Science and society in education

PARRISE

SCIENCE & SOCIETY IN EDUCATION

PARRISE (Promoting Attainment of Responsible Research and Innovation in Science Education) project

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Socio-Scientific Inquiry-Based Learning: connecting formal and informal science education with society

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Preface

This booklet is for teachers who want to expand their teaching approaches to include socio-scientific issues which enrich and give meaning to core scientific principles. It is meant to enhance young people's curiosity about the social and scientific world and raise important questions about issues which affect their lives. We call this approach *Socio-Scientific Inquiry-Based Learning*, or 'SSIBL' for short. Chapters 1 and 2 present an introduction to the theoretical background of SSIBL. In chapter 3, SSIBL will be approached from a classroom perspective, providing a simplified version of the framework and showing teaching examples.

Additional examples and materials for teachers and teacher educators can be found on www.parrise.eu.

1— Introduction

Science influences many parts of our lives. Renewable fuels, personalised medicines and communications systems all have the potential to transform our lives for the better. —

But there are scientific uncertainties in their development and social risks in their impacts. They are also underpinned by social, political and cultural values and controversies.

For example, renewables are seen as good solutions to replace fossil fuels. However, there are costs and jobs associated with their introduction and environmental hazards implicated in producing materials such as solar cells.

Since these developments and impacts affect all of us they present questions at personal, social and global levels. Addressing these questions through an inquiry approach is core to *Socio-Scientific Inquiry-Based Learning* (SSIBL). SSIBL attempts to find answers to those socio-scientific questions which puzzle us, and, within a STEM programme, raises challenges young people might want to do something about. Many teachers are understandably concerned that exploring ethical and social questions detract from the core scientific knowledge and understanding that is needed for passing science examinations. This is why scientific content is crucial to SSIBL. But we argue that engaging with the personal and social aspects of these questions deepens knowledge and also problematizes it. It makes us more critical, practical and understanding. *Box 1* provides a summary of the main features of SSIBL.

SSIBL for teachers

- Is a practical tool for enhancing teacher practice;
- Builds effectively on everyday teacher practice;
- Draws on state-of-the-art knowledge in science education;
- Fosters opportunities for implementing curriculum requirements;
- Links to real world developments in science and technology;
- Provides a means of collaborating with agencies beyond the school curriculum;
- Encourages young people to enact change in the real world.

Box 1 — Main features of SSIBL

We start from an inquiry-based approach. Inquiry means to ask questions and seek insights into problems that intrigue us. These questions can be broad but also focused. They can arise from curiosity about natural phenomena, or be more socially-oriented. What happens to clouds when they disappear? What makes sugar sweet? How can we eat more healthily and why does it matter? Are new technologies all they claim to be? Are e-cigarettes bad for your health?

This booklet will provide you with examples, tips, insights and ideas to apply this approach in your teaching. To do so, we:

1. Present the SSIBL-model or framework (chapter 2);
2. Suggest some activities to try out (chapter 3);
3. Provide many other strategies which you can draw on for advice and look through at your leisure (annexes).

A NOTE ON RESPONSIBLE RESEARCH AND INNOVATION

Responsible Research and Innovation (RRI) constitutes the main principles for socially desirable, ethically acceptable and sustainable development of science and technology. It forms the backdrop for SSIBL and the main points are explained in *Box 2*.

RRI

This is a term that is primarily used in science and innovation. The aims of RRI reflect the importance of public and stakeholder participation and mutual responsiveness - working with and for people - to product development in science and technology. In other words, how can science and industry develop knowledge and technology that is socially desirable, ethically acceptable and sustainable? e.g.: are genetic testing kits that can be bought via the internet socially desirable? How can we limit the exploitation of poor people in the mining industry (what is ethically acceptable)? And how do we ensure that new processes and products are sustainable from the environmental and political/social point of view? The term RRI has been coined in recent years. It is a crucial element of the European Union's recent science and technology policies. The PARRISE project has operationalized the concept of RRI in education.

Box 2 — Responsible research and innovation (RRI)

Figure 1 illustrates how the different components of SSIBL relate to each other. The outer layers of RRI and Critical Citizenship are the overarching principles of social justice. The inner core of SSI and Inquiry-Based Science Education (IBSE) operationalise these principles within informal and formal science contexts.

Figure 1 — Educational embedding of RRI (facilitating and empowering science teachers)

2— Pedagogical framework

Socio-Scientific Inquiry-Based Learning (SSIBL)

The SSIBL-approach connects science and society in the classroom as well as in informal learning, in an inquiry-based manner. —

In modern societies controversies often arise between scientific and technological research and development on one hand and public accountability on the other. The processes of production – encompassing socio-political values, economic considerations and technoscientific challenges – are complex and uncertain, and social demands are always changing. SSIBL addresses the contemporary problem of Science & Society through the underpinning motif of science *for* and *with* people. But in talking about people and the public we need to recognise that there are many diverse stakeholders and perspectives.

Stakeholders include all those who are impacted by science and technology – including young people now at school – and they will also have the greatest influence over developments in the coming years. SSIBL is an approach where young people as active citizens inquire into socio-scientific issues which interest them, taking action where necessary.

SSIBL draws together three pedagogical approaches, common in schools but often independently pursued – Inquiry-Based Science Education (IBSE), Socio-Scientific Issues (SSI) and Citizenship Education (CE).

Teaching SSIBL has three main stages: authentic questions, enaction and actions. Teaching starts with raising meaningful and *authentic questions* about 'socio-scientific issues'. For exploring these questions, social and scientific inquiry is used (*enaction*). Finally, students are stimulated to take action: form opinions and formulate solutions (*action*).

Aims

1.
Supporting young people in acting as knowledgeable social agents through inquiry promoting critical citizenship education.

2.
Encouraging young people to participate in research and innovation issues which are influenced by science and technology.

3.
Promoting young people's interest in science, mathematics and technology.

Box 3 — Aims of the SSIBL-approach

These three main stages and the underlying pedagogical approaches are represented in the SSIBL-model (see *Figure 2*). In the following section, these stages and approaches will be discussed in more detail.

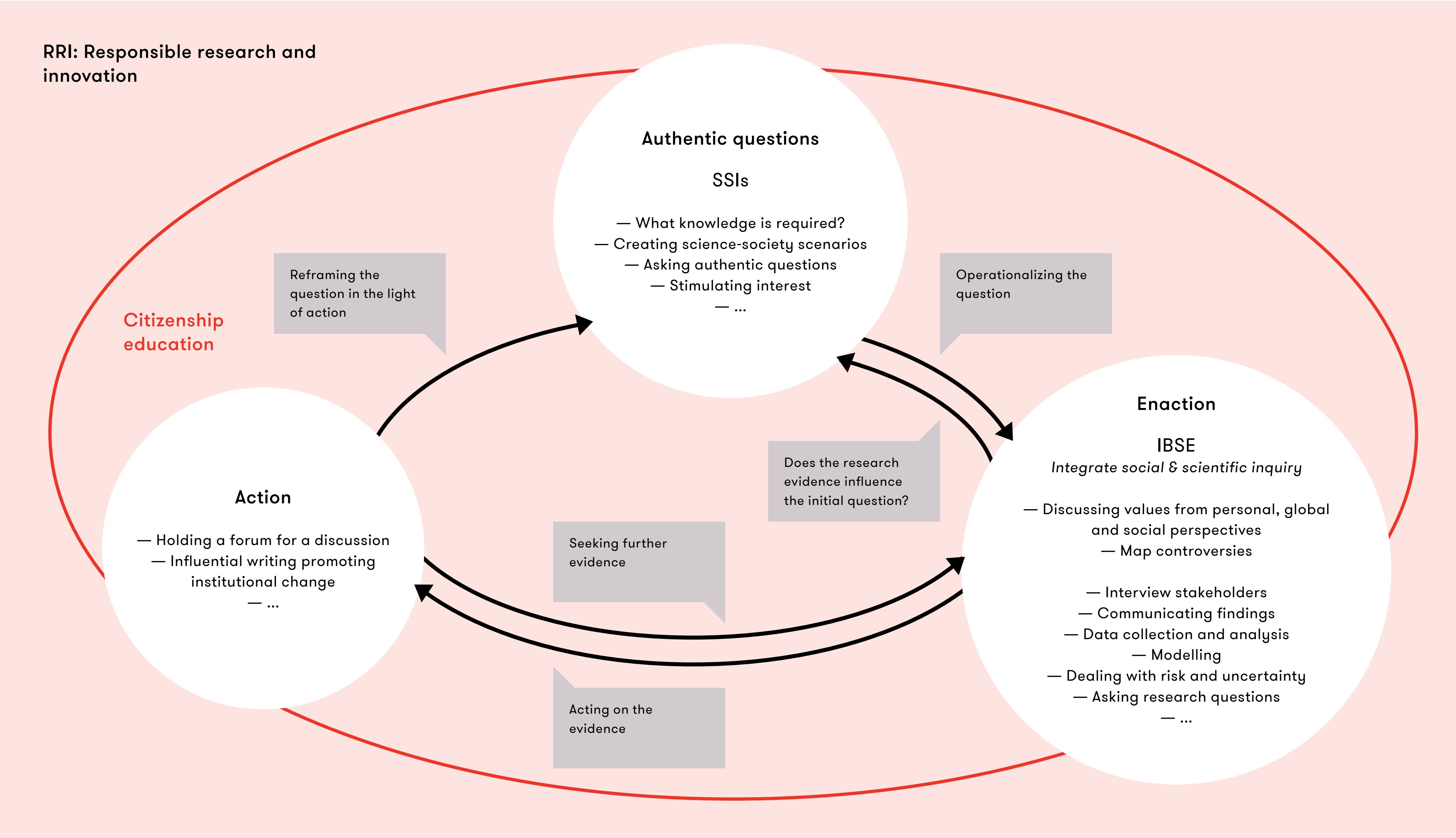

Figure 2 — Representation of the SSIBL-approach (embedded within the overall context of RRI)

Stage 1: Raising authentic questions — ('Ask')

Is cycling to school healthy for us? What are the problems with nanotechnologies? Are the products in our cell phones ethically sourced? How can we make our school more fuel efficient? These are examples of authentic questions.

Authentic questions include the following features. They:

- Proceed from questions which interest and engage students (personal authenticity) and through which they express a wish, and choose, to find collective answers (social authenticity);
- Involve real-world, complex, 'wicked problems';
- Are sometimes controversial in nature when there is no overall agreement about solutions or even ways to frame the question;
- Are gender inclusive and gender-sensitive;
- Are questions or issues that emerge from young people spontaneously or, more likely, with sensitive support from teachers;
- Presuppose change in that questions are asked about matters or issues which can be improved, e.g. made more socially and ethically desirable.

These features have implications. A mutually agreed purpose may go beyond the bounds of the school walls for participants, particularly where in finding the answers to questions, students might work with scientists, policy-makers, or other people with expertise.

SSIBL might involve interaction either in informal education contexts and/or working with agencies outside the school.

How such questions are raised is central to effective pedagogy in SSIBL. It is important to notice at this stage that all the conditions for authentic questions are unlikely to be satisfied. Students can, however, be taught to generate authentic questions themselves.

In annex 1 'The Scenario Machine' is a good way to help students structure authentic questions.

SOCIO-SCIENTIFIC ISSUES

Authentic questions often involve socio-scientific issues (SSIs). SSIs use scientific knowledge to address a social issue. For example, with energy use, young people need to understand the relationship between fuels and energy to appreciate that conservation of fuels is the real cost in economic and social terms. Personal harm from smoking can be informed through knowledge of the importance of oxygen diffusion to the body cells. This knowledge supports discussion about the ways of addressing smoking as a problem. For eco-friendly clothing, the particular chemical and physical properties of titanium dioxide (catalytic, nano-size) make understanding about its global distribution and social justice in production so urgent (see chapter 3).

Sometimes SSIs can be in the form of a dilemma or controversy but this need not always be the case. For example, all the participants might recognise a non-controversial problem and work together to find the best way to solve it. However, in other cases there may be real differences between participants. Controversies are deemed to occur when different parties have opposing arguments but where the arguments are bolstered by good reasons. People might agree that climate change is an urgent issue but disagree about the best way to tackle the problem.

SSIs: types of controversy

In SSIs there can be different types of controversy [1]. For example, all stakeholders might agree that action should be taken to clean a local watercourse but they might disagree about the factors responsible for the pollution because the *evidence* is complex. Stakeholders might also disagree if action should be taken at all because the cost of cleaning up the watercourse might affect the livelihoods of people who work in an industry that contributes to the problem. Such differences of *interest* are evident in the positions taken by many farmers over cattle tuberculosis in the UK as opposed to those of environmentalists. The UK National Farmers Union, for example, explain that wild badgers carry the tubercular bacterium and transmit it to cattle, hence the badgers must be controlled through culling. Many conservationists argue that farmers need better husbandry and that badgers are such an important part of the countryside that they must be protected. But there are also *uncertainties* in the science. Some scientists argue that culling badgers is an effective means of controlling cattle tuberculosis; others that not only is culling ineffective but that in some cases it spreads transmission. There is no single solution to the problem. *Core values and preferences* also play a role in decision-making.

So, socio-scientific issues are about establishing scenarios which provide a background for raising research questions.

In terms of socio-scientific issues, the examples in chapter 3 involve:

Aspects of disagreement or controversy (Given there are different ways to reduce heat loss in the school, what is the best way? Should novel ways of reducing pollution be used when the social costs of production are so high?).

Reasoning. Usually, discussion of SSIs is likely to involve both informal and formal reasoning. When students talk about their perspectives on an issue from their everyday experiences they are often using *informal reasoning*. Drawing on scientific knowledge through consistent logic to justify an opinion is an example of *formal reasoning*. Both types of reasoning are valid depending on the context and students should be encouraged to distinguish between the two forms of reasoning. Sadler et al. (2011) [2] show that there is some evidence that engaging in SSIs can support learning of science content although the learning is sharper if students are interested in the issue, and it therefore has some authenticity.

Uncertainty and risk. Many SSIs involve an appreciation of uncertainty and risk. Students should be encouraged to distinguish between different types of uncertainty. Taking measurements with a thermometer, for example in checking the temperature in different areas of the school (chapter 3), involve a degree of uncertainty depending on the precision of the measuring instrument. Predicting social impacts, such as whether young people will give up smoking even knowing the biological hazards, or whether people would wear clothing which purifies the air, are examples of *social uncertainty*. Risk is related to the chances of a hazard occurring. Older students should be able to distinguish between *relative* and *absolute* risk, and also understand that factors other than probability effect estimation of risk [3].

Sometimes, students come along with issues or questions they are keen to address. But it is more likely the teacher will help to stimulate interest in a particular theme using pictures, video clips, cuttings from newspaper reports, social media, which connect to students' lives and concerns. More information about SSIs is provided in annex 1.

1
Levinson, R. (2006). Towards a Theoretical Framework for Teaching Controversial Socio-scientific Issues. *International Journal of Science Education, 28*(10), 1201-1224.

2
Sadler, T.D., Klosterman, M.L., & Topcu, M.S. (2011). Learning science content and socio-scientific reasoning through classroom explorations of global climate change. In Sadler, T. (Ed.). Socio-scientific issues in the classroom. Dordrecht: Springer, 45-78.

3
Levinson, R. (2011). How Science Works: teaching controversial issues. In R. Toplis (ed.) How Science Works, London: Routledge, 56-70.

Stage 2: Enaction — ('Find out')

To move from question to solutions to actions, research and development for and with people needs to be participative and inclusive, involving inquiry-based learning and an understanding of the links between science and society.

These include three perspectives:

1. Personal (What does it mean to me?);
2. Social (What does it mean to my family, friends, community?);
3. Global (What does it mean more broadly?).

These enactions, constituted through the SSIBL pedagogic framework will be explained below using the pedagogical approach of inquiry-based science education.

INQUIRY-BASED SCIENCE EDUCATION (IBSE)

Inquiry-based science education (or inquiry-based learning) is at the stage of 'enaction'. Students need skills and knowledge to provide the necessary evidence to find solutions to an authentic question. These skills are multi-faceted because they involve collaboration with others, finding out the viewpoints of stakeholders as well as doing experiments.

Doing experiments might involve coming up with ideas and testing them, collecting and evaluating data, an awareness of uncertainty in the data collected and its interpretation, and possibly asking new questions as a result of reflecting on the data. Having collected evidence, students need to explain how the evidence helps them to answer their questions.

Teachers might want to scaffold student learning, particularly when they are new to inquiry learning. At first the teachers could set a particular question for students to explore. For example, using the example of energy loss in schools from chapter 3, the teachers could ask students to find out the sites of the school's greatest energy losses in winter so that they can make a case for action for better insulation. Some of the possible approaches are given in ***Table 1*** where the teacher could have a prepared set of prompts for the students.

One of the distinctive features of IBSE *within* SSIBL is that the inquiries are open and not predetermined and can involve a range of approaches including experiments, surveys and debates.

APPROACHING SSIBL THROUGH IBSE

Once students have explored a scenario for an issue they need a good *research* question for their inquiry. Finding a good research question is not an easy task and will need support from the teacher. First the question has to be *researchable* and have the following characteristics:

- The question fits the theme or scenario;
- The question is open and the answer not known;
- There is only one question (e.g. what are the main reasons year 9 students in our school give for smoking?) (Note that groups of students in an inquiry can pursue different research questions, as long as each group is only following one question);
- The question is clear and focused;
- The question is feasible: it is answerable and can be addressed in a fixed time;
- Data can be collected to answer the question.

Question	How can we cut down the school's energy losses in winter?
How to organise	How do we ensure everyone has a say? What do my friends think we should do? How do we decide on the best way of going about this?
Things to think about	Where are the best areas in the school to investigate? When should we take measurements? What equipment should we use? Should we take measurements at different times of the day?
Collecting data	How will we record the data? How can we make sure our data is accurate?
Interpretation	What does the data tell us? Where are the greatest energy losses taking place? What can we do about it?

Table 1 — Example of scaffolded inquiry

Stage 3: Action — ('Act')

The solutions to authentic questions must involve a form of *action*. By action we mean outcomes which address the original question and result in some kind of change, or in gaining relevant knowledge, or understanding reasons why change might not be desirable.

Actions can be of different kinds such as:

- Making an artefact;
- Lobbying powerful institutions;
- Generating instructional materials;
- Promoting institutional change, e.g. school policies;
- Holding a forum for a discussion;
- Staging drama to an audience to illustrate a dilemma;
- Influential writing;
- Poster displays to promote further discussion.

Finding a solution may lead to other questions, hence the process is circular in nature rather than linear (see ***Figures 2*** and ***3***). Actions may themselves raise further questions so that the process should be seen as spiral and reflexive rather than linear.

CITIZENSHIP EDUCATION

SSIBL supports young people in acting as knowledgeable social agents through citizenship education (CE). SSIBL involves young people making value-laden decisions together, which they then can enact. In a democratic society all stakeholders should be able to contribute and therefore SSIBL-activities should encourage participation and dialogue throughout the activity from raising questions, through carrying out an inquiry, proposing solutions and taking action.

Features of CE in SSIBL

The core idea of CE in SSIBL is to participate critically in taking action. To participate in critical and constructive dialogue is to:

- Argue a point with personal commitment using evidence and reason;
- Listen carefully and considerately to what others have to say;
- Be open to change your views. If another participant advances a better argument judge it on its merits;
- Respect the views of others. All participants have a right to put their views forward and be listened to. Racist, sexist and homophobic statements, and any statement demeaning the identity and character of a participant, are neither respectful nor inclusive and have no place in constructive dialogue;

- Be critical of arguments if there are points you disagree with, if they are based on insufficient evidence or on shaky premises;
- Encourage passion and commitment. Participants who have a very passionate and deep commitment to a particular viewpoint can sometimes stifle dialogue. But under conditions of openness and transparency this can often be put to good effect because it helps other participants to reflect more fully on their own views.

More background information about citizenship education is provided in annex 3.

Summary

Socio-Scientific Inquiry-Based Learning (SSIBL) operationalises RRI in the context of education. It is learning through asking authentic questions about controversial issues arising from the impacts of science and technology in society. These questions are open-ended, involve participation by concerned parties, and are aimed at solutions which help to enact change.

SSIBL features three main stages:

1.
Raising authentic questions about controversial issues (SSIs) arising from impacts of science and technology in society. ('Ask')

2.
Enaction: Integrating social and scientific inquiry (IBSE) to explore these open-ended questions. ('Find out')

3.
Action: Formulate solutions which help to enact change. ('Act')

Box 4 — Summarising SSIBL

3— SSIBL in the classroom

When using SSIBL as a pedagogical approach, a simplified version of the theoretical model can be used (*Figure 3*). This model uses the three educational stages Ask, Find out and Act.

Alongside these stages are the main aims of RRI: social desirability, ethical acceptability and sustainability.

Below we describe activities for three different age groups. ***Table 2*** on page 35 summarises the SSIBL-principles which feature in these activities.

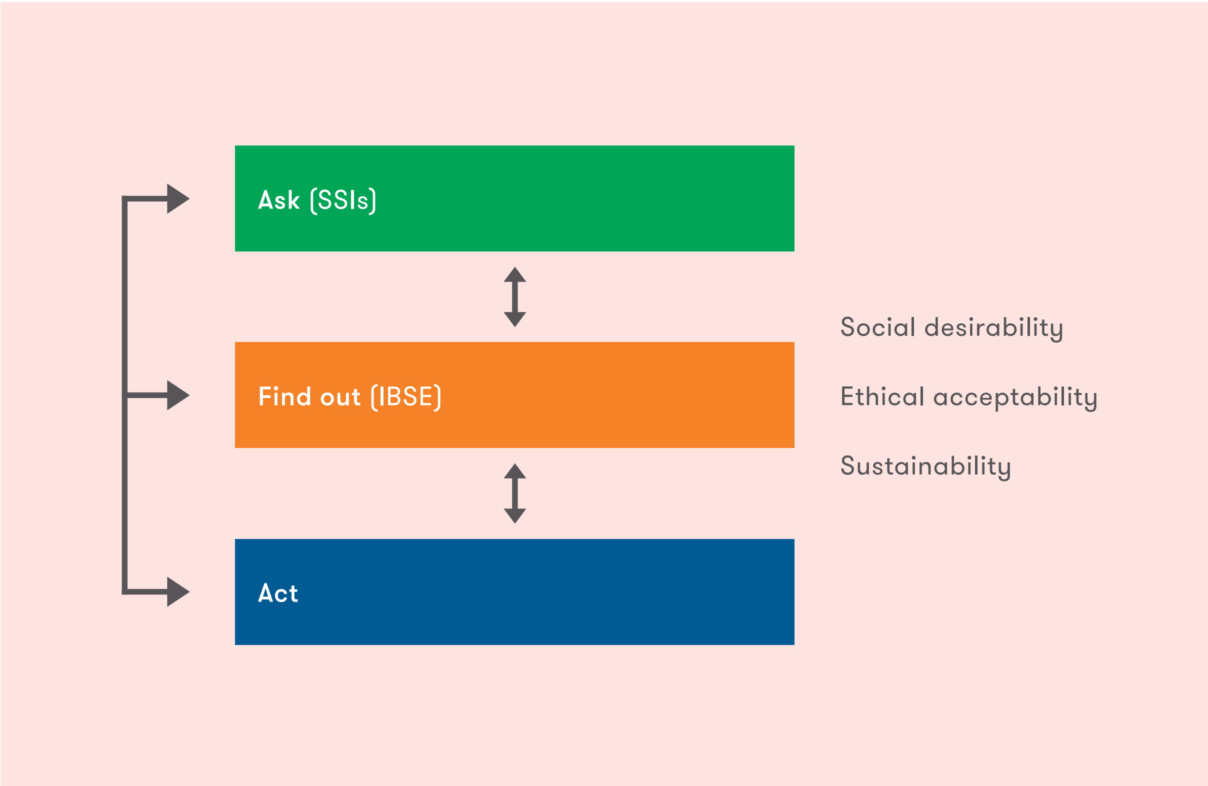

Figure 3 — Simple model of SSIBL

1. CUTTING DOWN A SCHOOL'S ENERGY LOSSES

A class of primary children are learning about energy. They come to understand that energy is the ability to do work and make changes take place. They learn that energy can be recognised through processes involving light, motion, heat, electricity, sound. They also know that their bodies use energy to make things happen such as lifting weights, walking to school, keeping warm at low temperatures. Intuitively they grasp the idea that they need food to do these things but they are not quite sure how food plays a role in this. So they are taught that food can be seen as a fuel like petrol, or coal, or gas; stuff that makes vehicles go and keeps us warm at home. Through observations and experiments they see that nothing happens to fuels unless there are certain conditions: the presence of air and a source of heat.

Through discussions about their experiments and the relations of energy use to their own lives and to the planet more generally they come to understand that fuels need to be conserved. So they decide to investigate how their school manages its energy use so that it remains warm during the winter and cool in summer time. Their inquiry takes place in four stages:

1.
Developing a plan for resolving the question of fuel conservation in the school. Their overall question becomes: How can we avoid energy losses in the school? ('Ask')

2.
They carry out a survey identifying sites which are cold and drafty in winter or hot and uncomfortable in summer. ('Find out')

3.
They search for information, and try out small experiments, e.g. how temperature loss can be reduced from a cup of hot water using different types of material to cover the cup, for reducing energy flow in winter and increasing it in summer. ('Find out')

4.
They design a pamphlet to suggest ways of making the school more energy efficient based on their evidence, including reducing use of lights and computer equipment, and discuss it with school management at the school 'energy day'. ('Act')

This involves teaching about fuels and energy transfer, for example:

- Examples of energy transfer;
- Fuels are needed as a starting point in an energy transfer system;
- Fossil fuels need air and a source of heat;
- Heat flows from regions of high to low temperatures;
- Energy transfer can be managed thereby conserving fuels and cutting down costs.

Adapting for SSIBL

Where does heat loss take place at home/at school? How can we find out how much heat is lost? Does heat loss vary with time of day? What data will we need to collect? How can we best represent and interpret our data (thereby using mathematics knowledge and skills)? What instruments will we use (e.g. thermal imaging cameras if available)? How will we present our data? How will we know our data is accurate and reliable? How can we translate our data into savings on fuel conservation and a better learning environment for students?

Students could research ways how buildings similar to their school are insulated. How do we prioritise ways to cut down energy losses? What resources will we need? How can we use the evidence to persuade management and governors to provide those resources? See also ***Table 2***.

2. WHY DO YOUNG PEOPLE SMOKE?

Teenage smoking is a problem, for example, in the U.K, particularly among young women. Students might learn about:

- The role of the bronchi and lungs and how their structure is adapted for function;
- Mechanics of breathing (the motion of the rib-cage and inter-costal muscles);
- The importance of oxygen for cell metabolism and the need to remove carbon dioxide;
- Oxygen and carbon dioxide diffusion across lung membranes and down concentration gradients;
- How blood transports gases to and from cells.

As part of the lesson on passage of O_2/CO_2 students are shown a smoking model (***Figure 4***) which demonstrates the effects of smoking. They could for example discuss how far this model represents what takes place at the surface of the lungs, the similarities and differences between the model cotton wool 'lung' and real lungs, the surface area of the lung, its spongy nature, how far tar stains the surface of the lungs, the role of the bronchial tubes during inhalation and exhalation.

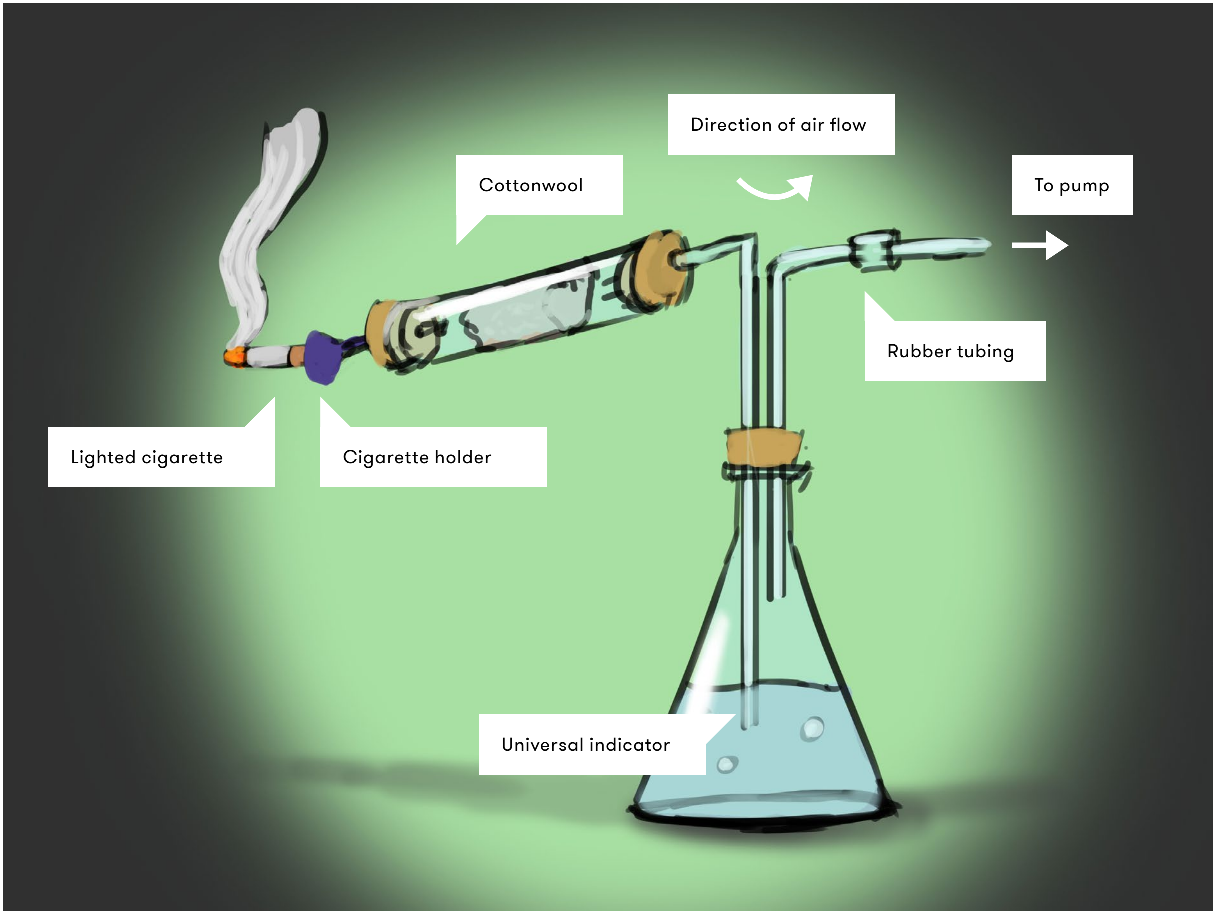

Figure 4 — Smoking model

Adapting for SSIBL

Students can research the impact of smoking on young people, the risk factors (the probability of contracting a serious lung disease combined with the seriousness of the impact) and whether e-cigarettes are a good alternative for young people who are addicted. Having seen the demonstration and understanding the biological effects the students can discuss how more knowledge would influence the smoking habits of their peers.

Students could devise an anonymised survey to find out how many of their peers smoke, why those who smoke do so and their views on 'passive' smoking. They could work in groups to devise and test questionnaires they can send to peers, e.g. through *Survey Monkey*. They could also gather data to find out the link between smoking and diseases later in life such as emphysema and lung cancer.

Based on their research students devise a poster which could be displayed in a prominent place in the school. The information they gather could also influence the way the risks of smoking are taught. See also ***Table 2***.

3. ECO-FRIENDLY CLOTHING

This example is based on a project with a class of 17 year olds studying chemistry. The context for this activity was a newspaper article brought in by a student during teacher professional development at University College London [4]. The article explains how air pollution can be reduced by wearing clothes which purify the air.

Catalytic clothing technology brings several different areas of chemistry together. Denim jeans are cleaned in a washing powder containing nano-particles of titanium dioxide, TiO_2, which has *photo-catalytic* properties. These particles of titanium dioxide act on liquid water and water vapour in the air in the presence of light (hence photo-catalysis), producing *free radical* molecules which are extremely reactive (free radicals had appeared in the students' chemistry course when they learned about the decomposition of hydrocarbons) and can react with toxic NO_x particles in the air, converting them to relatively harmless compounds.

This is particularly advantageous because the nano-sized particles are able to stick to the jeans and because of their small size produce a vast surface area, which helps to speed up the chemical breakdown of NO_x pollutants even more. Moreover, titanium dioxide has many other physical and chemical properties which have a role in everyday life (for instance in toothpaste, confectionery, sunscreen, cosmetics, and baking).

So, titanium dioxide and its role in catalytic clothing not only provide a fascinating context for photo-catalysis, free radical reactions and nanochemistry, but investigations into how effective catalytic clothing could be in purifying the air, and the cost-effectiveness ratio. For example, how many people would have to wear catalytic clothing to reduce the NO_x levels significantly? Students could use mathematical models and draw on secondary data. And might there be side effects?

The campaign and investigation took a different turn when a student researching the manufacture of titanium dioxide found out it was mined in Sierra Leone as the mineral rutile. Looking through websites he discovered something that wasn't mentioned in the main literature and was controversial: that the process of extracting rutile displaced many local people and itself degraded the environment of local people in Sierra Leone without giving them much benefit [5]. Furthermore, if the local environment in Sierra Leone was to be protected, and even improved through the mining, then the costs of rutile would go up enormously. This piece of information then prompted students to raise a new question about their investigation: Do the benefits from titanium dioxide outweigh the harm? If not, how can the technology of catalytic clothing be justified? The students worked on a controversy map (annex 2) to identify relationships between various stakeholders: mining company executives, miners, Sierra Leone government, fruit farmers displaced by the mines, chemical researchers, clothes designers, washing powder manufacturers, environmental campaigners, the rutile mineral, garments.

This question was then debated with the whole year group. The students felt the benefits of titanium dioxide were too important to lose but decided to alert local environmental groups to the conditions of production.

Table 2 on the following page summarises these SSIBL-activities.

4
The news article can be accessed from: https://www.theguardian.com/sustainable-business/sustainable-fashion-blog/clothes-tackle-city-pollution-laundry-additive. For other useful background information on catalytic clothing see: https://blogs.scientificamerican.com/guest-blog/catalytic-clothing-purifying-air-goes-trendy/

5
https://www.christianaid.org.uk/resources/about-us/sierra-leone-crossroads-seizing-chance-benefit-mining

Science content	Ask	Find out	Act	Social desirability	Ethical acceptability	Sustainability
Cutting down a school's energy losses						
Energy transfer, fuels, fuel conservation, insulation, thermal imaging, data gathering, sampling.	Where does the greatest heat loss take place in school? What can we do about it?	Best ways to measure heat loss; gathering accurate data; interpreting the data; efficacy of insulators; research into energy conservation in buildings.	Presenting information to the school authorities and school council about heat loss and ways of ameliorating the problem. Devising message in most appropriate ways to convince decision-makers.	Identifying means to improve comfort and wellbeing of school students through effective costing.	Consequences of actions are to improve conditions of learning, maximising benefits to all parties.	Fuel conservation.
Why do young people smoke?						
Lung structure and adaptation, mechanics of breathing, gaseous diffusion, role of blood in oxygen and carbon dioxide transport, cell metabolism, modelling the effects of smoking.	Do our peers know the effect of smoking on health? What do they think about passive smoking? What are the best messages in biology to raise with young people about smoking?	Compiling a valid survey; interpreting the results; exploring the relationship between knowledge of effects of smoking and behaviour; alternatives to smoking.	Making a poster to inform peers about smoking; negotiating a place for the poster in the school; raising consciousness among teachers and students about discussing effects of smoking.	Sensitive ways to raise consciousness about health effects of smoking.	Opens up discussion of health issue without revealing sensitive information.	Health promotion.

Table 2 — Summary of SSIBL-principles within activities

Science content	Ask	Find out	Act	Social desirability	Ethical acceptability	Sustainability
Eco-friendly clothing						
Free radical mechanisms, photocatalysis, nano-chemistry, NO_x pollutants.	How can we raise consciousness about eco-friendly clothing? What are the conditions for eco-friendly clothing to make a difference? Who is effected by the mining of titanium dioxide? What are the best ways to address the ethical problems?	Use of secondary data to evaluate the effects of wearing catalytic clothing, and how it can be upscaled? Identifying the conflicting values and interest positions in the production of catalytic clothing.	Opening up the controversy about mining with local environmental groups, based on evidence they have gathered about the production and benefits/drawbacks of titanium dioxide.	Use of products which improve air quality.	Takes into account benefits and losses to all stakeholders illuminating unfair conditions of production.	Social and economic conditions for environmental benefits.

Annex 1—

Raising authentic questions about SSIs: ‘Ask’

When figuring out whether the scenario chosen is suitable for SSIBL, the following Scenario Machine, developed by the Nijmegen team, can be used (*Figure S1*).

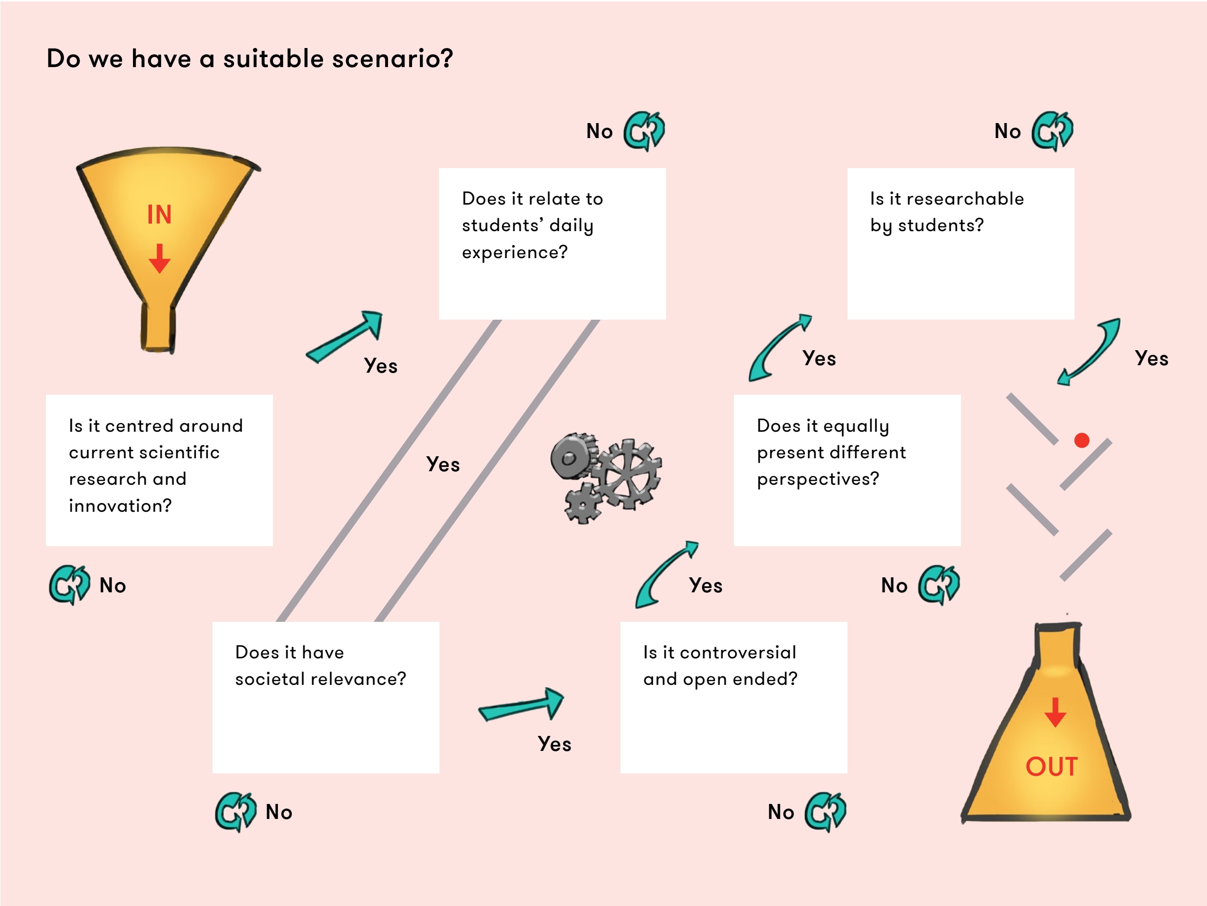

Figure S1 — The SSIBL scenario machine

Subject of article	SSI
Biology	
Vaccination and health issues	Vaccination in the Dutch bible belt; pregnant women, travelling and Zika-virus; Ebola and travel ban; animal testing.
Smoking and health effects	Smoking and governmental restrictions; worth of human life (disease vs. medicine); disease and life-style.
Food scarcity in 2050	What solution would ensure food supply in future years?
Stem cell research	Saving lives with stem cells, but some people might find it unethical. Should we carry on using stem cells?
Using fungi to fight plant disease	Can we – and should we – modify a fungus to change its behaviour to suit our needs?
Using gene therapy to fight Alzheimer's in mice	Animal testing. Use of gene therapy. Effects of Alzheimer's.
Coca cola lobbying against health protection laws	Should governments stop lobbying by multinationals particularly when there is a probability of unhealthy side effects of products?
Biology, Mathematics	
Teenagers drink and smoke more often when parents not at home	Using harmful substances and health issues.

Table S1 — News articles about SSIs chosen by Utrecht University pre-service teachers

Subject of article	SSI
Chemistry	
Using old car tyres to provide a base for sports fields	The car tyres contain PAHs (polycyclic aromatic hydrocarbons) which are implicated as a cause of cancer.
Urinating in the sea	Why do people believe it is harmful to urinate in the sea? What do scientists have to say?
Chemistry, Biology	
Plastics found in deep sea fish	Should we continue to use plastics which are not biodegradable?
High concentrations of pesticides found in muesli and other cereals	What are health effects of eating concentrations of pesticides? Should this still continue?
Chemistry, Biology, Astronomy	
Particles in the atmosphere of Mars	Particles in the atmosphere of Mars cause Alzheimer's, will we ever be able to live on planets other than Earth?

Socio-scientific issues from the news

Table S1 shows a range of newspaper articles chosen by pre-service teachers from Utrecht University, the Netherlands, the SSIs they link to, the questions they raise and the disciplines they relate to.

APPROACHES FOR SETTING THE SCENARIO FOR SSIS

Exemplar activity: Stimulating interest

An important challenge in teaching SSIBL is to stimulate student interest. Where students do not have pressing questions or a dilemma, a useful strategy is to draw on media representations to stimulate enthusiasm, hence discussion. This example comes from a SSIBL teacher development course on nanotechnology run by Malmo University, Sweden. *Ultra Ever Dry* provides a good example of a nanomaterial because it is hydrophobic, and is used as a deterrent against anti-social behaviour. One of its unusual applications is in the red light St. Pauli district of Hamburg where many of the walls are coated with Ultra Ever Dry. When drunken revellers pee against the walls, their urine is bounced straight back at them providing a deterrent. This product is now used in other cities **(6)**. Might this, though, be a means of avoiding building more suitable public toilets?

Examples of other resources for raising dilemmas can be found online **(7)**.

The topic of e-cigarettes has aroused a degree of interest in the media with experts taking up very different viewpoints. This should enthuse young people who are wondering about the pros and cons. Although e-cigarettes are banned in parts of the U.K. and Europe there are some authorities who feel they are a good way to wean people off smoking, see for example Professor David Nutt's article in *The Guardian* newspaper in October 2016 **(8)**.

The headline 'Vaping saves lives. It'd be madness to ban it' is the kind of headline that will provoke discussion when authorities have banned it. There are useful resources on e-cigarettes in the ENGAGE activities **(9)**.

6
See: https://www.theguardian.com/cities/2015/mar/04/st-pauli-pees-back-hamburg-red-light-district-revenge

7
See for instance: http://www.fi.uu.nl/toepassingen/28527/

8
See: http://www.theguardian.com/commentisfree/2016/oct/14/vaping-saves-lives-madness-ban-smokers-cigarettes-kill

9
See: http://www.engagingscience.eu/en/2015/10/13/electronic-cigarettes

Card games

There are a number of games which can be downloaded online which are very helpful in supporting student thinking about socio-scientific and socio-technical dilemmas. Those which are particularly suitable for secondary students on a series of issues are from Democs and can be found online, with a creative commons licence [10]. Card games to stimulate discussion about current issues including socio-scientific ones can be downloaded through *PlayDecide* [11].

Concept cartoons

Concept cartoons are another way of stimulating discussion about controversial issues. ***Figure S2*** is an example of a concept cartoon. Students and teachers, however, can make their own concept cartoon by creating speech bubbles with different views, around a particular scenario.

Structuring questions for a dilemma

Utrecht University used a carousel model in Teacher Professional Development sessions for pre-service teachers to help set the scene and to start thinking about different questions. Their grid (***Table S2***) has been modified for use with school students. The examples from chapter 3 have been used for purposes of illustration.

10
See: http://www.edinethics.co.uk/enhancement/ethentech-democs/democsgame.htm

11
See: http://www.playdecide.eu/about.html

Figure S2 — Concept cartoon example

Questions	Case A	Case B	Case C
What is the case about, what is the controversy?	Fuel conservation in school.	Smoking in young people.	Tackling air pollution.
Which stakeholders are involved (what are their interests?)	School students (studying in a healthy environment); school management (managing fuel costs); local authority (regulations on construction of buildings).	School students (smoking addiction, what can be done about it, what are the alternatives?); teachers (how to address the issue sensitively in the curriculum?); school management (what should school policy be?); parents (what information will help us?); health professionals (information about student attitudes); tobacco industry (profits, employment), government (important taxes).	School students (action against air pollution, relevant science); environmental groups (formulating policy in a local, national and youth context); local community (means of reducing pollution locally and practically); teachers (relating to chemistry curriculum).

Table S2 — Grid to prepare for different SSIBL activities

Relevant science content knowledge	Heat flow; conductivity; measuring temperature.	Respiration; mechanics of breathing; gaseous diffusion.	Catalysis; organic chemistry; nanomaterials.
What questions might be raised? What questions does the issue raise that your students could investigate?	Where are the 'leakiest' areas for heat flow in the school? How can we keep the school warmer in winter and cooler in summer? At the same time how can we conserve fuel?	What are the biological effects of smoking? What adjectives do tobacco industries use to make cigarettes more appealing? Why do young people smoke? What are the best ways to help young people stop smoking?	How does eco-clothing cut down pollution? How effective is eco-clothing?

RAISING QUESTIONS IN INFORMAL SETTINGS

An exemplar on raising research questions on generating electricity through a museum visit

Younger primary school children, visited an old power station to learn about different ways of generating electricity. Teachers were introduced to the SSIBL-framework and used this to plan activities on electricity generation. Through collaboration and experiential learning, including a visit to the Energy Discovery Centre (EDC) in Tallinn in Estonia, teachers planned sessions and discussed questions with the children before the museum visit, such as:

- Should people be able to decide which source of energy they want to use?
- How are decisions made about energy supply?
- Should children have a voice in making these decisions?

These questions help children to think about the problem focusing on the main question: How should electricity be produced in Estonia?

They find out about different means of energy transfer, e.g. experimenting with turbines, and the relation between motion and electricity generation (*Photo S1*), and also learn about historical stages of energy production.

Children are encouraged to ask questions about the ways in which electricity is generated in their home. They discuss in groups different courses of action they might take to reduce energy costs in their home and how they might use alternative sources.

Photo S1 — Children investigating connection between motion and electricity generation

Annex 2—

Enaction: ‘Find out’

Mapping the controversy

Controversy mapping is a means of organising diverse perspectives in a socio-scientific issue so that the connections between scientific, technological, social, ethical, political and legal aspects can be discussed. They also enable participants to reflect on influences at a personal, social and global level. The components of a controversy map can be human or non-human and are known as *actants*. Actants can be organisations or individuals.

You can write the dilemma in the centre of an A3 sheet of paper. Write down (for instance on 'post-its'):

- Stakeholders (actants) and their interest;
- Their opinions and arguments;
- Values you can identify;
- Try to relate them by connecting them with arrows.

Figure S3 shows work done by Israeli participants in organising a controversy map on immunisation. While immunisation is directed at the prevention of lethal infectious diseases it cannot be separated from the pharmaceutical companies who produce the vaccine (the vaccine itself being an actant because it draws scientists, patients, doctors and pharmaceutical companies into a particular type of relationship). When one actant changes or influences a relationship it has an effect on all the other actants.

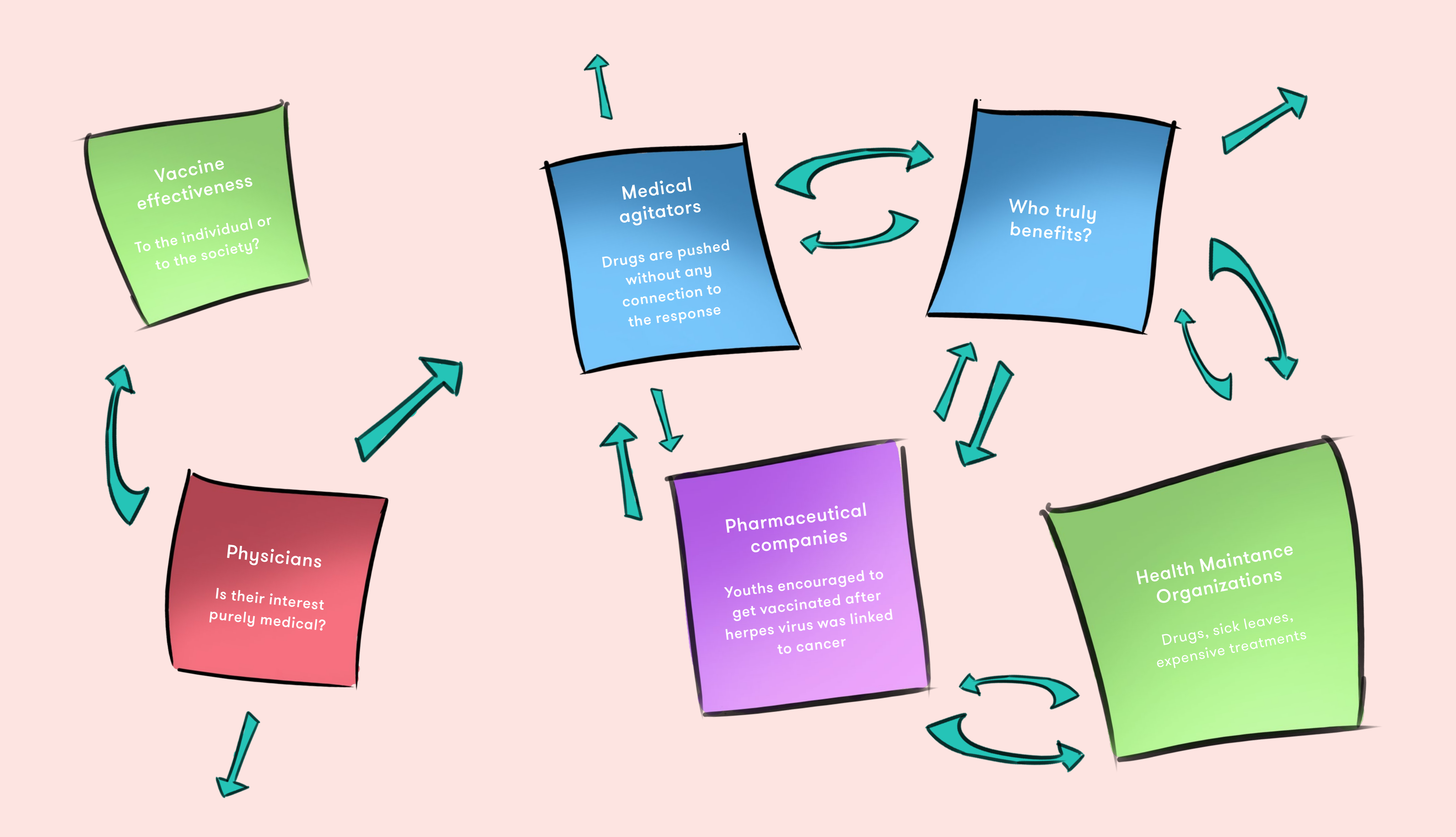

Figure S3 — A controversy map on immunisation

A new government might, for example, change the funding structure for the production of medicines which affects who gets vaccinated and how they prioritise it over other health issues. Organising a map collaboratively helps participants to discuss the issue, discuss the particular aspect or level of the controversy and focus on questions for inquiry.

Life-cycle analysis

As a result of the talk on risks of nanotechnology at a Teacher Professional Development (TPD) session at the University of Malmö one of the pre-service teachers decided to do a life-cycle analysis on a nano-material *Ultra-Ever Dry* whose hydrophobic properties have many applications in civic and domestic areas. An outcome of the life-cycle analysis was to generate a map linking different stakeholders (***Figure S4***). This helped participants identify the stakeholders and the pros and cons of the technology particularly in terms of the ethical acceptability of products, their social desirability and sustainability.

Exemplar activity: modelling

This activity was used by colleagues in the University of Porto, Portugal on health risks caused by nicotine and alcohol addiction. A central feature of this activity is the use of *Daphnia magna* as a model system for detecting nicotine and alcohol activity. *Daphnia* is a tiny crustacean with a translucent exoskeleton, and its heartbeats can be counted easily under a microscope.

Models are representations of systems and allow scientists to predict effects but it is important to distinguish between models and reality. Models are simplifications and approximations, and can present different aspects of the same phenomenon. For example the Bohr model of the atom helps students understand electron transfer but does not give an indication of 3D orientation of orbitals which the orbital model does. Skeletons show positions of joints in the body and can show degrees of freedom of movement but a fuller understanding of motion needs to be complemented by other representations such as medical imaging showing muscle attachments, and videos demonstrating a human walking.

With small children a good start to modelling is to show them a 3D model of a flower or animal and ask them to explain how the model differs from the real version. There are also increasing examples of online simulations [12] which allow students to explain phenomena, make predictions and solve problems but need to keep in mind the ways in which models are simplified and variables reduced.

12
See for instance: E-chalk (http://www.echalk.co.uk) and PHET (https://phet.colorado.edu), which provide examples in diverse areas of science which impinge on SSIBL activities.

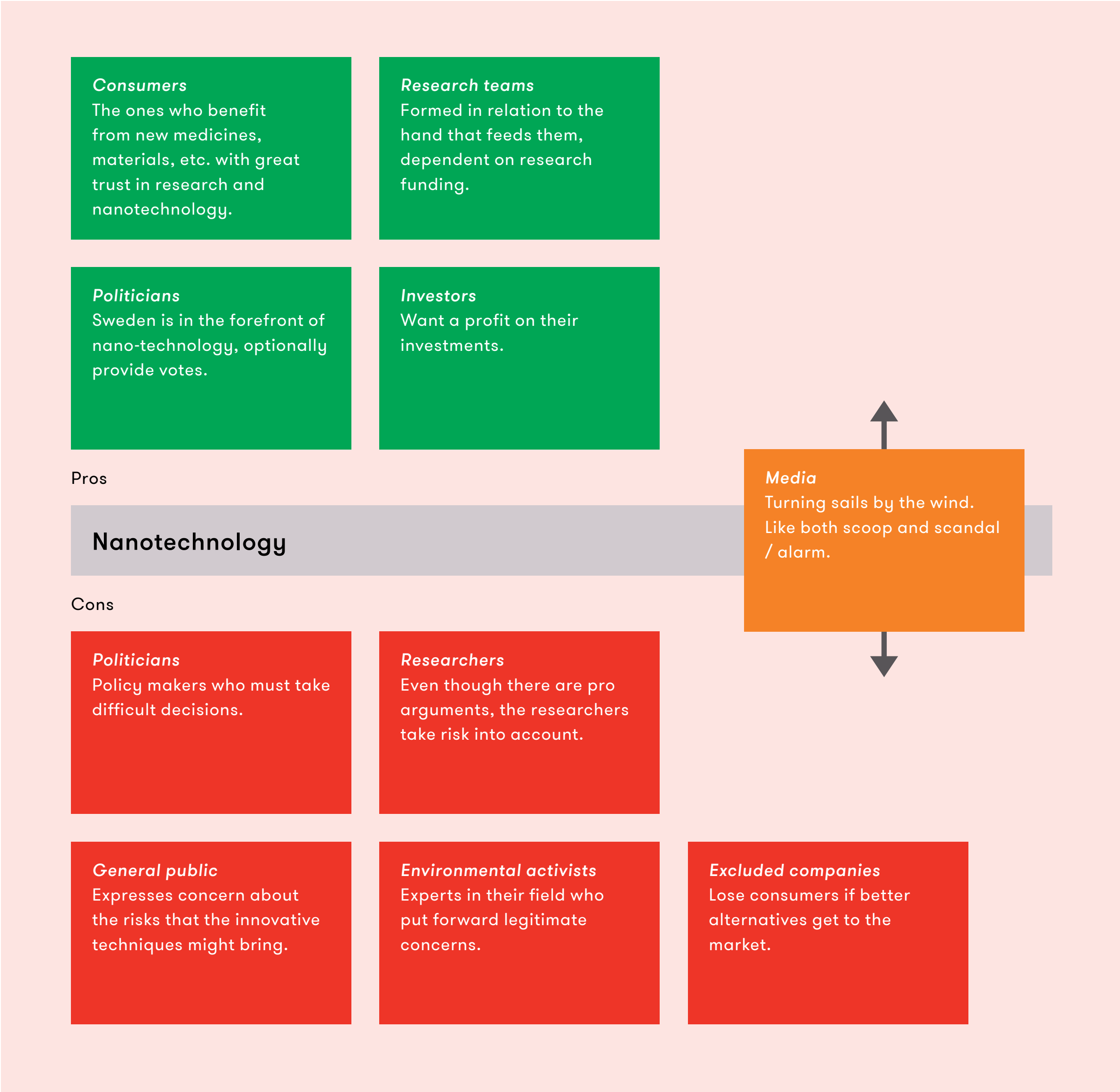

Figure S4 — Mapping interest groups for nanotechnology products

Large climatic phenomena such as the *Greenhouse Effect* can be modelled, for example, by using plastic bottles to mimic conditions inside a greenhouse (See for example 'The greenhouse effect -1' in The Royal Society of Chemistry's *Classic Chemistry Demonstrations*).

Exemplar activity: risk and uncertainty

An important aspect of SSIBL is understanding risk and uncertainty. In terms of climate science these are crucial concepts because any action taken involves uncertainty and unknown risks. Risks can be formally understood as the probability of an event occurring and its impact. So, while the probability of a tsunami occurring in a particular location might be very low its impact would be very high. On the other hand, people often look askance at regular events such as falling down which occur with high frequency because their impact is usually low. Estimating risk is itself uncertain. Although there is an argument that risk can be objectively measured by collecting relevant statistics, the personal and social effects often have to be factored in.

For example, flying in an aeroplane is deemed to be very low risk. But some people are so anxious about flying that it can be detrimental to their health and needs to be factored in estimating the risk.

Any action taken on the environment carries certain risks. Some of these risks might not be obvious. For example, the use of solar panels as a means of transferring light energy from the sun through electricity generation has no apparent detrimental impacts. However, the manufacture of solar panels uses up large amounts of energy and the materials for their production can have toxic side effects particularly when produced at low cost [13]. David Spiegelhalter's website provides animations for students and teachers to discuss risk and uncertainty [14].

Communicating findings to influential parties

An important aspect of SSIBL is enacting change where there is perceived to be a problem. Students should therefore spend time enhancing their arguments to convince stakeholders who can make things happen. Important criteria include:

13
See for an article on this: http://news.nationalgeographic.com/news/energy/2014/11/141111-solar-panel-manufacturing-sustainability-ranking

14
See: https://understandinguncertainty.org/view/animations

- The medium to make their case: poster, short film, dramatic presentation, an article in a newspaper, lobbying politicians.
- Presenting evidence. This is organising the data in such a way to make a compelling argument.
- Reasons. Presenting sound and convincing reasons for their case.
- Suggesting alternatives to the status quo.
- Coherence. Are the points concrete, made one at a time and in a logical order?
- Keep it short and understandable.

Annex 3—

Citizenship Education (CE)

Approaching SSIBL through Citizenship Education (CE)

Some nice examples of using citizenship education in the classroom can be found online [15]. These resources consist of activities for promoting group work and collaboration throughout a SSIBL-activity.

Controversy line

Once participants have been oriented towards a controversy, they organise themselves along a position line depending on the extent to which they agree or disagree with an issue (***Figure S5***). This is taken from the above example from a Teacher Professional Development (TPD) session at the Cyprus University of Technology on the use of antibiotics in livestock.

How participants position themselves along the line can promote discussion, for example, participants near each other can negotiate which one is nearer the agreement/disagreement end. Those on different ends of the spectrum can work in groups to further refine the views about which they differ. One way to promote deliberation is:

1. Ask two groups of participants (group A and group B) on opposite ends of the line to tease out their areas of disagreement;
2. Both groups are given time to prepare their arguments;
3. Group A then presents their position within a three minute time slot;
4. Group B listens and then has to represent Group A's case even more strongly back to group A and, if possible, with stronger backing and evidence;
5. The positions are then reversed;
6. Only when each group has ensured their positions are understood do they then discuss their differences.

This supports active listening and the use of evidence and logic in discussion. This activity can be enhanced by introducing a rational and emotional axis, using 'Arguments in motion' from Van der Zande (2012) [16]. During this activity, the four corners of the classroom represent 'for with the heart', 'against with the heart', 'for with the brain' and 'against with the brain' (***Figure S6***). Participants take place in the room, showing their opinion about the central statement (for and against) and the way they came to this opinion (heart and brain). The idea is that participants are able to 'see' the different opinions, ask questions to each other and are able to change places. Participants can also go to other places in the room and think about arguments for that location, thus reflecting on other opinions.

Figure S5 — Controversy line

15
This activity has been adapted from the Association for Citizenship Teaching in partnership with the National Citizen Service Trust (https://www.teachingcitizenship.org.uk/resource/ncs-key-stage-3-curriculum-activities). Another resource which supports small group discussions and argumentation can be found at: https://www.pstt-cpd.org.uk/ext/cpd/argumentation/unit1.php

Teachers presentations of interest-based perspectives on the topic of antibiotics in livestock (e.g. from the point of view of a farmer, government agency, concerned scientist) from an experiential approach to the activities can be seen on: https://youtu.be/kuGOJ7mXEFM.

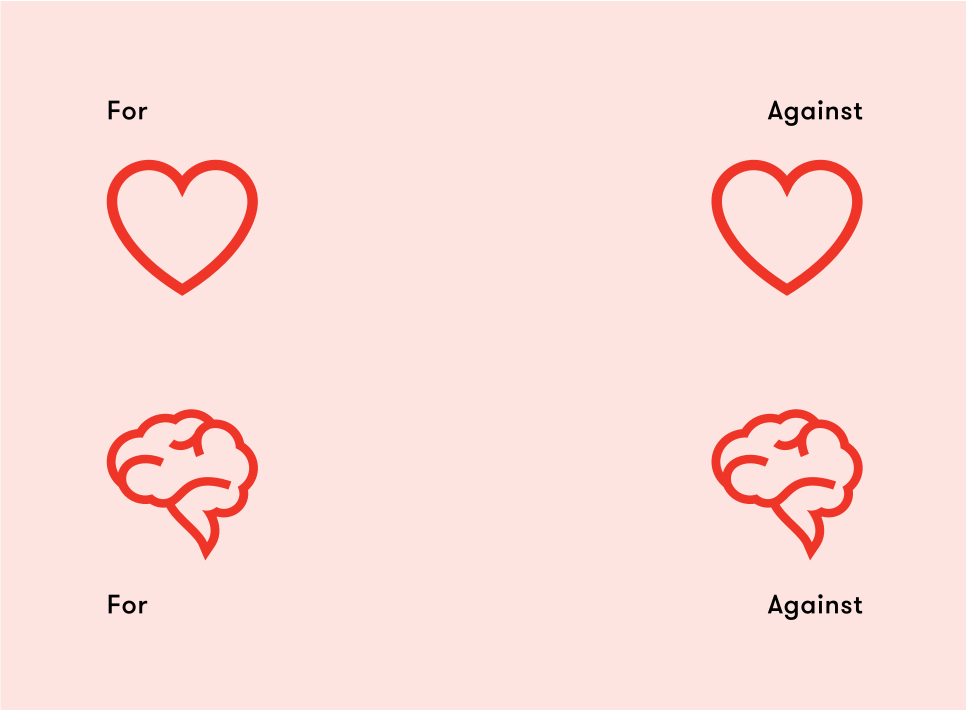

Figure S6 — Arguments in motion classroom setup

16
Zande, P.A.M. van der (2012). Beweegredeneren, een werkvorm bij dilemma's in de klas. See also: https://elbd.sites.uu.nl/2017/07/28/beweegredeneren-een-werkvorm-bij-dilemmas-in-de-klas/

Values clarification

Having set the scenario for an issue students can use an ethical matrix adapted from Mepham (2005) [17] which maps the views of different stakeholders against three main ethical principles. These principles are:

- *Well-being*: Respect for the interests of the stakeholder involved and to do as little harm as possible to their interests.
- *Autonomy*: respect for individuals' rights (whether human or non-human) to act and live their lives in their own preferred ways.
- *Fairness*: to act in a just and fair manner.

The cells of the matrix are there for students to populate with their points of view. An example is taken from use of antibiotics in livestock in ***Table S3***.

Taking action

During SSIBL-activities there will come a point where a class or a group will be debating action, having arrived at one or more solutions. How this is done will depend on whether the particular activity is carried out as just one group of, say, four or five participants; a number of groups working on different aspects of the issue, or as a whole class activity. Even if the issue is addressed by only one group the whole class can discuss their views on what action to take. Each member of the class could be asked to suggest a particular course of action, and puts their ideas into a box. The teacher sifts the decisions into categories (some ideas will overlap). The class is then divided into half (say, 12 and 12 in a class of 24). (If there are odd numbers in each class one student can be appointed as time-keeper or helper). A space is then created in the classroom with chairs in two concentric circles so participants sitting in the inner circle face those in the outer circle.

The teacher distributes strips of paper each with one or two possible courses of action to each student in the inner circle. They discuss the possible courses of action with a student sitting opposite them in the outer circle for two minutes. Then the students in the outer circle shift one seat to the left. The discussions continue with different students for three to five interactions depending on the number of solutions available. The class then comes together and reports on their favoured courses of action.

17
Mepham, B. (2005). Bioethics. Oxford: Oxford University Press.

Respect for	Wellbeing	Autonomy	Fairness
Farmers	Improves their income and living conditions.	Can make their own decisions as to what circumstances to use antibiotics on their cattle.	Can price their products fairly in the market place subject to fair laws and practices.
Consumers	Receive a supply of food from healthy livestock.	Can choose which produce to buy.	A supply of food available to the whole population.
Cattle	Right to a healthy life and minimisation of suffering.	Their natural way of life is not inhibited, e.g. grazing, sleeping.	Treated as sentient beings in their own right not merely as instruments for increasing value for farmers.

Table S3 — Ethical matrix for Antibiotics in livestock

PARRISE (Promoting Attainment of Responsible Research and Innovation in Science Education) project