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Socio-Scientific Inquiry-Based Learning as a means towards Environmental Citizenship

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Abstract: This paper draws on the meta-theory of Critical Realism providing a theoretical basis for the pedagogical approach of Socio-Scientific Inquiry-Based Learning (SSIBL) in supporting Education for Environmental Citizenship (EEC). We argue that while there are different configurations of EEC, inducting citizens in decision-making needs to satisfy these criteria: (a) relevant transdisciplinary knowledge, (b) a values orientation towards both the complexity of, and the necessity for a sustainable world, and (c) a confidence for, and commitment to socio-political action at indivdual and collective levels. In order to provide a rich perspective about how SSIBL has been operationalized in various national contexts through specific teacher professional development, we present four cases purposefully selected as exemplars from different European countries (The Netherlands, Spain, UK and Cyprus). The four cases provide powerful scenarios to discuss different ways in which the SSIBL approach can be implemented in teacher education to meet the criteria identified and thus promote informed and responsible action in relation to socio-environmental issues. The whole picture shows a consistent theoretical foundation and interesting opportunities for teacher education, as a relevant strategy to prepare teachers in taking risks and integrating SSIBL within school curricula to foster environmental citizenship.

Keywords: socio-scientific inquiry-based learning (SSIBL); education for environmental citizenship; teacher education; critical realism; transdisciplinarity

1. Introduction

In a recent interview Bill Gates opined that the coronavirus pandemic was a mere episode compared with the existential threat to the planet posed by environmental degradation [1]). Life on Earth has become one of the BBC flagship programs, and its presenter, Sir David Attenborough, a global campaigner for environmental protection. At the other end of the age scale, teenager Greta Thunberg has stirred people of all age groups to take a position on excess consumerism. Pressure groups like Extinction Rebellion have gathered popularity from many sections of the population. Likewise, more than 94% of a sample of 27,881 EU citizens reported, in face-to-face interviews, that the

environment is personally relevant to them [2]. 'Sustainability' and 'Environment' have now become key terms in socio-political action.

Environmental Education has gradually been incorporated into school curricula with distinct philosophical approaches, some focusing on the importance of fundamental change in practice (Education for Sustainability, EfS), some on the three pillars of 'economy', 'society' and 'environment' (Education for Sustainable Development, ESD) and some which align Environmental Education more closely to science education [3]. Whichever educational approach is adopted, they draw on common knowledge and skills: a depth of scientific (including environmental) knowledge and an understanding of citizenship action personally, socially and globally [4]. This type of Education for Environmental Citizenship (EEC) has therefore become a central aspect of debate in recent times, for instance through the ongoing European Network of Environmental Citizenship [5,6] which raises the need for further theorization of EEC from an epistemological perspective.

Socio-Scientific Inquiry-Based Learning (SSIBL) has been placed within the pedagogical landscape of EEC by the European Network for Environmental Citizenship [6] We intend to provide a theoretical foundation to this pedagogical approach and to discuss various learning scenarios developed in collaboration with teachers, to illustrate how SSIBL has been operationalized in four different countries through teacher education. The learning scenarios co-designed with teachers in the four different countries will be discussed on the basis of the underlying values, the relevant transdisciplinary knowledge mobilized and their potential to support responsible and informed socio-political action.

Therefore, the main objectives of the present work are:

1. To provide an epistemological foundation for the SSIBL model, as a powerful pedagogical approach to support education for environmental citizenship.
2. To illustrate how the SSIBL pedagogy has been operationalized in four different countries through teacher education.
3. To provide concrete co-designed learning scenarios to apply relevant transdisciplinary knowledge and a value-based orientation to develop commitment to environmental socio-political action at personal and communal levels.

2. Theoretical background

One of the problems facing both science and environmental educators today is the diverse approaches to epistemology. There are two distinct educational discourses (and many intermediate ones). One argues that non-specialists have misconceptions about the causes of environmental phenomena and that any action taken presupposes authoritative scientific causal explanations, for example about atmospheric effects [e.g., 7-10]. For any action to be effective, actors must understand the scientific explanations behind these effects. Another discourse maintains that scientific and environmental knowledge is derived and contextualized as a result of action; participants learn as they go along and the 'knowledge-in-practice' they accrue is often used to answer specific questions, in other words knowing-in-action [11-12]. These poles of research traditions reflect Simonneaux's [13] hot and cold extremities of educational priorities. At the cold end is mastery of 'sedimented' knowledge in the promotion of technoscience; issues are drawn on to illustrate or reinforce central scientific concepts. At the hot end, students understand the need to recontextualize destabilized knowledge in dealing with controversial issues.

This spectrum is characterised in three teaching traditions in environmental and sustainability education [14-15]. The *fact-based tradition*, consistent with the cold end of the spectrum, relates most closely to the emphasis on scientific knowledge as a precursor to solving problems. Scientific concepts are taught, and it is assumed they can be applied to a particular issue. The environmental problems are mainly seen as ecological and detached from a social context. This essentialist approach focuses on disciplinary knowledge compared with the progressivism of the development of the individual [16].

The second, *normative tradition* recognizes that human wellbeing is inseparable from the sustainability of the planet, derived from a shared sense of the common good, and that authoritative scientific knowledge can provide a guide to the best way of living. Problem-solving of this nature takes experience and attitudes into account; teaching strategies might entail groups with different experiences using their knowledge to help solve a problem. With its reliance on the authority of science it has connections to essentialism with progressive approaches.

The third teaching tradition, the *pluralistic tradition*, is reconstructionist in that it recognizes that social justice is intricately bound with problems of sustainability, that science alone cannot provide solutions, but that a transdisciplinary approach is called upon drawing on science, humanities, the arts as well as human experience in order to address moral and political problems relating to the environment through democratic participation and action [17]. It is this third teaching tradition that the Socio-Scientific Inquiry-Based Learning (SSIBL) pedagogical approach adheres to [18-19].

2.1 Socio-Scientific Inquiry-Based Learning (SSIBL)

SSIBL [18-19] conforms broadly to a pluralistic approach in that it is inquiry-driven and identifies problems which need solving drawing on transdisciplinary methods in seeking solutions to a variety of common problems associated with the uncertainties of a post-normal world [20], i.e.one such as in the present COVID pandemic where facts are uncertain, values in dispute such as the push or resistance to the global distribution of vaccines, stakes are high in literal terms of life and death, and decisions urgent, for example the need to trial vaccines before standard regulatory periods. Figure 1 demonstrates the approach behind SSIBL [19]. SSIBL was formulated through an EU project, 'Promoting Attainment of Responsible Research and Innovation in Science Education' (PARRISE), to bring to the fore transnational ideas, best instructional practices and resources relating to learning about responsible innovation [21]. SSIBL links three pedagogical approaches: a) Inquiry-Based Science Education (IBSE) which takes inquiry as its starting point where knowledge can both be used and constructed, b) Socio-Scientific Issues (SSI) in which inquiry takes place through examining social issues with a strong scientific content such as sustainability, and c) Citizenship Education (CE), which focuses on participatory learning and inquiry, with objectives consistent with democratic practices. These ideas can be encompassed through inquiries which are directed towards sustainable, socially desirable, and ethically acceptable outcomes [22].

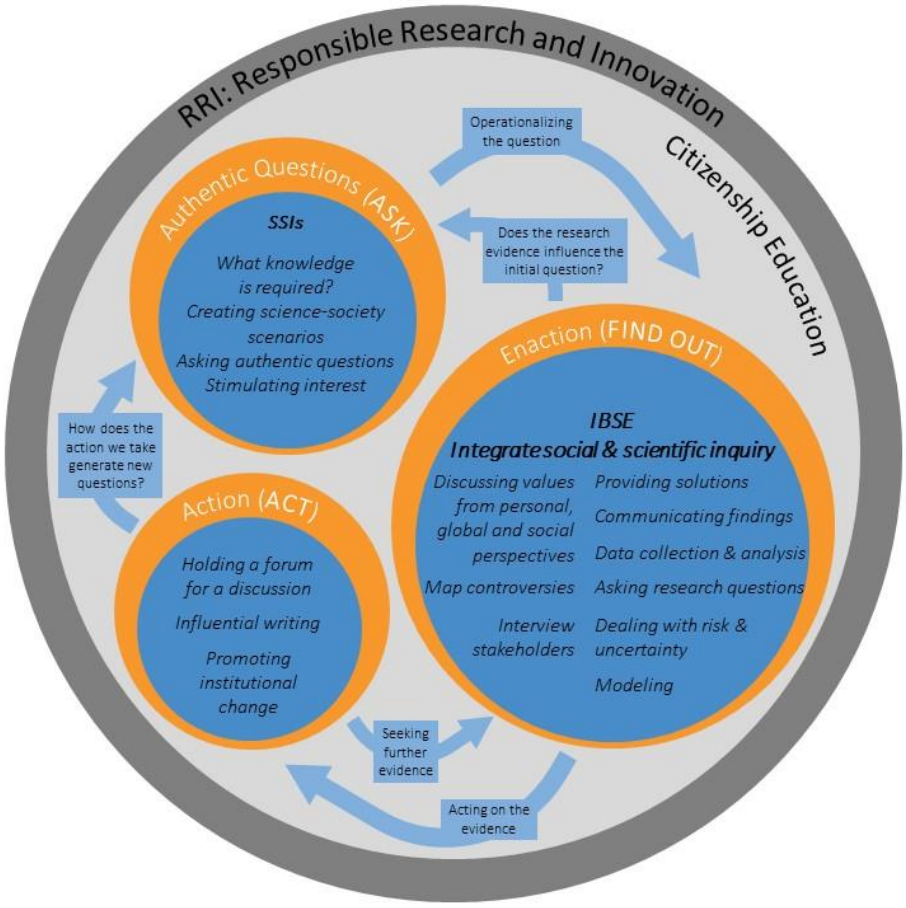

Figure 1. Socio-Scientific Inquiry-Based Learning [19].

The three pedagogical approaches and their interconnections illustrated in Figure 1 have been organized into three instructional phases formulating a practice-based model that can be used by educators across age phases and with teachers. These instructional phases consist of:

a) **ASK**, which focuses on posing *authentic questions* framed within particular SSI-based perspectives that can be investigated by students;

b) **FIND OUT**, which focuses on students *enacting* or carrying out different types of socially responsible inquiries (structured, guided, open) [23] in order to collect evidence and unveil different perspectives to answer their questions; and finally

c) **ACT**, which focuses on how active citizenship is enacted by students, who consider the outcomes of their investigations and devise appropriate forms of *action* (e.g., campaigning for climate action, writing to their local authorities) that can empower them to contribute responsibly within their communities, at local, national or global levels [18-19].

In the following sections, we discuss how the theoretical framework of critical realism [24] can provide the underlying epistemology for the SSIBL pedagogy within a pluralist teaching tradition [25] which emphasizes transdisciplinarity, action and a values-oriented educational approach. This aims to address what we consider to be shortcomings of the fact-based and normative teaching traditions, previously identified in environmental and sustainability education [14-17]. Our focus on transdisciplinary inquiry, action and values-orientation through SSIBL promotes the idea of human emancipation in the context of sustainability, and fosters environmental citizenship.

By emancipation we draw on the praxis of actors making sense of their communal lives and acting in ways which are consistent with their values, reason and experience

[26]. For the sake of illustration, it is possible to exemplify how emancipation might be achieved. One approach might be for a student to learn from a more experienced and wiser other, for example a teacher, and to act accordingly based on advice. Another way might be a 'pragmatist' perspective [27] which is to make an efficacious decision based on deciding rationally what are one's own best interests. The problem with the pragmatist perspective is that actions might be based on false beliefs. A third position, and one which is consistent with a critical realist approach, is that action takes place within a framework of meanings: social discourse elaborates a social reality which offers itself open to critique, hence an understanding of social science and the dialectic of reasons would underpin SSIBL.

2.2 Critical Realism as a background epistemology to SSIBL

Critical Realism exposes the epistemic fallacy: what we know is not the same as what is. It recognizes the difference between a real world, a realist ontology, and our knowledge of it. Hence it differs from empiricism where data correlations conflate reality with knowledge, and also from interpretivism because it recognizes a reality beyond subjectivity [28]. In science domains, an important aspect of a critical realist (CR) approach [24, 25] is that explanations are mediated by the real world we live in, a world which is an open system in scientific terms.

At some stage of their school lives pupils are taught about the Law of Falling Bodies often accompanied by an apocryphal account of Galileo at the top of the Leaning Tower of Pisa dropping two objects of very different masses at the same time and demonstrating that they hit the ground simultaneously. But everyday experience suggests this is not the case. Drop a lead weight and a feather at the same time and the lead weight will always reach the ground first. It seems that everyday experience contradicts the validity of a scientific law. This difference can be explained by the fact that the law only holds true in an airless medium, a vacuum, and that air currents impede the fall of the feather. The distinction drawn here is between what within CR would be considered as the closed world of Covering Laws and the open systems of the real world we inhabit and experience. The Law of Falling Bodies holds true in closed systems, i.e., in a vacuum, but needs to be amended in open systems, the world we experience.

One way to take account of the lived experienced world is to draw on the fact that objects have causal powers or *tendencies* [29]. Using a causal powers explanation [30] we can state that the Earth has a tendency to draw objects towards it such that they accelerate towards its centre regardless of mass. Objects have a tendency to fall towards the center of the Earth. Air currents have a tendency to resist the fall of objects. If we see these objects – the Earth, falling objects, air currents – as having causal powers or tendencies then we can explain the observed behavior in the world of experience in terms of interactions. We do not need to start with a vacuum and demonstrate ideal closed conditions; we can start with the real lived world.

To take another example, metallic zinc has the 'power' or potential to reduce solvated hydrogen ions in an acid into hydrogen molecules in the form of hydrogen gas.

$Zn(s) + 2H^{+}(aq) = Zn^{++}(aq) + H_2(g)$

The term 'power' is used because this potential is only activated when the zinc is immersed in the acid. Similarly, the acid has the potential to strip electrons off zinc when they react together. The reaction is explained by hidden mechanisms, in this case electrode potentials which contribute to redox reactions. The redox chemical reaction – the event – takes place when these powers or tendencies are actuated. So, one aspect of a CR pedagogy in science is to start from events or issues which pupils experience – problems which need solving, and thus require *taking action* - rather than abstract concepts.

2.2.1 Values, Transdisciplinarity, and Emergence

A central concern of CR is the concept of 'emergence'; that understanding a particular phenomenon goes beyond explaining its constituent parts. An example is water, H_2O, a

liquid at room temperature. Water is comprised of two elements (hydrogen and oxygen) both of which are flammable gases at room temperature. The compound liquid water is chemically different from its constituent elements; we can deduce this a posteriori.

A more complex example is consciousness. Consciousness implies a sentient mind. A necessary condition of consciousness is physico-chemical and biological: a sentient mind relies on a functioning nervous system, itself dependent on the supply of nutrients, in other words a balanced and varied diet. But consciousness reflects a psychological state of mind, a social awareness of others and an understanding of historical and cultural context. A pre-requirement of consciousness is physico-chemical mechanisms, but it can only be more completely understood through psychological, social and political contexts. Any conditions which might prevent that level of reflection and awareness, for example, sustenance, leisure, social contacts, education, impede human autonomy and emancipation. Consequently, a consideration of SSIBL based on the metatheory of CR also necessitates the inclusion of values, social justice and transdisciplinarity as important dimensions of understanding emergent issues and events.

Further, events such as the maintenance of multispecies habitation of a pond, the flourishing of a forest, the visit of a robin to a garden feeding spot can be explained by a variety of mechanisms at different disciplinary levels. Only by incorporating these levels into an overarching explanation can the event be understood. Concepts from different fields of study need to be brought together to make sense of experience or an event meaning that transdisciplinarity is a necessary dimension of a CR pedagogy, and a key principle of the SSIBL pedagogy.

Within SSIBL, events or issues rather than concepts form the basis of study. Consider a typical SSIBL activity such as pupils inquiring into heat loss in their school and wastage of fuel. Such an inquiry might involve measuring where the heat loss takes place, how it can be reduced through an understanding of heat transfer, what materials might be needed to do this, how resources might be harnessed to enable this to take place, persuading relevant authorities that action needs to be taken. Importantly, reflection on values also becomes part of the learning process (e.g. considering reducing the consumption of fossil fuels).

2.3 SSIBL as a pedagogical means towards environmental citizenship

According to Hadjichambis & Reis [4], environmental citizens become agents of change through individual and collective actions aimed at creating a more sustainable and just world, exercising their rights and duties as responsible citizens in the public and private spheres. Environmental citizenship is considered a prerequisite to sustainability [31], as it can enable young people to take action and develop pro-environmental behaviors. At the same time, EC is a complex, multifaceted and multidimensional concept, that requires engagement and action at local, national, and global levels, individually and collectively, privately and publicly [5].

All three instructional phases of the SSIBL pedagogical approach (ASK, FIND OUT, ACT) require students to equip themselves with the knowledge, dispositions and skills they need to act as environmental citizens. When students engage in the exploration of contemporaneous environmental issues or dilemmas through the SSIBL approach, they apply experimental or social inquiry processes utilizing transdisciplinary knowledge to develop an in-depth view and to collect research evidence. They identify multiple perspectives and interest groups while combining scientific knowledge with social, environmental and ethical considerations and they use democratic processes and open deliberation to make informed decisions and take action. Organizing such transdisciplinary inquiries is clearly a pedagogic challenge [32-33]; it requires whole school support, requisite teacher training, and a willingness of both teachers and pupils to work on a transdisciplinary basis amongst others. In the following sections we use four exemplars to illustrate how the SSIBL approach can be implemented to emphasize

transdisciplinarity, action and a values-oriented educational approach as a means towards environmental citizenship.

3. Implementation of SSIBL in different national contexts

Four cases have been purposefully selected from different European countries (The Netherlands, Spain, UK and Cyprus) that participated in the PARRISE project and utilized SSIBL within teacher professional development (TPD) courses with pre-service or in-service teachers at the elementary (Cyprus) and secondary (The Netherlands, UK, Spain) education levels. Each case provides insights on the multiple ways in which SSIBL has been implemented in order to address socio-environmental issues placing emphasis on the diversity with which a novel pedagogical approach can be adapted in different educational contexts [34]. The cases presented illustrate the affordances of SSIBL as a means towards environmental citizenship in each context, through a focus on informed and responsible action-taking in relation to environmental and sustainability issues, the ways in which a values orientation to recognizing the complexity of sustainability issues is considered by teachers, and how transdisciplinarity has been used.

3.1. SSIBL in the Netherlands

In the Netherlands, the secondary science curriculum pays explicit attention to reasoning on socio-scientific dilemmas. Students of chemistry, biology, and physics need to be able to distinguish between scientific facts, normative-societal considerations, and personal opinions when evaluating SSIs. Among the SSI contexts included in the curriculum, many relate to sustainability, such as human influence on the Earth system, energy preservation and sustainable production processes. The chemistry curriculum, which was revised in 2016, goes further. It builds upon the principle of 'green chemistry' (Groene Chemie), which includes such skills as recognizing realized, possible, and desirable changes in industry and chemical processes [35] (p.6).

Despite this explicit presence of SSI and sustainability-related contexts in the curriculum, many Dutch science teachers experience difficulties in incorporating them into their daily practice [36]. Dealing with personal values and beliefs, and ethical aspects of science, is challenging for many teachers, and other parts of the curriculum are experienced as needing more time or being more important for national exams. Teachers indicate lack of time as one of the main difficulties.

To support science teachers in addressing sustainability issues in their daily practice, SSIBL was implemented in pre-service teacher training across 11 cohorts (n=86) at Utrecht University over the last five years. For these training sessions, SSIBL was operationalized in seven stages: i) introduction to the dilemma, ii) initial opinion-forming, iii) creating a need-to-know, iv) inquiry into scientific, social, and personal aspects of the dilemma, v) dialogue, vi) decision making, and vii) reflection [36]. At each stage, examples showing how to introduce SSIBL in classroom practice were discussed and pre-service teachers (PST) could practice specific stages in small-group tasks. The SSIBL training consisted of two 1.5-hour face-to-face sessions and a take-home (group) assignment to design a SSIBL lesson, within the context of a 20-week pre-service training course.

Lesson design plans made by the student teachers were collected (n=39), 19 of which were based on sustainability-related SSIs by the PSTs own free choice. Additionally, PSTs completed a questionnaire with five evaluative, open-ended questions on the SSIBL approach. These were analysed for common themes in their perceived possibilities of SSIBL as well as their expected struggles with the approach. The 19 lesson designs were analysed based on the occurrence of the ASK, FIND OUT, and ACT instructional phases, and how PSTs addressed these phases in their teaching and learning activities.

3.1.1 Findings

Overall, the teacher training sessions supported PSTs in designing SSIBL-based lessons, although certain aspects seem underexposed. The analysis of the 19 lesson designs showed that the ASK phase was mainly initiated by media of some form to raise students' questions, including watching video footage (4 designs), reading articles about the SSI (4 designs), and dialogue about statements regarding specific SSIs (2 designs). In the FIND OUT phase, inquiry was more readily applied on social aspects (10 designs, e.g., mapping stakeholders' positions, interviewing parents), and scientific aspects (9 designs, e.g., literature research or other types of sources-based research), with personal inquiry being least common (5 designs, e.g., students articulating their personal values and beliefs in a dialogue). Common interpretations of the ACT phase included constructing a poster (5 designs), writing an article or essay (5 designs), forming an opinion on a dilemma (3 designs), and giving advice, by means of letters to stakeholders (2 designs). Four designs lacked a clear ACT phase, and half of the designs were explicitly linked to the national curriculum.

To illustrate what these lesson plans look like, we will discuss one design in more detail. In this design, consisting of four lessons, the PST selected an environmental issue from the students' community (local issue). This issue involved a chemical company that dumped their waste into a local river, thereby introducing the potential carcinogen C8 into the environment. In doing so, the company stayed within boundaries set by the government, yet inhabitants of the area did not trust the guidelines. They feared the potential carcinogen was responsible for the inexplicable illnesses from which some of the factory workers suffered.

The main goal of the PST's design was to foster students' informed opinion-forming about this issue. The first lesson focused on the ASK phase. Students watched a documentary about the C8 issue, while individually answering opinion-forming questions, such as 'Do you think the boundaries set by the government are fair?', 'Do you think residents have a reason to worry?'. Afterwards, students discussed their views in small groups. They had to list stakeholders of the issue as homework. The second lesson made them discuss the views of these stakeholders and consider with which stakeholders they identified most strongly by physically positioning themselves on a line in the classroom. Their position on the line represented with which stakeholder they identified most (controversy line activity). With this activity, content-related and normative student questions were raised. As a next step in the design the PST raised the question 'What do we need to know before we can form a well-informed opinion about this issue?'.

The FIND OUT phase started after the first lesson, with a homework assignment. Students had to seek information on the potential toxicology of C8. To facilitate this, the teacher provided some pointers. In the third lesson, they performed scientific inquiry by doing a titration experiment on a water sample of the polluted river. Students titrated several samples, each representing different areas of the river, both upstream and downstream of the factory. In this way they identified the absence or presence of (different) C8 concentrations in the river water.

During the final lesson, the ACT phase started with students discussing the issue based on statements reflecting different sides of the dilemma (e.g., banning C8 from industry, the financial value of human lives, conflict of interest when companies determine the toxicity of their own processes, and governments basing policy on scientific research as opposed to the gut feelings of stakeholders). As a homework assignment, students had to write an argument to substantiate their point of view. Finally, students reflected on the lesson series and their own personal growth in understanding the issue by answering a set of reflective questions. The connection of the lesson plan to the seven educational stages through which SSIBL was operationalized is depicted in Table 1.

Table 1. Representation of the seven educational stages in the lesson module on C8 in river water.

SSIBL phase	Educational stages	Activity in the lesson plan
ASK	i) Introduction of the dilemma	Documentary on the SSI
	ii) Initial opinion-forming	Answering questions individually during the documentary, with subsequent discussion
	iii) Creating a need-to-know	Making students experience the different perspectives of stakeholders, raising normative and content-related questions
FIND OUT	iv) Inquiry into scientific, social, and personal aspects of the dilemma	Listing stakeholders and discussing their views (social inquiry), seek information on the potential toxicology of C8 & carrying out the titration experiment of river water sample (scientific inquiry), exploring their own position during the controversy line activity (personal inquiry)
ACT	v) Dialogue	Discussion about the dilemma, based on different statements (personal inquiry)
	vi) Decision making	Looking back on first opinion and on previous activities by answering reflective questions Writing an argument to substantiate their point of view
	vii) Reflection	Reflective questions about students' learning process and progress

3.1.2 Reflective points

This SSIBL design of four lessons shows the transdisciplinary nature of SSIBL-lessons, which involve scientific, social, and personal inquiry. Students view a real life, local issue through the eyes of different stakeholders. They perform different kinds of inquiry, for instance, relating to scientific processes and normative considerations about the issue. Exploration of values, from both the students themselves and the different stakeholders involved in the selected issue, is central to this design. This way, they experience how SSIBL can be used to make sense of actual, real life issues in their own community.

Based on the analysis of 19 of these lesson designs, we found that the SSIBL guidelines were helpful in structuring SSIBL-based lessons, implementing a diverse range of environmental issues that were linked to the regular curriculum. However, most lesson designs included scientific and social inquiry activities, underexposing personal inquiry.

The open-ended questionnaire showed that PSTs felt SSIBL was of added value, e.g.: *'SSIBL is very appealing to me. It makes students think about social, moral and complex issues to which there is usually no unequivocal answer. It teaches them to look at issues in a more nuanced way'* [PST-18]. PSTs indicated that SSIBL could show how science at school relates to the real world, e.g. *'SSIBL is important because it connects topics with 'the real world'. This answers the 'why should I learn this' question. I like connecting school topics with contexts (teaching doesn't stop outside the classroom)'* [PST-4]. Moreover, they indicated that it makes science more interesting to students and stimulates critical thinking, but they perceived it would take much time to effectively implement it into their teaching, e.g. '*The downside is, it takes time; the curriculum is already overloaded*' [PST-9].

The educational sequence used in these teacher training sessions will help science teacher educators and teachers to enact SSIBL, thereby fostering students' opinion-forming and decision-making skills in complex environmental issues.

3.2. SSIBL in Spain

The main aim of the Spanish case is to describe how the SSIBL approach has been introduced in teacher initial education in Spain at both primary and secondary school levels, and to illustrate how it might be used to design classroom activities that empower students to act on contemporary socio-scientific issues as responsible environmental citizens.

The SSIBL approach was first introduced in Spain in 2015 at both primary and secondary school levels. The preliminary work focused on finding connections between SSIBL and the Spanish educational curriculum [37]. Curriculum mapping was considered essential to show teachers how SSIBL might assist students in achieving the intended learning outcomes. Connections between SSIBL and the Spanish curriculum have been identified both in terms of key competences and transdisciplinary learning outcomes such as critical thinking or problem-solving skills, and in relation to content knowledge associated with different school subjects (math, science, citizenship education), as illustrated in the example shown in Table 2.

After the curriculum mapping task, a model for SSIBL teacher education was developed through different cycles of implementation, evaluation and improvement. The model was based on the specialized literature about effective teacher professional development [38] and has at its core the three instructional steps of the SSIBL approach: ASK, FIND OUT, ACT. The outer circles in Figure 2 represent the different phases of the Spanish Teacher Professional Development (TPD). The SSIBL model represented by the inner cycle was a referent point in any of the six TPD phases represented by the outer cycles, thus supporting teachers to acquire, experience and implement the SSIBL model: Spanish PSTs were introduced to contemporary issues using news and media, they were immersed in socio-scientific inquiry about them in order to experience the SSIBL approach as learners, they reflected on the educational potential of the process as future practitioners, were invited to co-design new SSIBL activities, and discuss them with other colleagues building a community of learning and practice [39].

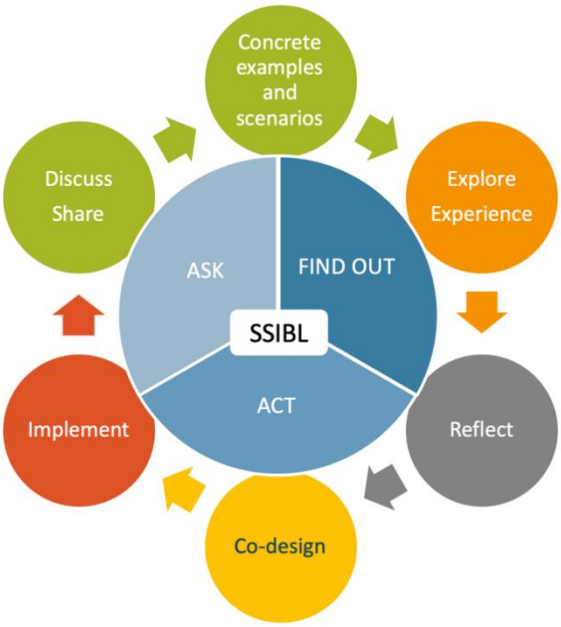

Figure 2. Teacher Professional Development for SSIBL in Spain.

Special attention was paid to the process of co-design. PSTs were provided with explicit criteria to design high quality SSIBL activities, well aligned with the SSIBL framework (Figure 1). Quality criteria referred to making good use of media to bring authenticity into the science classroom through the selection of contemporary socio-

scientific issues unravelling the complexity of the issue through controversy mapping [40], identifying links with the Spanish curriculum, defining consistent learning outcomes and assessment processes, formulating questions for learning, scaffolding and encouraging students' inquiry and action-taking. Quality criteria were discussed with PSTs in advance and were later used for self-evaluation and peer evaluation [41-42].

To illustrate how the SSIBL approach might be used to educate scientifically literate students and responsible environmental citizens, we present in more detail an exemplar SSIBL design developed by Spanish secondary school PSTs. The starting activity designed by PSTs provides students with news about COVID-19 and asks them which type of face masks they would choose and why, to protect themselves and others from COVID-19.

To respond to the emergent issue and the initial questions posed, students are asked to inquire about the SARS-CoV-2 virus and how masks protect people from infection. Besides health issues, choosing a particular mask has a wide range of social, economic and environmental implications. To evaluate environmental implications, students should find out, for any type of mask, where raw materials come from, under what conditions they are produced, how long the transport routes take to bring raw materials and final products, how often they are used, and how they are disposed of.

The SSIBL approach provides opportunities for conducting both social and experimental science research. Inquiry activities resembling social research are a) making a survey to learn about a local population's mask preferences, as well as a local population's health and environmental awareness; b) researching about the life cycle of different types of masks, and c) collecting key information from reliable information sources (those supported by scientific evidence and widely recognized institutions). Inquiry activities resembling experimental research are d) the analysis of masks' permeability to coloured liquids sprayed from various distances, and e) observation of how contact and distance influence pathogens' infections, by checking, over time, how pieces of fruit located at different distances from mouldy oranges might get infected. Table 2 includes the key elements of the SSIBL lesson plan about masks for protection against COVID-19.

Table 2. The Spanish case: masks, sustainability issues and COVID-19.

SSIBL Phase	Lesson element	Specifications
ASK	Overarching question	Which type of masks would you choose to wear and why, to protect yourself and others from COVID-19?
	Guiding questions	What do you need to know about masks and COVID-19 in order to make a good decision? Which different aspects might influence decision-making (health and safety, economic, environmental, social…)? How does SARS-CoV-2 infect people? How do masks protect people from infection? **Concerning sustainability issues**: What is the mask made of? Where do the raw materials come from? How, where and under what conditions are they produced?

FIND OUT		How long are the transport routes to bring raw materials and final products? How often is the product used, and how is it disposed of?
	Social research	Making a survey to know about mask preferences and health and environmental awareness among the local population.
		Researching about the life cycle of a particular product (different types of masks).
		Collecting key information from reliable information sources.
	Experimental research	Analysis of masks' permeability to coloured liquids sprayed from various distances
		Observations of pathogens' infections depending on distances: The situation might be modelled checking infection over time among pieces of fruits located at different distances from mouldy oranges.
	Content knowledge	**Maths**: Making estimation and calculations (costs, life cycles, usage…); length units applicable at small scales
		Biology: Health and virus (size, infection, reproduction cycle, activation…)
		Physics and chemistry: materials' properties, dissolutions.
	Transdisciplinary	Maths, Biology, Physics and Chemistry
		Social Research & experimental research
ACT	Attitudes and values	Developing a sense of responsibility and care about common health and safety.
		Awareness of the environmental impact of daily products.
		Developing criticality towards the reliability of information sources.
	Competences	Designing experiments to test ideas
		Analysing data from different sources, including media and freely available articles and reports.
		Identifying different aspects influencing decision making (environmental, economic, socio-cultural, health and safety issues)
		Making informed decisions based on evidence and social and environmental responsibility.
	Action-taking	Distribution of leaflets to their community with key information for making informed decisions about COVID-19 and masks.

463

464

3.2.1 Reflective points 465

In the following, we discuss how the SSIBL lesson design developed in the Spanish context by secondary PSTs is aligned with the epistemology proposed in this article and exhibits the key features of the SSIBL pedagogy, as an interesting approach to education for environmental citizenship.

To address the emergent issue about masks and COVID-19 protection using a SSIBL approach, students should ASK key questions, FIND OUT about them to collect substantial evidence and take consequent ACTIONS based on their findings. The whole process is addressed from a pluralistic perspective aligned with the metatheory of CR and therefore, students are encouraged to explore the implications of wearing different types of COVID masks from the perspective of individual and public health, the economy and the environment, using a wide variety of sources and methods. Therefore, to make an informed decision they should combine both social and experimental research and make meaningful use of relevant knowledge from different disciplines while inquiring about virus infection and a material's properties, or while applying mathematics to estimate economic costs and the life cycle of the masks' components. Assessing the life cycle of a particular product is a challenging but inspiring task, where it is necessary to consider a wide range of different aspects, such as, where and how the raw materials are obtained, the manufacturing process requirements (water, heating, electricity, ventilation), where they are produced and transported and how long is the path between the origin and the destination of the products. Finally, it is important to consider if the products can be reused, for how long or if they can be recycled. The environmental implications of choosing one product over another should be evaluated, not only in terms of resources and energy consumption, but also, in terms of the impact of the processes involved (pollution, greenhouses emissions, altering ecosystems, etc.).

Finally, the lesson design encourages students to take informed actions in relation to mask wearing, developing environmental awareness and individual and collective responsibility for both health and sustainability issues, thus exhibiting a values orientation and a commitment to both individual and collective action. Action at the individual level mainly concerns the private sphere where students can make informed choices to reduce the environmental impact of their own actions related to choosing and wearing a particular mask and to exercising their duties and responsibilities as citizens, when creating safe and fair living conditions, protecting themselves and others. The social level is addressed when students engage in collective actions such as distributing information leaflets to disseminate their research results or campaigning to raise public awareness of the different implications of particular behaviours, in this case, taking the social responsibility of wearing a mask for COVID-19 protection and caring about the health, economic and environmental implications of choosing one mask over another.

The above considerations illustrate how the SSIBL approach may be enacted in a particular context (the Spanish context), to empower teachers to develop values-orientated educational interventions, where students can go through both social and experimental inquiry about relevant emergent issues to construct and use transdisciplinary knowledge, while developing a commitment for informed and responsible action.

3.3. SSIBL in England

As part of the PARRISE project, a SSIBL-focused TPD for PSTs was embedded in a secondary science initial teacher education program in the south of England. Across three years, 103 PSTs took part in SSIBL-based activities engaging them in scenarios as learners (e.g. 'Would you vote against drugs testing on animals?'), as designers and teachers (planning and implementing SSIBL-based lessons), and as reflective practitioners (reflecting on using the SSIBL framework, and on their students' learning during that process). A case study of one male PST in his early 20s, Ryan (a pseudonym), who showed a keen interest in the SSIBL approach at the start of the academic year is presented to illustrate how SSIBL can function as a pedagogical means to environmental

citizenship. Data collected from Ryan include his lesson plans, and classroom materials (e.g., PPT presentations, and student worksheets) from teaching 12-16 year olds, a SSIBL lesson observation (Energy Sources, Table 3), and a reflective discussion about the lesson observed. This data set is analysed to illustrate the ways in which transdisciplinary inquiry, action and the value and necessity of sustainability were addressed in Ryan's design and implementation of SSIBL lessons.

3.3.1 Findings

Ryan designed and implemented three sustainability-focused SSIBL lesson topics (two lessons per topic), with three different year groups. For each of the three topics Ryan designed and taught two lessons following a similar approach across topics. The first lesson of each topic focused on Ryan presenting to students the topic, key questions and socio-scientific context (ASK). The 'Energy Sources' topic was contextualized for the students at a personal and local level, by using the example of an energy power plant in their own town, with implications directly affecting them. The 'Recycling' topic had both a local and global context as it was based on an imaginary scenario of students and residents of a town working together to decide whether they should ban plastic bags from their shops [43]. Students had to consider what they would do at a personal and local level as residents of this imaginary town ('what would YOU do', Table 3), but they were also dealing with a global issue, as the ways in which plastics are sourced and disposed are both socio-environmental issues. Finally, the socio-scientific context for the 'Digging for Trouble' topic was at a global level based on mining in different countries (e.g., Brazil, China) but also asked students to consider on a hypothetical level what they would do.

Transdisciplinary knowledge within socio-environmental issues was included in Ryan's lesson designs as illustrated through the keywords chosen, which were used when introducing the socio-scientific context of each lesson. For instance, in the 'Digging for Trouble' lessons, the keywords were: 'Environment, Social Issues, Cultural Issues, Finance'. Evidence from students' presentations for the topic, indicates that student groups were able to incorporate environmental knowledge (e.g., pollution of the Amazon) as well as other types of knowledge, such as political (e.g., role of governments), social (influence on people) and financial (economic impact on people's livelihoods). In the Energy Sources lessons the keywords given were 'Environment, Financial issues, Social issues', again emphasizing the environmental dimension of the issue discussed as well as its socio-scientific context, and the presence of controversy, creating the conditions for emergence of issues, that were the starting points for students' socially-responsible transdisciplinary inquiries. Scientific knowledge required was focusing on the types of energy sources that exist (e.g. fossil fuels, biomass, solar power), which students had previously learned about. The FIND OUT instructional phase was based on structured inquiry [23] requiring students to work in groups to collect evidence through the sources provided (printed material, online sources), to analyse this evidence and answer the key questions given to them. The Recycling topic similarly required and included consideration of scientific knowledge ('environmental aspects associated with using polymers', lesson plan) and when considering the benefits and challenges of recycling (e.g. 'melting plastics needs heat. Supplying heat may use up fossil fuels and produce greenhouse gases'; student handout) as well as financial (impact on local shops and shoppers) and social implications.

ACT was framed in Ryan's lessons around informed decision-making. During the second lesson of each topic, students were asked to create a group presentation outlining the results of their investigations, suggest actions they could take to address their findings and justify their decision. Ryan's approach to the ACT instructional phase was analysed using a three-level framework emerging from previous analyses of SSIBL lesson designs [44-45] (Figure 3).

Figure 3. Continuum of levels of representation of the ACT instructional phase in SSIBL as visualized by Amos & Christodoulou [44].

The three levels of ACT are placed on a continuum from raising students' awareness and knowledge of an SSI (Level 1), to creating the intention to act by providing students with opportunities to consider what actions they would take at a hypothetical level (Level 2) and modelling those in class (e.g. taking a vote on an issue), and finally, enabling and supporting students both to consider actions they would take and most importantly, enact change as a result of their learning (Level 3). Table 3 summarizes the three levels of representation of the ACT phase in Ryan's lessons.

Table 3. Levels of representation of the ACT phase in each of the three sustainability-focused topics taught by Ryan.

Levels within the ACT phase	Evidence from lesson materials
L1 - Raising Awareness of issue: Students create a presentation summarizing their findings	<u>Science in Society – Energy Sources</u> Learning Objectives: To collect evidence about a specific case study [of an energy source, e.g. fossil fuels] To create an action plan for this case study To create a presentation outlining what you have found (Source: PPT slides)
L2 - Intention to Act: Students make presentations of their findings to other groups and, students suggest a course of action they would take personally and justify it	In the second lesson, students will be expected to summarize what action they would take and why (source: lesson plan) What I think should be done (and why). (Source: student handout)
L2 - Intention to Act: at the end take a vote in class on what the council should do about the energy plant	[Students] will take a vote as well (Source: student handout)
L2 - Intention to Act: students suggest and justify the course of action they would take personally	<u>Science in Society – Recycling</u> Your final task for this lesson is to summarize what you've learned! Before you can leave, you'll need to tell me: - What YOU would do about the plastic bags -Why you would do it (source: PPT slides) What I think Sustown should do about plastic bags: I think that the best thing for

L2 - Intention to Act: students suggest and justify the course of action they would take personally, with emphasis on social wellbeing	Sustown to do is:…… …… I think this because…… (Source: student handout) Science in Society – 'Digging for Trouble' Your task is to research the case study you've been given and decide what needs to be done to fix any problems in the area. Include: - What's being mined, what is it used for? - Who benefits from the mine? - Who is harmed by it? - What would you do to keep everyone happy? Why? (Source: PPT slides)

The approach to informed decision-making and taking action that Ryan used when enacting SSIBL was represented at the level of 'intended action' in all three topics. Ryan was able to move beyond simply raising awareness of these socio-environmental issues but at the same time, he did not explicitly enact action within his planning and teaching. For instance, in the Energy Sources topic Ryan initially asked students to summarize their findings in the form of a short presentation; he then focused on the students' intention to act by asking them to consider what they would do and why, before also allowing students to participate in voting for which energy sources they thought should be used by their local council. Level 3 of the action continuum could be represented by students writing to their local council to share the results of this voting and to make their views heard.

3.3.2 Reflective points

Ryan's SSIBL lesson designs and implementations were consistent with SSIBL's focus on socially responsible transdisciplinary inquiries, whereby students were asked to investigate a question to enact change [18-19, 21-22]. The sustainability-focused lessons analyzed illustrate how the various levels of civic engagement for environmental citizenship (local, global scales) [5] can be addressed in different ways within and beyond classroom settings. Education for environmental citizenship using the SSIBL framework, can challenge the distinction that is often made between these levels as such issues can emerge as objects of investigation at multiple levels and scales. For instance, contextualizing and presenting to the students the Recycling lessons at both public (local, global) and personal levels made the dimension of personal action more evident in the students' learning, and at the same time allowed them to consider this socio-environmental issue in relation to society at large; this approach to contextualizing socio-environmental issues provides affordances for developing students' environmental citizenship.

Further, Ryan's SSIBL lessons illustrate how citizenship and action-taking can be conceptualized in educational settings through a focus on decision-making. Ryan's inclusion of the opportunity to vote at the end of the lesson on what action to take about the socio-environmental issue in hand, offered students opportunities to engage in learning that had elements of democratic participation (i.e. taking a vote on an issue). This in turn created affordances for students to engage in environmental citizenship learning as part of their science lessons, and made stronger the presence of citizenship dimensions (e.g. person action, taking a vote) in students' learning. At the same time, the third level of ACT was not present in Ryan's lessons, indicating that enacting action

within classroom settings can be a challenging area, which requires continuous engagement and explicit consideration by teachers as they learn to enact SSIBL.

3.4. SSIBL in Cyprus

In Cyprus, several co-design groups were created, each consisting of in-service science teachers and a university researcher who facilitated each co-design group. Over the course of the two iterations of the TPD, 67 Biology, Chemistry, and Elementary School science teachers collaborated in 12 co-design teams, to produce SSIBL curricula that adopted the ASK, FIND OUT, ACT approach, and were built around (a) socio-scientific controversies with local impact, (b) student inquiry, and (c) active citizenship decision-making.

The TPD's co-design approach situated professional learning in actual practice, established teachers as intellectual partners in design and, thus, augmented the sustainability of an innovation such as the PARRISE SSIBL approach [46]. Each co-design group met both face-to-face and online for a total of 39 (TPD1) and 43.5 contact hours (TPD2). Each group developed and enacted a SSIBL learning module, several of which had a sustainability focus, such as:

- Endangered species (lower secondary biology education and elementary science group 1)
- Biodiesel or petroleum diesel (lower secondary chemistry education)
- Disinfecting drinking water (upper secondary chemistry education)
- Which shopping bag should you use (elementary science group 1)

In this article, we draw from one of the 12 co-design groups; this co-design team included five in-service elementary school science teachers, who taught 2nd, 3rd, and 4th grade at four different schools. The teachers, with the support of the university researcher, met regularly and co-designed a SSIBL module that was subsequently implemented with 73 students. The SSIBL module was designed for five 80-minute lessons, and the activities centered around the ASK, FIND OUT, ACT dimensions. The driving question for the students was formulated as *"Plastic, biodegradable, or fabric bags? Which one would you choose to carry your groceries?"* This was an authentic question at the time of the co-design, as the law banning the use of free plastic bags was not instituted in Cyprus until two years after the conclusion of the co-design unit.

In the FIND OUT phase, students engaged in different inquiry activities designed to help them understand which of the different types of materials would be more environmentally sustainable. The jigsaw approach [47] was adopted: jigsaw is a collaborative pedagogical approach, in which students work in small expert groups to investigate complementary but different aspects of a problem. In our case, each expert group took on the role of a stakeholder group. Following their investigation, the expert groups break up and form synthesis groups, each one comprised from one representative from each expert group. The synthesis groups discuss and, through dialogue and evidence from the sources they studied, reach a decision on the driving question, which they then propose to the plenary. Through these activities students were expected to understand that terminating the use of plastic bags does not automatically lead to resolving the impact on the environment, as it increases the use of other raw materials, something that may also impact the environment.

After their work in the expert and synthesis groups, the students participated in plenary discussions that connected the classroom activity with their local context. Students decided to take action; the following are some of the actions realized by the 73 students with the support of their teachers:

- Creation of a survey on the use of plastic bags, which was administered to peers, teachers, and parents and was used during the students' decision making.
- Creating informational leaflets and sharing them with their peers, their parents and from door to door in their neighbourhood.
- Creating fabric bags from reusable materials and explaining their advantages.

- Participating in a TV show.
- Participating in awareness campaigns, including video conferences, with students in other schools.
- Proposing mitigation measures to the Mayor, the Environment Commissioner, the Minister of Education and Culture, and to the Parliament.

Table 4 illustrates the key points of the SSIBL module.

Table 4. The SSIBL dimensions of the elementary science co-design on which bag one should choose to carry groceries

SSIBL phase	Main activities
ASK	The learning activity begins with the following event, presented to the students via an animation their teachers prepared: A family is at a supermarket cashier, who presents them with three alternatives to carry their groceries: Plastic, biodegradable, or fabric bags? The students' mission is to find out which is the most environmentally sustainable and appropriate choice to carry their groceries.
FIND OUT	Students work in groups following the collaborative inquiry -- jigsaw puzzle approach. Each group adopts the perspective of one of the main stakeholder groups: plastic bag factory owners, consumers, and environmental organizations. Students interpret various information sources, collected by their teachers and themselves (i.e., from comics, videos, articles, interviews, posters), which represent the differing viewpoints of the main stakeholders to prepare an evidence-based answer to the driving question.
ACT	Following the work of the expert and synthesis groups (of the jigsaw puzzle approach) students collectively decided to take several actions to raise their community's awareness about the use of plastic bags and the informed decision to use alternative solutions.

Data from classroom implementations were collected in the form of videotaped lessons, students' constructed artifacts, researcher field notes and teacher reflections and were analyzed qualitatively. After the classroom implementations, the co-design team, consisting of the in-service teachers and the researcher, met to discuss the effectiveness of the SSIBL materials; during these meetings they constructed a SWOT (Strength-Weaknesses-Opportunities-Threats) analysis of the learning module and then proceeded with suggestions for the refinement of the activities in the learning module, based on the teachers' reflections.

3.4.1 Findings

A main question of interest is whether the implementation of the SSIBL approach fostered students' environmental citizenship. Even though the implementation presented challenges, especially due to the teachers' own lack of familiarity with methods such as the jigsaw approach [47], but also due to students needing time to understand how to engage in this new approach, the teachers documented benefits from the implementation of the SSIBL unit, such as an increase in students' participation and active engagement with the learning activities, increased competencies for communication, collaboration and argumentation, self-confidence, scientific, environmental, and social literacy, and improved learning outcomes. When the co-design teachers were asked by an independent evaluator to compare the learning that occurred during the SSIBL unit implementation, as compared with other non-SSIBL implementations, they overwhelmingly reported positive outcomes as well. The

following excerpt represents the teachers' impressions of how their students approached SSIBL and what they had learned:

> *…the only thing I can say is that many times we can ask our students something and they do not remember anything or remember very fragmented information. In contrast, through this program the children learned a lot of things, and they kept them in their memory, because they learned them on their own, we did not teach them. They found out on their own, they discussed them on their own, they supported them on their own, they communicated them to others on their own, so when this knowledge became their experience, they learned it better…this is definitely something they will not forget, as we see unfortunately happening with the lessons we do in our other subjects.*
>
> Teacher, 4th grade, Elementary Education Co-Design Group 1

3.4.2 Reflective points

The SSIBL module on the most environmentally appropriate choice to grocery shopping bags required students to acquire transdisciplinary knowledge, in that it focused on a social issue that required knowledge about environmental impact and an understanding of the complexity of multiple stakeholders' interests to make an informed decision on which bag is best to use. The students began their quest with an emergent real-life problem they needed to solve; with the support of the jigsaw puzzle pedagogical strategy, they then explored the topic in depth and in breadth, with age-appropriate activities. To be able to decide, students needed to understand the advantages and disadvantages of each type of bag, based on personal criteria but also based on criteria shared by the stakeholder groups.

The SSIBL materials and learning activities encouraged respectful dialogue and exchange of ideas between students, supported the development of personal and group-based evidence-based answers, promoted argumentation and debate, and created an environment for collective citizenship actions. As evidenced from the teacher reports, classroom observations, and the analysis of students' actions and artifacts, the SSIBL pedagogical framework had an impact on students' interest, motivation to engage with environmental citizenship ideas; most importantly, it also led to the discussion of actions students wished to take to inform others in their community of what it means to act responsibly regarding their everyday choice of grocery bags. As their teachers reported, many of the citizenship actions that were undertaken by the students go far beyond what these students would usually propose in non-SSIBL units. These actions imply an understanding that moves beyond the conceptual and the cognitive, extending to the consideration of personal choices and the development of values and attitudes connected to the controversial socio-scientific topic under investigation.

4. Discussion

The SSIBL approach, as underpinned by Critical Realist metatheory, is transdisciplinary in addressing sustainability issues as has been illustrated in the four cases presented. Starting with PSTs learning to enact SSIBL is promising because they can bring fresh ideas into a school setting, which are restricted by a subject-based curriculum, the importance of examinations and time, and as the Dutch case demonstrates in particular these are real constraints for teachers. Nonetheless, these limitations can be overcome by forethought in carefully linking subject concepts to the inquiry so that they aid the solution to problems rather than become learning objectives in themselves. The potential link of SSIBL activities to different subjects and content knowledge is clearly signalled in the Spanish case (see Table 2). As several of the cases presented show such an approach has the potential to enhance the learning of subject matter but also fosters motivation to engage in and act upon the ideas. The Spanish case illustrates how a current problem arising in everyday life brings the need for inquiry and empirical evidence to

make informed and socially responsible decisions. In the example shown, the transmission of disease and the effectiveness of masks in a pandemic can be gauged by testing the permeability of different types of face masks, inquiring about the life cycle of different products or studying the spread of mould from fruit. Using the SSIBL approach to investigate and act on issues of sustainability can enhance the learning of core concepts. But, importantly, this learning has durability because students realize the value effect of their learning. A transdisciplinary approach towards inquiry, with social justice inquiry at its core, is not therefore a diversion but a means of developing and consolidating learning.

Current conceptualizations of EEC and its pedagogical implementation as reported by Hadjichambis and Paraskeva-Hadjichambi [6] focus on using inquiry as one of six stages that teachers and students work through, with the other stages being: planning actions; critical and active engagement and civic participation; networking and sharing at the local, national and/or global scale; sustainable environmental and social change; and, evaluation and reflection. Any of these stages can be the entry point for initiating learning within this EEC framework [6]. However, the SSIBL approach within a pluralistic teaching tradition starts with emergent events that are problematized as socio-scientific, controversial issues that require solutions; thus, it establishes the need for finding a solution through decision-making and action as an inherent dimension of SSIBL, and consequently, as the means towards environmental citizenship. Rather than having a pedagogical approach for EEC that can start from any of the stages mentioned above, the starting point should be identifying events and issues that require a solution and this should be framed within an inquiry-based learning approach, rather than considering inquiry as one part of the learning process. A core aspect of SSIBL is that it expands the conceptualization of inquiry as a scientific process and considers it as socially responsible inquiry; that is, inquiry presupposes skills and attitudes that are a prerequisite to social justice such as personal responsibility, ethical sensitivity and openness and honesty in dialogue. These skills are also core to the promotion of EEC [4], and further support the use of SSIBL a means towards environmental citizenship, since focusing only on promoting subject knowledge within EEC can be counter-productive practice in supporting young people develop pro-environmental behaviours [48].

Achieving sustainability and environmental citizenship requires a pedagogy that can transcend the physical and educational structures, and limits, of schooling since individuals should be able, and willing, to act inboth the private and public sphere, which require an outwards engagement from schools into their communities. At the same time, we need to consider what is achievable within those school boundaries that can establish a basis for considering how actions, values and behaviour can be addressed within and outside of school. Using SSIBL as theorized based on a CR position, and having as a starting point issues or events to initiate a need for learning, can support students and teachers in problematizing knowledge, address these issues and support the development of environmental citizenship in young people.

Perhaps the most difficult aspect of SSIBL is what counts as action. A simplistic view of action can negate learning in favour of the need to change. In the UK case study the teacher focused on action by focusing on justified decision-making; this brings to the light the problem that change always involves some kind of trade off and democratic participation is making decisions in full awareness of what is at stake. The UK case also shows how action can be enacted at different levels within classroom settings, which can provide affordances for engaging students with this SSIBL dimension, as also shown by the Cyprus case. At the same time, embedding and enacting taking action within classroom settings can be a challenge for teachers.

A note of caution is how the personal, local and global are interlinked; the importance of critical EEC is apprehending the interrelationship between global, social and local aspects of sustainability, a point that needs emphasis in EEC [49]. As encountered in the Dutch study, engagement with the global context of sustainability can overshadow more

personal aspects but if the personal and the local or global contexts are presented concurrently through a focus on personal decision-making, as enacted in the UK case study, these different dimensions can become part of EEC.

5. Conclusions

We have drawn on postulates of Critical Realism to underpin the epistemology of SSIBL and its appropriateness as a pedagogical tool in promoting sustainability and a means towards environmental citizenship. Its requirements might seem problematic in terms of school curricula but the illustrated cases of SSIBL indicate real opportunities for promoting EEC within traditional school curricula and PSTs prepared to take risks. We recognize that schools are organized into different disciplines of knowledge, and subjects, which are often compartmentalized. Biology and social science teachers, for example, have different curricula, different expectations, and different aims. Most schools are not organized for a SSIBL-based curriculum as they are often organized for fact-based approaches. Further, EC is not a well-defined concept in the current literature, and teachers are less aware of its multiple dimensions [31]. As research in EEC continues to develop, the role of teachers needs to take a central position within this, in order to address the multidimensional nature of EC within educational practices. To do so, it requires teacher education environments that allow PSTs and novice teachers to engage with the conceptual and pedagogical dimensions argued for here, such as ways in which transdisciplinary knowledge is used to address socio-environmental issues, and the ability and willingness to consider social sciences knowledge, and values.

The illustrative cases presented in this article also emphasize the importance of teachers experiencing SSIBL as learners which is an important aspect of encouraging democratic deliberation and of politically responding to diverse views [50] and should be a key component of teacher professional development for EEC. We have illustrated how SSIBL can be used in a tiered manner as teachers learn to engage with it and use it as part of their practices. As a first step it might be best to start at a simple level where an activity is highly scaffolded by the teacher and might be carried out in one day or in one lesson. Teachers can provide students with the overarching questions to investigate as in the four cases presented, rather than expect students to devise their own investigation questions. They can then work with their students to progressively support them in developing skills in asking authentic questions and considering ways of investigating them, taking into account societal, scientific and environmental dimensions and implications of the issues explored. A more sophisticated activity might involve teachers from different disciplines collaboratively working together across the curriculum designing SSIBL activities so that their students can engage in socially responsible inquiries in an interdisciplinary manner [33,51].

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