Title
Really Working Scientifically: strategies for engaging students with socio-scientific inquiry-based learning

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30 word Overview: We showcase activities designed for and used with pre-service teachers learning to implement SSIBL in practice, with a focus on raising authentic questions and working with evidence within societal contexts.

100 word Abstract:
SSIBL engages learners with local and global issues in which science and technology are interwoven aiming to empower them to become active agents of change for their local communities. Within the PARRISE project, we worked with pre-service teachers on prioritising an '***it matters***' approach to science education using strategies presented in this article. Using the chemistry curriculum, consumerism and the over-use of the Earth's resources as linked contexts, we discuss strategies for enabling students to raise authentic inquiry questions, for considering the ethical dimensions of technology use, and for working with evidence when learning about climate change.

Why an 'it matters' approach to science inquiry in school?

Science teachers generally recognise the value of inquiry learning, particularly when stemming from students' own curiosity. However, making the time and curriculum space available for inquiry learning can seem too much of a challenge. We argue that school science has a vital part to play in raising students' awareness and active engagement with personal, local and global issues in the 21st century, for which science and technology play a part, and for which different levels of controversy might exist (also known as socio-scientific issues). The PARRISE project (Promoting Attainment of Responsible Research and Innovation in Science Education) showcases training approaches and activities for both pre-service and in-service science teachers aimed at improving skills and confidence in teaching inquiry by embedding socio-scientific issues (SSI) alongside the skills of practical investigation (Levinson, Knippels, van Dam, et al. 2017).

The pedagogical framework for Socio-Scientific Inquiry-Based Learning (SSIBL) conceptualised and implemented by the PARRISE consortium, sets out a three-stage process for inquiry in science education (see Levinson, this issue):

1. Raising an authentic research-based question about a socio-scientific issue (ASK)
2. Carrying out research based on the question to enact change (FIND OUT)
3. Finding a solution and taking action (ACT)

The first stage requires teachers to think about building an open science classroom in which questions are welcomed and can initiate or contribute to learning. The second stage requires teachers and students to engage in inquiry-based learning activities in order to explore the SSI at hand, within authentic contexts. This might involve carrying out experiments, conducting surveys, analysing data, collaborating with others and communicating findings. The third stage allows students to become active, social agents within their local contexts by encouraging them to take action in order to address the issue that they have been investigating.

Allowing children to think deeply about being part of a society that prioritises socially-responsible inquiry whilst learning the day-to-day curriculum (e.g. inheritance, the elements, different energy sources) was a key goal for the PARRISE project. In England, the most recent reform to the science National Curriculum for 11-14 year olds (DfE, 2015, emphasis added) requires that:

> *Pupils should <u>decide on the appropriate type of scientific enquiry</u> to undertake to answer <u>their own questions</u> and develop a deeper understanding of factors to be taken into account when collecting, recording and processing data. They should evaluate their results and identify further questions arising from them*.

To explore potential inquiry which goes beyond typical practical inquiry, we asked pre-service science teachers (PSTs, n=106) and experienced teachers (n=15) during training courses at UCL Institute of Education, Southampton and ASE annual conferences for their opinions on the 'big challenges' we face in the 21st century. Box 1 includes the recurring themes identified in the teachers' responses. We believe that in using these ideas, science teachers can identify opportunities and activities for incorporating short episodes of SSIBL on a regular basis in their teaching practice more easily, which consequently increases the perceptions associated with such socially-responsible and relevant inquiry activities as achievable rather than daunting or unrealistic.

Box 2: Objects for the Kinder™ egg mystery box

Objects	Photographs
Kinder egg and all its layers	'Red mud' flooding disasters (e.g. Hungary, Brazil)
Sample of 'bauxite' rock*	Workers harvesting cocoa pods
	Crude oil refinery
	Container ships
	Recycling heaps (for aluminium cans, plastics etc.)

*beige coloured rocks can be used to represent bauxite. If genuine bauxite samples are used, place in sealed plastic bags to avoid contact with 'red dust'.

The context of consumerism has been shown to be fruitful and accessible for understanding the aims of SSIBL. For instance, the STEPWISE project running in Ontario, Canada advocates the premise that any object we use in everyday life has a 'history' and network of impact connections about which we should all become actively knowledgeable if we are to act as responsible citizens (Bencze, 2017). Therefore, we used consumerism as an overarching theme for the SSIBL scenarios and strategies we present in this article.

Materials and the atmosphere curriculum focus

In this article, we report on some of the strategies designed and implemented during our 3-year involvement in the PARRISE project mainly within our respective pre-service teacher preparation programmes for secondary science. The activities developed are underpinned by an '*it matters*' approach to science education and the implementation of SSIBL. The strategies we discuss focus on the chemistry curriculum for 11-14 and 14-16 year olds students within the wider socio-scientific context of consumerism and the over-use of the Earth's resources. We present these ideas following the three steps of the SSIBL pedagogical framework. First we present and discuss a mystery box activity to highlight how the context of 'use of materials' can elicit students' own questions to initiate and direct SSIBL. Then, we present two scenarios (SMART phones, climate change) through which the enactment of SSIBL can take place and finally we provide some reflections on how these ideas can be used to encourage students to take action as a result of learning science within such societal contexts. Our aim is that teachers can readily draw on and adapt such activities, resources and scenarios, particularly when contemporary issues present themselves in everyday life, so that inquiry learning can be seen by students as a personally relevant and responsive process.

Repetitive we present"

ASK and FIND OUT: the mystery box activity

We designed the 'Kinder™ egg mystery box' to promote the use of physical artefacts as stimuli for inquiry learning about our 'need and desire' for manufactured products. Drawing on an activity developed by the Centre for Alternative Technology (CAT) in Wales (http://learning.cat.org.uk/en/resources), students examine the layers of a Kinder™ egg and ask questions related to the impacts of their origins and production.

We hide the Kinder™ eggs in mystery (egg) boxes, along with other objects (Figure 1). Box 2 provides suggestions for the contents of the mystery box. Learners open the box and after exploring the objects and photographs are encouraged to ask questions about their nature and origins. As questions emerge, students imagine the links between the artefacts in order to develop the wider ‘stories’ and connections about the production of the Kinder™ egg. At first, if the approach is very open, students puzzle over what the connections might be, but as they (are prompted to) raise a series of questions about sources and production processes which have impacts on people and the environment, the underlying social, environmental and technological dimensions of the object start to make sense to them.

Figure 1. The contents of the Kinder™ egg mystery box activity and pre-service teachers exploring the mystery box.

Box 3 illustrates some typical, open-ended dialogue between three PSTs at UCL Institute of Education, when given no specific direction ahead of opening the mystery box. Although at first their discussion might appear ‘messy’ and rather unfocused, key elements of the activity’s story are revealed, such as the materials needed to produce the Kinder Egg as well as the processes by which these materials are extracted and processed.

Box 3. ‘Messy’ dialogue between a group of PSTs raising questions about sources of materials

Speaker	Transcript
PST2:	(opens the mystery box. Audible gasps):
PST1:	Oh my, it’s a Kinder egg! Oh right, so the Kinder surprise has a toy in? Which is plastic...
PST2:	Um yes....
PST1:	Which comes from oil ...
PST3:	Yes but we need to think about the outside ... think about the wrapper first, not the toy (laughs)
PST1:	I’m thinking about the chocolate!
PST2:	So it’s got milk, and cocoa in the chocolate ... not sure if that’s important?
PST3:	Can we think of something to connect the rock, the egg and the picture? So like the extraction of rocks…from the environment …to make … so Kinder eggs are ‘human’ ...
PST1	(picks up and examines the Kinder egg, looking at the information on the wrapper): Ah, if we think about the wrapper ... I wonder if this is aluminium?
PST3:	It’s to do with re-using resources maybe? Is it recyclable?
PST1:	It’s recyclable, yes.
PST1:	(examines the rock sample): And so could this be aluminium ore?

It might appear, on first reading, to be a waste of time having students ‘wondering’ about the artefacts and their connections. But it is precisely this open, flowing stream of thought and conversation which fosters students’ own curiosity, rather than have them always follow our (adult) pre-conceptions of ‘*what matters*’. The open questions can then be used in guided inquiry activities to address subject knowledge relevant to the curriculum. In order to support teachers’ knowledge of issues surrounding the production and use of aluminium, for example, Levinson (2009) elaborates key issues, which link with ideas about elements and the Periodic Table in the chemistry curriculum (Figure 2).

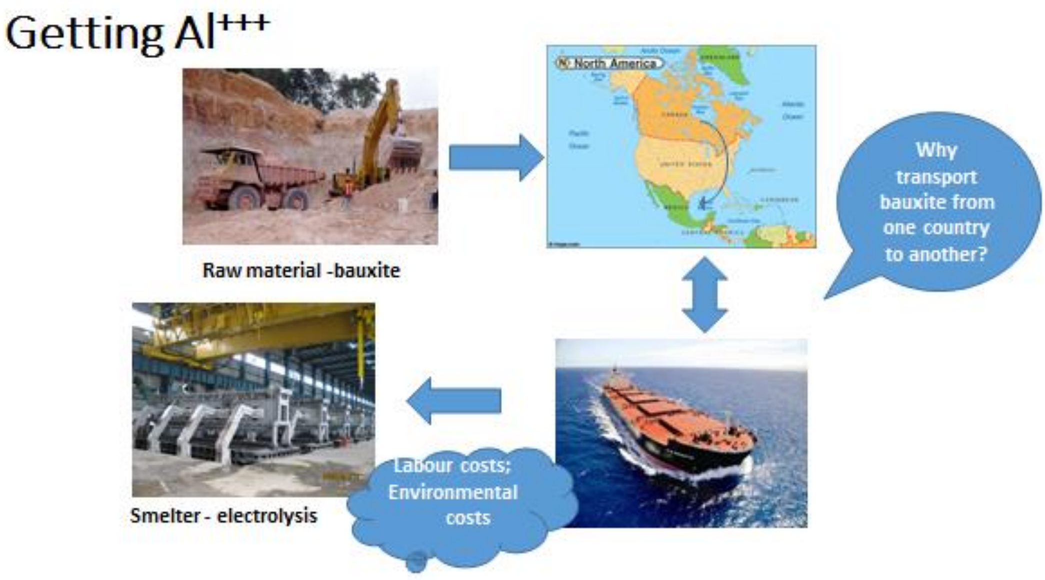


Figure 2. Steps in extracting aluminium (based on Levinson, 2009)

This activity has therefore the potential to open up and address a range of socio-scientific issues which require students to consider knowledge within a context, for instance by taking into account the ethical dimensions of chocolate production, or the production, re-use and re-cycling of materials such as plastics and aluminium. This activity concludes by asking students to seek solutions (i.e. Stage 3 ACT) for re-using the plastic 'egg' component of the Kinder™ egg. Box 4 illustrates some of the ideas provided by our pre-service teachers:

Box 4: Ideas for re-using plastic Kinder™ eggs

How can we re-use the plastic component of our Kinder™ egg?

✓ Spice holders	✓ Toothpaste container for holidays
✓ Wonky-shaped table tennis 'balls'	✓ Coin holders
✓ Glitter pots	✓ Individual ice cube makers
✓ Pill containers for each day of the week	✓ Used tissues / chewing gum holder (until I find a rubbish bin)
✓ Mini paint pots	✓ Alka-seltzer™ fizz reaction container

Stage 2 FIND OUT - SSIBL Scenario 1: What's in a SMART phone?

This SSIBL scenario developed and implemented with PSTs at UCL Institute of Education puts the connections between science, mobile technologies and consumerist attitudes in our society to the forefront, and addresses the 21st century 'big challenges' of depletion of resources and the production of mobile technologies, as identified by science PSTs and in-service teachers (Box 1). The development of SMART phones is a key technological innovation which, whilst welcomed by many, generates controversy. The question:

"What's in a SMART phone?"

initiates SSIBL in an area of the curriculum that can sometimes be rather dry. It is tempting for chemistry teachers to use the elements sodium, magnesium, chlorine and oxygen as illustrative examples when atomic structure is being explored. However, if students ask, '*what's in a SMART phone?*' they discover the presence of 50-60 elements. Given the emergence of unfamiliar contexts in this year's new national examinations for 16-year olds in England (https://www.masteryscience.com/), this is an excellent justification for being more adventurous. Each student could be asked to choose a substance to research and present to the class (Box 5 contains some possibilities):

Box 5: Types of substance and their use in a SMART phone that students could research

Substance	Use
• Lithium	• Cathode in the battery
• Gold	• Conductor
• Aluminium (anodised)	• The phone case
• Tantalum	• Tiny capacitors
• Yttrium	• Tiny amounts in the screen

By exploring these elements, teachers can provide a context for the story of coltan to emerge in students' investigations and research. Coltan is the ore which provides the key metal tantalum currently used in SMART technologies. The mining of coltan is controversial with ethical, social, political and financial dimensions (e.g. see the effects on mining communities in the Democratic Republic of Congo as revealed in a Sky News investigation in 2017, https://news.sky.com/video/inside-the-congo-mines-that-exploit-children-10784310).

Students can explore contemporary elements, providing a positive stimulus for examining chemistry concepts within a SSIBL context. They can also consider the conditions under which materials for objects they use on an everyday basis are produced as well as considering how a simple act of buying a new smart phone can have implications for people of their age in other remote parts of the world. Therefore, the inquiry gives students knowledge of situations about which they were previously unaware and stimulates debate about whether to upgrade phones as often as manufacturers suggest, and discussions about consumerist attitudes. This can lead to further questioning about how to influence manufacturers to maintain support for older models; in other words, solutions need collaborative actions as well. Bringing in this kind of learning through SSIBL is a key responsibility of science education within our society (Levinson, this issue).

One PST was inspired by the coltan story to draw his students' attention to the large number of water bottles being bought in his placement school and then the plastic bottles being thrown away. He initiated a discussion with his 15-16 year old students about what could be done, and students recognised the need for change. They wanted to write a letter to the Head teacher and canteen staff to suggest taking away the plastic bottle drink dispensers in the school. However, the students then became worried that their intervention would be seen as critical of the school's policies and decided not to go ahead with writing the letters. The PST realised that bringing authentic '*it matters*' questions into science lessons can be challenging, and more importantly, enabling and empowering students to take action needs to be addressed consistently if knowledge is going to be transformed to action. More recently, awareness of billions of tonnes of plastic floating in our oceans has been raised and one wonders whether these students would have felt more confident to pursue their goal of reducing the sale of plastic bottles in school if this campaign had been 'live' at the time of their SSIBL activity.

Stage 2 FIND OUT - SSIBL Scenario 2: Is it our fault that our planet is getting hotter?

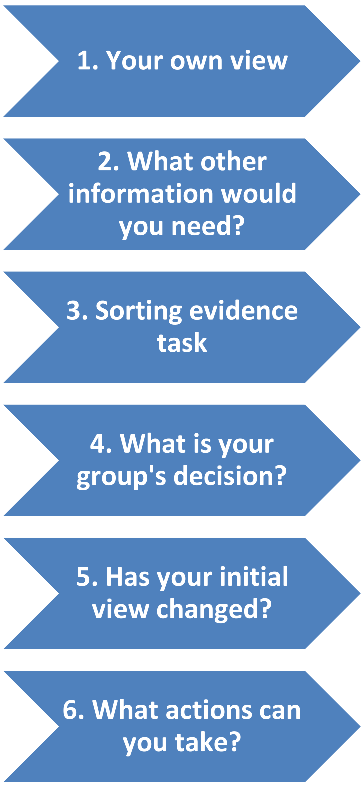
Another way by which consumerism and energy consumption can be explored is through the socio-scientific context of climate change. This is an issue that features frequently in the news, especially since the recent decision by the USA to withdraw from the United Nations Paris Agreement established in 2015, which saw 55 nations coming together to agree common goals and targets for tackling climate change. Climate change was also an issue identified as one of the big challenges of the 21st century by science teachers (Box 1). Learning about the controversies surrounding global warming and possible resulting climate changes can be addressed at a personal, local and global scale, and can thus be ideal for adapting into SSIBL activities. We used this scenario with 144 PSTs at the University of Southampton across 3 years in order to illustrate how types of scientific inquiry other than controlling variables and practical experimentation can be used in the science classroom (e.g. using secondary sources) and for exploring the role that scientific evidence can take in science inquiry. In the process of raising authentic questions that could then initiate students' inquiries, two key questions were posed, each representing a different level of controversy around the issue of climate change:

Is climate change really happening?

Is it our fault that our planet is getting hotter?

It was important to address both questions, as younger students often first need to establish whether climate change is taking place and then consider who/what is causing it. This activity fits in with the 11-14 and 14-16 year old students' programme of study, which states that students should learn about 'the production of carbon dioxide by human activity and the impact on climate', about 'evidence, and uncertainties in evidence, for additional anthropogenic causes of climate change', and about the 'potential effects of, and mitigation of, increased levels of carbon dioxide and methane on the Earth's climate' (DfE, 2015).

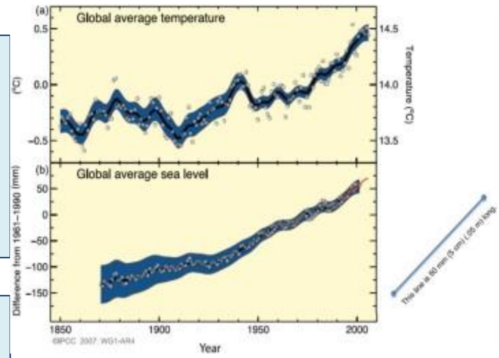
In engaging our PSTs with the issue of global warming, we adapted a six-step decision-making framework (Ratcliffe & Grace, 2003) in order to allow our students to consider their own views on the issue, investigate and then reconsider taking into account not only scientific evidence but also knowledge from other disciplines (e.g. ethics, economics). Figure 3 provides a summary of the six steps used, the 'sorting evidence' table provided to students and some examples of different evidence statements or graphs provided. A 'sorting evidence' task was used to allow students to work together interrogating the evidence provided and raising questions for further discussion and investigation. Sorting or classifying evidence into different categories (e.g. for or against) requires coordination between theory and evidence, and allows learners and teachers an insight into whether information is understood or not. When set up as a group activity it can also facilitate collaborative argumentation between students. The sorting evidence activity required students to classify evidence statements that were adapted from information discussed by Wolff (2014) in a special issue of *School Science Review* on Energy and Climate Change.



Climate change is…	Evidence for…	Evidence against…
human-made (anthropogenic)		
naturally happening		

a) The concentration of CO_2 in the Earth's atmosphere has increased by 40% since the early 19th century. Scientists have found this by measuring how much CO_2 there was in air bubbles trapped in ice, and from measuring the CO_2 in the atmosphere routinely since 1959.

b) Scientists have found that the Earth's average surface temperature has risen by 0.8 °C since 1900.



c) Carbon dioxide is a natural part of the atmosphere.

Figure 3. The collaborative decision-making task used when exploring climate change, and the Sorting Evidence task with some examples of evidence statements provided (graph provided sourced from Busch, 2016, p. 149).

A key point addressed through this enactment of SSIBL was the nature of evidence presented to students, its function and quality. For instance, evidence statements provided were in support or against the position that climate change is human-made, but other evidence provided was not clearly positioned as for or against (e.g. evidence statement C in Figure 3), and this prompted a discussion about the strength of evidence needed when arguing for a position and about the quality of evidence used. The use of graphs requiring students to interpret data was also a useful heuristic for discussing with students the nature and function of evidence in scientific practices, and in their own decision-making process.

The subsequent discussion on teaching about climate change included a consideration of challenges often encountered when such discussions take place with students. Busch and Osborne (2014) list five such challenges (scepticism, complexity, uncertainty, scale and emotion). Uncertainty was particularly important for our PSTs as they reported not being sure how to approach it in general within their teaching. Scale was also extensively discussed as it is an essential dimension of the SSIBL framework in the form of 'taking action'; students need to understand the issue as having personal relevance in order to be able to take action.

One SSIBL lesson designed collaboratively by a group of PSTs focused on the concept of 'carbon footprint', framed around getting students to measure and compare their own carbon footprint, in an attempt to make the context personally relevant for their students, and also raising the issue within their local context. The SSIBL lesson required students to design a questionnaire to be distributed to the school's student population in order to collect data. They then had to design a presentation to the school's Student Council on ways in which their school could reduce its carbon footprint, and should use the findings from their research to inform their proposed actions and solutions to the issue. Within this scenario, students become active agents of change, as addressed by the third dimension of the SSIBL framework, by taking action both at a personal level and within their localised context in order to address an SSI.

Stage 3: Taking Action

A key component of the SSIBL approach is that it encourages students to take ownership of their learning in a way that empowers them to become active agents of change for their local communities. The aim is not only to educate our students about the content of science, but also to teach them how they can use this knowledge as active citizens. When analysing SSIBL lesson plans designed by PSTs in both institutions, we found that PSTs' conceptualisations and enactment of the 'taking action' dimension could be represented on a continuum (as represented in Figure 4) from having at the one end 'raising awareness of an issue' as the underlying aim (e.g. make a poster to detail your findings), to 'promoting intentionality of taking action' based on hypothetical scenarios (e.g. take part in a debate about what should be done about the construction of a new wind farm; making a decision on a given scenario – what would you do as doctor/patient/family member?) to enable action to happen on the other end of the continuum (e.g. making a presentation to older students to convince them to not buy drinking water in plastic bottles; creating a survey to investigate a topic - e.g. smoking; calculating the school's carbon footprint and making a case for ways to reduce it).

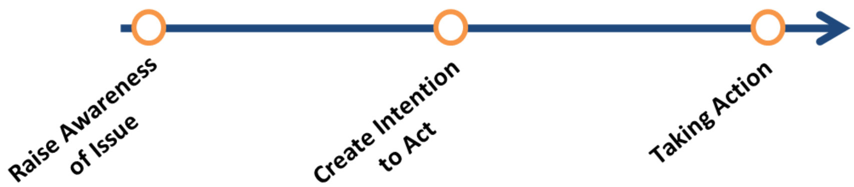


Figure 4: A continuum of taking action in pre-service teachers' enactment of SSIBL

We consider all stages of this continuum important; it might be that 'taking action' is more challenging to address in some lessons compared with others. However, we believe that this continuum could be used as a heuristic tool for facilitating discussion and hopefully reflection on how we can embed elements of 'taking action' into our everyday science teaching, and gradually promote a sense of social and ethical responsibility within our students.

Conclusion

SSIBL means students research and evaluate the impacts of scientific and technological innovations on their own lives and on our planet within any prescribed curriculum, asking vital questions such as

'who gains, who loses'

about such developments and their resulting products. Students can propose and enact creative solutions which have the potential to tackle issues and concerns, if given the appropriate support. Moreover, secondary teachers are constantly seeking ways to encourage independent learning as students prepare for external examinations, so adopting SSIBL approaches at both primary and secondary levels has the potential to foster knowledge and skills which they can apply in different contexts.

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