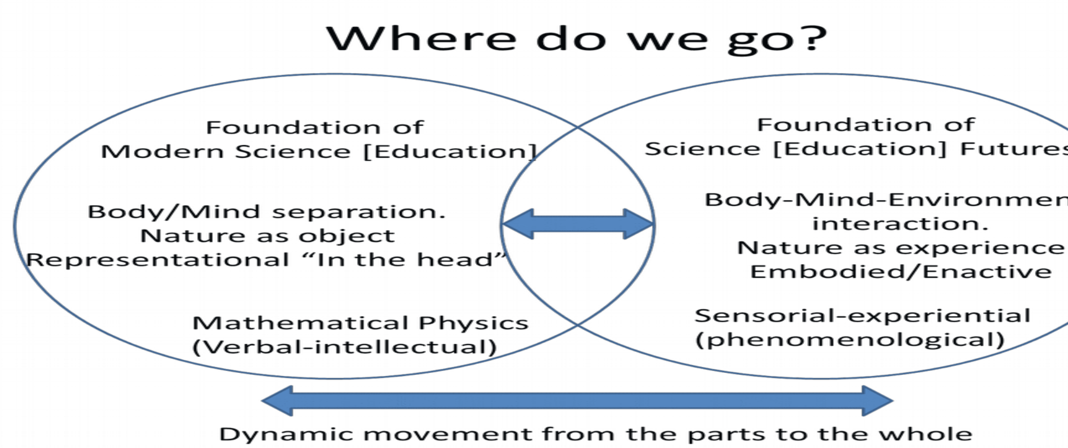
From OIL to SOIL.

In the current age of the Anthropocene, where we are beset by global problems primarily linked to industrial development and commercialisation around oil-based energy and products, and the ubiquitous digital network, it is worth referring back to the statement by Gilbert (2016) introduced earlier. If we accept, and I think most people do accept, that carbonised modernity, as we know it, is coming to an end and that we can manage to resolve the problems it has created, then we must consider what form science education takes to prevent such global problems reappearing in future. This article has tried to address some of the issues and propose some areas that we can look at to try to re-orientate science education away from an economic perspective to a more eco-logic perspective. There has to be a renewed focus on the purpose of science education, which, it can be argued, has to be about providing a much greater understanding of the interconnectedness of global systems and our embeddedness in those systems. For too long science and science education have acted as if we can safely situate ourselves outside of Nature, when in fact we are an embedded part of it. This must be recognised and science education reconfigured to reflect that. The North-East of Scotland is one of the leading centres for oil and gas developments in Europe and, interestingly was also home to one of the early pioneers of environmental education, Patrick Geddes. Geddes was very much of the mind that we need to get young people outside to experience nature and we should keep his words in mind as we move forward:

> *…the advocates of science have not succeeded in fully adapting their studies to the growing mind…too much the advocacy of "Natural Science," and too little an opening of the classroom into Nature itself, a leading out of the pupil into direct and first-hand acquaintance with her varied and living reality...* (Geddes, 1902, p.527). …
> *Nature is thus the ultimate teacher and examiner no less than examinee.* (p.528)

Summary

The diagram below is an attempt to provide an overview of some of the arguments presented in this paper as we, inevitably, must transition from a modern science [education] built on some foundational propositions and perspectives, to a future oriented science [education] which learns from the mistakes of the past and endeavours to put the Earth at the centre of our thinking rather than commercial exploitation.



What does this mean for Science Education Futures? The following are some suggestions that emerge from the visions this paper has endeavoured to present. We should let Nature be the teacher. Ensure its presence as the natural environment in which our mind develops and learning takes place. Thus we should start with experience. The expert is one who experiences. To experience we should use the body in order to move and act. The human body is a learning body that explores, discovers and builds through experience. In all our activity we should use technology wisely. Consider carefully the human value schemes and the socio-economic interests involved in its development. As we learn we should integrate the scientific knowledge we build with other knowledges. Interdisciplinary and transdisciplinary perspectives enhance the why, the what and the how of science. Above all, we should remember the doughnut! Our future (not just that of science) depends on maintaining the fragile balance between environmental safety and social justice.

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VISIONS REVIEWED DOI: 10.13135/2384-8677/2783

Mauro Balboni, (2017) *Il pianeta mangiato, La guerra dell'agricoltura contro la terra*, Lucca: Dissensi

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ISSN 2384-8677 **DOI:** http://dx.doi.org/10.13135/2384-8677/2783

Published online: June 21, 2018
Citation: Cingolani, G. (2018). *Mauro Balboni, (2017) Il pianeta mangiato, La guerra dell'agricoltura contro la terra*, Lucca: Dissensi, *Visions for Sustainability,* 9: 00-00.

Competing Interests: The author has declared that no competing interests exist.
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As the world population is projected to reach 10 billion inhabitants within a few decades, the failings of industrial food systems cannot be denied. Several studies[1], commissioned by International Organizations have concluded that the modern global agriculture system has to be radically transformed to avoid ever greater environmental and social problems. Modern industrialised food production methods contribute to the global pollution of air, soil and waters. They are the cause of malnutrition. They are also inequitable and unjustifiably wasteful. And they are concentrated in the hands of a few corporations and subject to increasing financialization. Linked to the many crises humanity is facing, the problem of a sustainable food system should be considered a key challenge of our times.

Balboni's book, *Il pianeta mangiato, La guerra dell'agricoltura contro la terra*[2] is a good addition to the Italian literature on this subject. The author aims at increasing the awareness of Italian citizens and politicians about the impact of the global agro-food industry. By producing, transforming, and distributing food on a global scale, it is heavily responsible for our rapidly approaching and/or going beyond planetary limits, which in environmental literature are described in terms of climate change, biodiversity loss, nitrogen and phosphorus cycle disturbances, increasing rates of soil use changes, depletion of fresh water, chemical pollution, ocean acidification, and atmospheric ozone depletion.

The author, starting from the ideas of William Vogt presented in "Road to Survival" (1948), appears to see himself as one of the so-called "apocalyptic environmentalists". His major concerns can be summarized as follows: *The present global system of food production, which has been evolving through the 10.000 years of Holocene, is conflicting with the global common goods (fertile soil, water, climate and biodiversity) because of both population growth (especially in Africa Asia and even USA) and urbanization and increased purchasing power of emerging bourgeoisies.* Collapse of the present food system can be seen as likely within a few decades – the author indicates the year 2080 – with the inevitable impossibility of ensuring adequate food supply for everyone.

Within such a gloomy perspective, the author cannot see any viable solution, since the present alternative narratives about the future food production appear to him as looking backwards:

1. Intensifying the output of agriculture through the common model of petrochemical, large-scale, one crop, intensive farming: the so called "green revolution" model;
2. De-intensification of production going back to an "idealised" more natural way of producing food of the pre-industrial period.

With rich documentation and cogent reasoning, the author illustrates the unfeasibility of the first alternative, because of the environmental damages and resource shortages it procures, along with its impact on the population's health: obesity being the product of processed food high in fats, sugar and sodium. This narrative, promoted mainly by the big agro-industrial complexes, is based on the false assumption that the increasing world population needs more food, whereas the real problem is malnutrition due mainly to the increasing dominance of corporations that for short-term profit-making objectives are supplying more and more processed food and animal proteins. These trends in production of so-called "dense loaded and layered food" rich in fats, sugar and sodium from a very limited number of crops (manly maize, soybeans and palm oil), are the combined results of big financial corporations aiming only to maximize short-term profits and the increased number of people residing in urban or semi-urban locations.

[1] IAASTD – International Assessment of Agricultural Knowledge, Science and Technologies Reports – A joint initiative of the World Bank, the UNDP, The FAO of the UN and other institutions involving over 400 scientists. Subsequent international studies by the UN Conference on Trade and Development and the UN Special Rapporteur on the Right to Food annual Reports.

[2] In English: *The Eaten Planet. Agriculture's War Against the Earth*

To highlight the unsustainability of the industrial food system, Balboni discusses its impact on climate due to its huge greenhouse gases emissions, the problem posed by nitrogen-based fertilizers, like eutrophication of water resources, the question of pesticides and herbicides, the loss of agrobiodiversity, and the new plagues of globesity (global obesity) and metabolic diseases such as diabetes. At the same time, he also contests the unrealistic position posed as the second and alternative narrative by those thinking that the future should rely on an ancient agricultural system that was hardly capable to support a population of 5 million people at the beginning of the Holocene and less than 2 billions during the industrial revolution, but at high costs in terms of social inequity (e.g. serfdom and slavery).

The author, reminding us that the cultivated field is a simplified ecosystem, criticizes naming *natural* the products of pre-industrial agriculture, a practice used for marketing even by modern food processing firms. The agroecosystem is different from a natural ecosystem because of the human-induced loss of the complexity of plants and animals that once allowed an ecological homeostasis. As such, the cultivated field, the Latin *ager*, cannot survive without man: it is a product of both nature and culture.

The author does not limit himself to a presentation of detailed documentation of the causes that will lead us to a disastrous collapse of the present industrial food system, but also makes recommendations for technical, economic and political measures to mitigate and indeed avoid it. His view on the present socio-political order is very pessimistic and he maintains it is impossible to see any current action aimed at changing the situation. Neither national governments nor the European Union are acting to change the Common Agricultural Policy which annually spends almost 500 billions in subsidies to farmers, most of them applying polluting production processes and contributing to the speed of the trajectory toward global collapse.

The author is also critical of many current positions concerning the concept of sustainability. In a chapter, titled "Sustainababble" (a neologism created by Robert Engelmann, the president of the WorldWatch Institute) the very idea of sustainable development is questioned as an oxymoron. All too often the definition of sustainability merely refers to the capacity of our planet to replenish resources exhausted or damaged by human civilization with the objective of allowing it to carry on in its present course. That is, sustainable development is something that the present rich population of the world desire in order to carry on with its consumption models.

Even the European Commission document "Sustainable Food" (Nov. 19, 2015) presents us with the same contradictions. After defining sustainable agriculture as a process that will allow us to maintain food production even in the future, it indicates, among others, the goal of a growth of the food industries: the very cause of the problem.

Similar approaches to and definitions of sustainable food can be read in the documents of *Big Food* companies (industrial firms devoted to the production, trade, processing and distributing business of food). They stress the question of economic sustainability, forgetting that the present costing of food does not include its hidden costs due to negative externalities. The current food system produces many externalities, and a lot of the costs do not appear in agriculture production, but rather in recovering from soil, water and air pollution and in human consumption because of the high charges for food-related diseases.

A common refrain among advocacy militants for an alternative food system is "use your purchasing power by abstaining from buying the 'wrong' foods". The author thinks, however, that this commendable behaviour of individual aware consumers is not sufficient for the needed changes. At the same time, he considers any action that increases the consumers' awareness to be very positive.

He is quite pessimistic about the actions of democratic institutions because they have a short-term horizon (4 to 5 years) and are very weak in facing the lobbying actions by big corporations involved in producing inputs for all the phases of the food systems as well as in the processing and distributing of outputs. He also stresses the need for urgent actions. There is urgent need for a global authority. Unfortunately, “there is no other world order but a wildly individualistic market”.

However, the author thinks that some remedies may come from proposals such as taxation of energy dense food, food education in the school system, reduction of greenhouses gas, getting ready for resilience measures to the Anthropocene climate, new food production without soil, chemical synthesis of proteins, insect rearing for food, and redirecting CAP[3] budget to food production innovating systems.

Unfortunately, the political question is not adequately dealt with. The global monopolies of the industrial agro-food complex, with the help of international finance institutions and the complicity and inadequacies of national governments, have created and continue to support a global food system that is socially, environmentally, and financially dysfunctional.

Food has become another commodity subject to financial speculation. Although the author denounces the trends in genetic simplification and power concentration of *Big Food*, there is no analysis of the links between the capitalist economic system in its present financial stage, and the ills of the food system.

In addition, the narrative about the future of the food system is lacking a full discussion of Agroecology and the question of Food Sovereignty. There is considerable literature[4] on these questions, which is documenting analyses and proposals, presenting also the organized actions of the victims of the food systems being they agricultural labourers, small peasants, labourers in the processing agro industries, and consumers.

In conclusion, Mauro Balboni has certainly to be commended for its successful endeavour in presenting such a multifaceted subject in a format accessible to a large audience, while maintaining a technically accurate presentation. His professional experience as an international executive in the agribusiness sector and the painstaking digging into official institutions reports and academic researches make this book a good advocacy text for ways of changing the present trends in the food production sector.

[3] CAP: Common Agricultural Policy in the European Union (EU)

[4] See proceedings of two conferences at Yale University in the New Haven, Sept. 2013 and at the ISS in the Hague, January 2014. See also The Journal of Peasant Studies, 2014, Vol. 41
FAO/UN, International Symposium on Agroecology for Food Security and Nutrition, Sept. 2014 and 2nd International Symposium on Agroecology: Scaling Up agroecology to achieve the Sustainable Development Goals (SDGs) in April 2018.
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