An educational sequence for implementing socio-scientific inquiry-based learning (SSIBL)

Marie-Christine P.J. Knippels and Michiel van Harskamp

Abstract We present a sequence of professional development sessions to support science teachers in designing socio-scientific inquiry-based learning (SSIBL) lessons to foster democratic citizenship. We focus on seven stages for enacting SSIBL: (1) introducing a dilemma; (2) initial opinion-forming; (3) creating a 'need to know'; (4) inquiry; (5) dialogue; (6) decision-making; and (7) reflection. These stages were practised by pre-service science teachers ($n = 79$) in designing SSIBL lessons ($n = 30$). Activities trialled in the sessions as well as the challenges and opportunities identified by the pre-service teachers will be discussed.

We live in a rapidly changing world in which the internet makes sources of information readily available, major social networks influence our day-to-day relationships, solar panels and windmills are slowly replacing fossil fuels, and we can alter organisms or even build whole genomes from scratch. These developments in science and technology impact on our society as well as our personal lives. They often improve our wellbeing but also carry with them scientific uncertainties and social risks. There is thus a need for scientifically literate citizens who are able to make informed decisions about these emerging socio-scientific issues (SSIs). Fostering opinion-forming and democratic citizenship are important aims of science education, both on the national (Bron, 2006) and international levels (European Commission, 2015). However, implementing aspects of democratic citizenship education to foster critical and responsible participation in society is still challenging. In daily practice, driven by time constraints and national assessment strategies, there is an understandable tendency to focus on examined core knowledge. Additionally, societal and ethical aspects of science are underexposed in teacher training programmes, or are often not the main concern of pre-service teachers.

In this article, we present guidelines that support science teacher educators and teachers in implementing socio-scientific inquiry-based learning (SSIBL) (Levinson, 2018) in their classroom practice more easily and flexibly. These guidelines were introduced, discussed and practised in the pre-service teacher training programme at Utrecht University, the Netherlands (9 cohorts: $n = 79$ with 38 female, 38 male and 3 gender unknown; specialisms: 37 chemistry, 36 biology, 4 mathematics, 1 physics and 1 information technology; average age = 30.5 years).

The SSIBL approach consists of three key elements:

- **'Ask'**: raising authentic questions about controversial issues arising from impacts of science and technology in society;
- **'Find out'**: integrating social and scientific inquiry to explore these open-ended questions;
- **'Act'**: formulating solutions that help to enact change (Levinson *et al.*, 2017).

We introduced and structured these three key elements in our teacher professional development sessions by means of *seven educational stages* that served as guidelines for the pre-service teachers to design a SSIBL lesson and that provided the 'backbone' of the sessions:

1. **Introduction of dilemma**: connect to student's daily life, interest;
2. **Initial opinion-forming** (individually or in small groups);
3. **Raise questions**: 'need to know' (e.g. content-related, social and/or personal questions);
4. **Inquiry**: students answering the questions raised through social, personal and scientific inquiry;
5. **Dialogue**: value clarification and communication;
6. **Decision-making**: formulate solutions that help to enact change;
7. **Reflection**: on student's opinion-forming process (metacognition).

In each stage, examples showing how to introduce this in classroom practice were discussed and pre-service teachers could practise specific stages in small-group tasks. The developed programme consisted of two 1.5 hour face-to-face training sessions and a take-home assignment to design a SSIBL lesson, within the context of a 20-week pre-service training course. We will present the main activities and rationales as implemented in the teacher professional development sessions. The sessions aimed to develop the pre-service teachers' understanding of, and competence in, teaching and learning through SSIBL. The overall goal is to support teachers in developing SSIBL teaching and learning activities, and to contribute to their teaching repertoire by providing them with the means to foster scientific literacy and democratic citizenship in science education.

'Ask': Introducing a dilemma and raising a 'need to know' question (stages 1–3)

The educational stages discussed in this section are:

1 **Introduction of dilemma**: connect to student's daily life, interest;
2 **Initial opinion-forming** (individually or in small groups);
3 **Raise questions**: 'need to know' (e.g. content-related, social, and/or personal questions).

In classroom practice, it is important to start by introducing a dilemma that is relevant and compelling to students (Sadler, 2011) so that they get involved and interested in the issue and are willing to know more about it (i.e. raising a 'need to know'). Current news articles can be used to introduce SSIs, and narratives with a human storyline have also proven effective in engaging students in the dilemma and prompting opinion-forming. For instance, Boerwinkel, Knippels and Waarlo (2011) used *YouTube* videos on elite sports in the context of genetic testing, and Knippels, Severiens and Klop (2009) used a clip from the movie *GATTACA* in the context of genetic modification (*stage 1*).

Since most students have an initial opinion or gut feeling about the issue, it is important that they be given the opportunity to formulate their opinion individually first (e.g. by writing it down) or discuss it in small groups, before being challenged by other students in the classroom (*stage 2*). *Stages 1–3* can also be implemented by enacting a dilemma on a controversy line, an activity that was used to start our pre-service teacher training session (Box 1).

Box 1 The controversy line activity

Briefly introduce the issue (by means of a picture or article) and present a statement. For example:

> '*We should intervene when animals in the "Oostvaardersplassen"* [a nature reserve in the Netherlands] *are threatened by starvation.*'

Ask students to position themselves along a line between two corners of the classroom, ranging from 'agree' to 'disagree' (Figure 1).

- Students think for a minute about the statement and take up their position on the line.
- They discuss their position with neighbours on the line, mentioning arguments and beliefs for their position, and questions for the others.
- The teacher (educator) briefly questions students at different positions on the line.

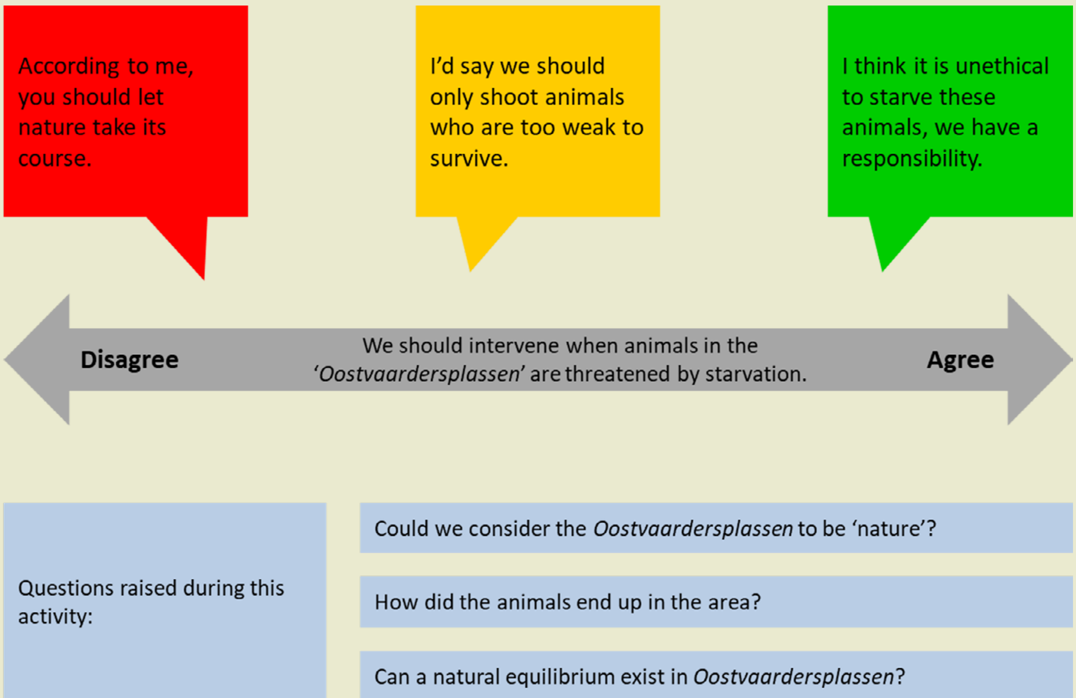

Figure 1 Example of a controversy line with positions and questions about the '*Oostvaardersplassen*' dilemma; the questions below the line represent questions raised, which inform stage 4 – inquiry

Introducing SSIs by means of narratives and/or a controversy line activity elicits a diversity of student (teachers') questions (*stage 3*). These kinds of questions served as the starting point for the inquiry phase (*stage 4*).

Next, the pre-service teachers become more familiar with SSI characteristics by means of a 'carousel task'. They were introduced to multiple SSIs such as genetic testing, nanotechnology, plastic waste and climate change, or brought in their own SSI example. They then discussed these controversies in small groups (Figure 2), exploring the following questions:

- What is the SSI about – what is the controversy?
- Which stakeholders are involved – what are their interests?
- What science content knowledge is relevant?
- Which questions might the issue raise that your students could investigate?

In a plenary discussion, the pre-service teachers reflected on their findings, identifying and discussing characteristics of these controversies and how to address them in classroom settings (Box 2). They developed arguments about whether and why SSIs should be included in the science curriculum and how they could link these to the formal science curriculum.

Pre-service teachers discussed the types of questions these SSIs raise that students could inquire about (the 'need to know'). Examples include:

- How does a genetic test work?
- Does everyone in the world have access to these tests?

Figure 2 Pre-service teachers discussing SSIs in the 'carousel task'

- Are costly patents involved in the production process of these tests?
- What chemicals are produced during development?

Such questions illustrate the diverse nature of questions that students could conduct inquiry in (content, societally, ethically, personally related questions).

Box 2 Outcomes of the carousel activity – examples of answers provided by the pre-service teachers during the plenary reflection

During reflection on SSI articles in the teacher training sessions, characteristics that were indicated often were:

- all include a dilemma, controversial issue or societal issue;
- no simple or clear-cut answer or solution;
- linked to science and developments in science;
- usually interdisciplinary in nature;
- involves making a choice/decision;
- both scientific content knowledge and emotions play a role (different kinds of knowledge).

Incorporating SSIs in science education is important because it:

- promotes scientific literacy;
- promotes citizenship education;
- asks for scientific and moral reasoning concerning authentic problems (societal issues);
- is present in national curriculum aims of the Netherlands;
- connects their science subject to the student's daily life.

'Find out': Scientific and social inquiry (stages 4–5)

The educational stages discussed in this section are:

4 **Inquiry**: students answering the questions raised through social, personal and scientific inquiry;
5 **Dialogue**: value clarification and communication.

In answering the questions raised, active inquiry into solutions is needed. Most science teachers are well acquainted with various scientific inquiry methods but feel less comfortable with, or equipped for, methods of social, personal and ethical inquiry. Therefore, the teacher professional development session emphasized ways of carrying out social inquiry (*stage 4*). First, ideas about how to scaffold student inquiry were discussed, such as a planning and consultation phase:

- What information do you need and how do you determine whether the source is reliable?
- Which scientific idea(s) is (are) relevant?
- Which inquiry approach will you choose?
- How will you collect and interpret data?

Next, examples of activities for social inquiry were discussed and practised. In social and personal inquiry, clarification and communication of values and beliefs is essential. A more in-depth analysis of the controversy and related stakeholders is needed. Mepham's (2005) ethical matrix can help to clarify different values and compares the views of various stakeholders in the dilemma through three main ethical principles, namely autonomy, well-being and fairness (Table 1). Newspaper articles, internet data sources, stakeholders' websites,

Table 1 Example of an ethical matrix for the 'Oostvaardersplassen' issue, mapping the views of various stakeholders in the dilemma against three main ethical principles

Stakeholders	Respect for:		
	Well-being	**Autonomy**	**Fairness**
Visitors to the park	Pleasant visit to the national park	Able to enjoy the national park in their own way	Assure affordability to visit the national park
Animals	Enough food to live	Are able to migrate to areas with enough food	Sustainability of population, intrinsic value
Forestry Service	Feel successful in and capable of performing their job in the available time	Able to perform their job in the way they prefer	Ensure natural ecosystem equilibrium
NGOs	Animal rights laws respected	Able to act on their values and beliefs and fulfil their professional mission	Duty of care

interviewing stakeholders, and discussion of ideas in small groups can inform this process.

After this more in-depth inquiry into the controversy, special attention was paid to the dialogue (*stage 5*) and contrasting it with activities such as a debate or assigning groups of students as being 'for' or 'against'. The dialogue format emphasises listening to each other and asking clarifying questions, and is an activity focusing on value clarification and communication instead of convincing someone of your personal viewpoint. Depending on the teacher's role in the dialogue, the focus will be more on value clarification, communication and/or transmission. We developed a tool, *Dialogue and decision-making: a dialogue tool for teachers*, which was presented to the pre-service teachers. This tool lists possible teacher's roles in classroom dialogue and shows how suitable such roles are for different learning goals; see Table 2, which is based on Harwood (2001) and Waarlo (2014). Additionally, the tool provides questioning techniques and frames, and is available online in Appendix 3 of the teacher's manual (Overbeek, Knippels, Boerwinkel, de Bakker, Weetzel and van Harskamp, 2014).

These inquiry activities should provide answers to the questions raised, or might prompt new questions or the need to explore additional sources. The 'expert' method might be helpful in dividing work up: letting groups of students perform in-depth inquiry into specific questions so they become comparative 'experts' in a particular section

Table 2 The teacher's roles in dealing with the value component of socio-scientific issues (SSIs) in classroom dialogue; the various roles are more (++), less (+) or not ( ) appropriate depending on the nature of value formation aimed at transmission, clarification or communication

Role of teacher	Role description	Development of values through:		
		Teacher as transmitter	**Teacher supporting clarification**	**Teacher supporting student communication**
Participant	You are free to express ideas, opinions and emotions, like the pupils. (This can be confusing for pupils, since teachers are the professionals.)	+	+	+
Impartial observer	You do not interfere in the dialogue, but only observe the pupils.		+	++
Instructor	You clarify relevant information, concepts and ideas. You ask questions to assess the level of understanding. You give positive or negative feedback to input from pupils.		+	+
Devil's advocate	You take on contradictory points of view to stimulate the dialogue.		+	++
Advocate	You present all possible points of view and conclude with your own opinion, supported by arguments.	+		+
Impartial chair	You stimulate pupils to contribute to the dialogue and keep an eye on the rules of the dialogue, but do not give your own opinion or positive/negative feedback on the input of pupils.		++	++

of the topic being researched; and exchanging information. Based on the available time for your science lessons, you can choose one or more of the presented activities.

'Act': Decision-making and reflection (stages 6–7)

The educational stages discussed in this section are:

6 **Decision-making**: formulating solutions that help to enact change;
7 **Reflection**: on student's opinion-forming process (metacognition).

The various inquiry activities should provide students with an insight into different arguments, interests and values involved in the controversy, an understanding of underlying scientific concepts as well as scientific uncertainties, and a more profound insight into their own values and beliefs. This scientific, social and personal knowledge should inform students' decision-making processes (*stage 6*). A decision intrinsically holds possible actions, for instance feeding the animals in '*Oostvaardersplassen*' or writing a letter to the protesters to convince them that feeding the animals will not preserve the natural ecological equilibrium. In school, in addition, students can also design a poster or leaflet and present this to their peers or discuss their opinions at home with their family.

In order to make the opinion-forming and decision-making process more explicit for students, a stage of reflection is important (*stage 7*):

- What have you learned?
- Did your opinion change during the lesson(s)? Why/why not?
- What steps have you taken to inform your opinion?
- How would you approach such an issue next time?

SSIBL designs

At the end of the first teacher professional development session, the pre-service teachers brainstormed in pairs about a SSIBL lesson design that they could teach in their own training school (with the aid of a worksheet including the seven educational stages). They were given a take-home assignment to design a SSIBL lesson (individually or in small groups) and to present and discuss the design in the next session (approximately three weeks later).

In our programme, a total of 30 SSIBL lesson designs were collected. Themes ranged from 'sustainability of biodegradable plastics' and 'oil spills in urban areas' to 'health effects of sugar', and all could be fitted into the following categories:

- energy;
- food;
- health;
- genetic modification;
- biodiversity;
- global warming;
- sustainable materials.

Two examples of pre-service teachers' SSIBL lesson designs are shown in more detail in Table 3.

Pre-service teachers' opinions

A questionnaire consisting of five open-ended questions was administered at the end of our programme, asking the pre-service science teachers ($n = 79$) how they valued SSIBL and what opportunities and challenges they foresaw in implementing SSIBL activities in their classes. Seventy-nine of them answered that SSIBL was of added value to their teaching repertoire. The main reason indicated was that SSIBL makes the relevance of science clear to the students (Figure 4) since it connects science with daily life. As illustrated by a comment from a pre-service teacher:

> *Students are involved in concrete and real subjects that have a lot of added value since biology deals with daily life experiences.*

Additionally, the pre-service teachers felt that SSIBL is a useful alternative teaching strategy, as it stimulates opinion-forming and motivates students.

All pre-service teachers were able to think of at least one challenge concerning SSIBL education. They most often mentioned time constraints when asked about the challenges (Figure 5). Other responses included overloaded curricula, uninterested colleagues or an unfavourable school climate. One pre-service teacher stated that '*the amount of freedom the school allows you to spend on it is challenging, a lot of teachers stick to the textbook*', and that they had a lack of trust in their own abilities to use SSIBL strategies.

So the pre-service science teachers all valued the SSIBL approach and the teacher training session stimulated them to think of opportunities for social and ethical student inquiry into SSIs in their classroom. They perceived the SSIBL approach to be of added value to science education, since it draws on the authentic nature of socio-scientific controversies, which motivates students to explore the dilemmas and underlying concepts and to develop their own opinions. However, the pre-service teachers faced challenges in implementing SSIBL activities in the available time, in an overloaded curriculum, and they continued to feel less competent in guiding social inquiry. In that respect, the training sessions could devote more time to practising and scaffolding these

Table 3 The seven stages in example lesson designs developed by pre-service teachers

Stage		Biology lesson	Chemistry lesson
		Topic and subject themes	
		Nuclear energy and governments handing out iodine pills; thyroid function	Environmental impact of Tesla electric cars; energy transactions
		Science concepts	
		Function of the thyroid, health effects of iodine deficiency, effect of nuclear radiation on thyroid function	Energy transitions, potential energy, global warming potential of gases
		Length	
		2 × 45 minutes	1 × 70 minutes
1 & 2	Introducing SSI and forming initial opinion	Letter from Dutch government about iodine pills and nuclear risk zones, sent to all citizens in a 100 km radius of nuclear plants (Figure 3)	Internet news article on environmental impact of Tesla electric cars
3	Raising questions	Teacher presents stakeholders and shows actual medicine package sent by government, leading to the question: why is this necessary and is it worth the risk?	Sentences with critical questions blanked out; asking the students what they know to be fact, what they do not know, and how to find this out
4	Social and scientific inquiry	Students are divided into groups, with each group finding information related to one stakeholder; finding biological aspects and arguments; reading sources critically; interviewing three people at home about their opinion – what should the government do?	Doing literature research on the chemistry behind Tesla's motor; looking for information online about the social impact of Tesla cars, and reasons for choosing Tesla or not; specific attention to reliability of sources
5	Dialogue	Sharing outcomes of interviews; displaying opinions and arguments of various stakeholders	Sharing ideas, opinions and reasons for choosing Tesla or not in small groups; asking clarifying questions
6	Decision-making and action	Writing a patient information leaflet on risk and the biological background of the problem, to be sent with the iodine pills; focus on awareness	Students present their findings to the class; teacher and students summarise and make a list of the findings together
7	Reflection	Present in writing the patient information leaflet; summarising opinions and biological background	Reflection using questions provided by teacher: Enough information to answer your questions? Did you learn from the views of others?

Figure 3 An extract from the leaflet sent to citizens in nuclear risk zones notifying them that they will be sent a pack of iodine tablets; the Dutch text shown reads: '*During the week of 9 or 16 October 2017 you will receive a box of iodine pills at this address. Look after them well!*'

kinds of inquiries. Nevertheless, experiencing and practising SSIBL activities in classroom practice over time should add to these teachers' self-efficacy.

Conclusion

We provided an educational sequence aiming to foster meaningful science education derived from societal dilemmas, in which attention is paid to conceptual development, social deliberation (value clarification and communication) and personal opinions (values and beliefs) by means of inquiry-based learning. We hope this educational sequence is helpful for science teacher educators and teachers and may guide and stimulate them to implement SSIBL activities in their own classroom practice in order to contribute to democratic and scientific citizenship. In doing so, science education will more effectively prepare students to actively and responsibly participate in our fast-changing society.

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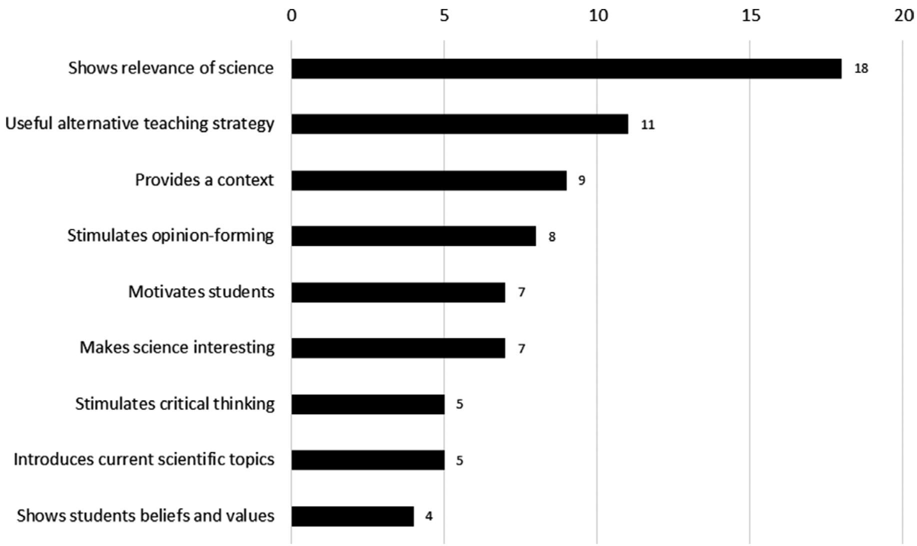

Figure 4 The added value of SSIBL as indicated by the pre-service teachers ($n=79$) in their questionnaires; only topics that were mentioned by four or more teachers are shown

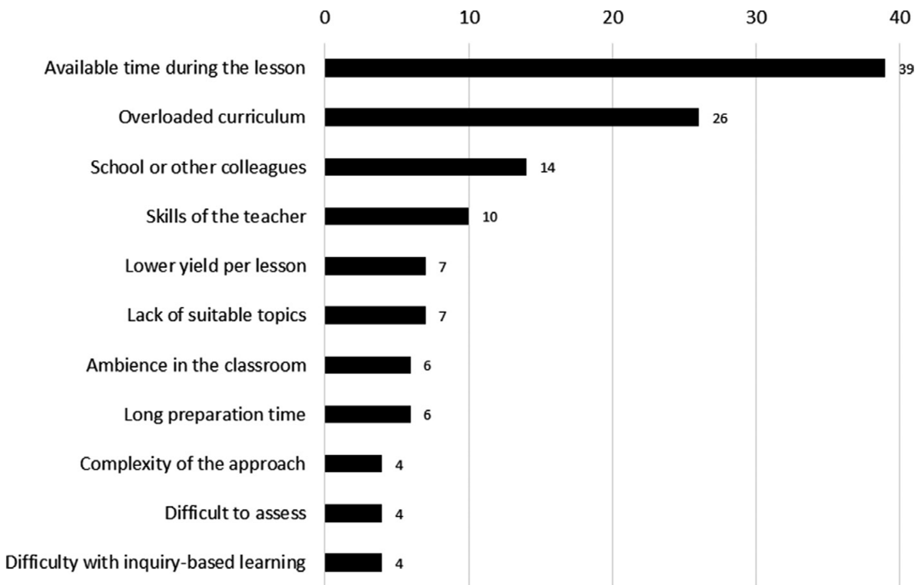

Figure 5 Challenges in implementing SSIBL as mentioned by pre-service teachers ($n=79$) in their questionnaires; only topics that were mentioned by four or more teachers are shown

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