Chapter 11
Sustainability Issues in Lower Secondary Science Education: A Socioscientific, Inquiry-Based Approach

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Abstract Environmental Citizenship (EC) has the potential to mitigate current unsustainable processes. However, science teachers experience a lack of suitable teaching approaches for implementing EC in classroom practice, thus preventing students from developing the necessary competences for EC. Socioscientific Inquiry-Based Learning (SSIBL) has the potential to promote the key competences necessary for EC. However, SSIBL has not been extensively tested in classroom practice. Therefore, the aim of this study is to explore SSIBL's potential for developing Environmental Citizenship in lower secondary students. In order to reach this aim, a Lesson Study (LS) with six science teachers and three educational researchers was carried out. A lesson module about the mining of elements for smartphones was developed and tested in two classes (average age 14.6). Audio recordings of the lessons, of student interviews, of development and reflection discussions with the teachers, and written educational materials were collected. Results show that the module enables students to appreciate the complexity of the issue by using multiple perspectives. Opinion forming and decision making are stimulated too, but students struggle to use findings from their inquiry to develop solutions. Concluding, SSIBL has potential to promote aspects of EC in classroom practice.

Keywords Environmental citizenship · Socioscientific issues · Inquiry-based learning · Science education

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11.1 Introduction

Sustainability issues such as pollution and the energy transition demand a suitable response from society. For this response to be effective, it is instrumental that both collective, organized action and individual, personal actions are taken (Dobson, 2007). These two compounds of Environmental Citizenship (EC) are essential to mitigate adverse effects of current unsustainable processes and for preventing new issues (Dobson, 2007; ENEC, 2018). Sustainability issues are open-ended, difficult to solve, and have personal and global implications. Further increasing their complexity, sustainability issues consist of ecological, economical, and societal aspects. Finally, because of their open-ended nature and since they have repercussions on both scientific and societal fields, they can be typified as socioscientific issues (SSI; Kolstø, 2001).

For people to be change agents, transition managers, or problem solvers for sustainability issues, people need a specific set of competences. Wiek and colleagues (2011) constructed a framework that synthesizes the five most commonly listed competences for sustainability graduates, at university level. These competences are (i) Systems thinking competence, across multiple domains such as people, planet, and prosperity; (ii) Anticipatory competence, dealing with possibilities, probability, and risk; (iii) Normative competence, about justice, fairness, and sustainable targets; (iv) Strategic competence, dealing with actions, transition strategies, and solutions; and (v) Interpersonal competence, for instance, collaboration, leadership, and empathy.

Specific educational approaches need to be employed to develop these kinds of competences. Teaching approaches should offer ample opportunities to engage actively with authentic, real-world problems, in order to help learners in approaching dilemmas from different viewpoints and perspectives and develop higher order thinking skills (Sadler et al., 2016). Socioscientific Inquiry-Based Learning (SSIBL) is an educational approach that potentially fulfils these prerequisites (Levinson, 2018). SSIBL combines Socioscientific Issues-Based education with Inquiry-Based Learning and aims to foster Citizenship through science education. It provides teaching and learning in three phases—ask, find out, and act—during which learners examine authentic dilemmas and explore solution strategies that they subsequently implement. In this way, SSIBL can be used to create opportunities to develop the five key competences necessary for effective EC. Although science teachers see the added value of SSIBL for their teaching repertoire (Knippels & Van Harskamp, 2018), its practical implementation in the classroom and its applicability for sustainability education has not yet been extensively tested.

Science teachers struggle with the social and personal sides of SSIs, for instance with guiding discussions and covering the ethical implications of science, and other normative aspects of EC (Tidemand & Nielsen, 2017; Van Harskamp et al., 2021). These social and personal aspects have been shown to be of equal importance as the scientific content during SSI-based education, for together they form a holistic image of sustainability issues (Sinakou et al., 2019). Science teachers experience

a lack of competence with regard to citizenship education and therefore students lack opportunities to intensely think through their own and their peers' feelings and opinions about SSIs (Day & Bryce, 2011). Since SSIBL offers opportunities for students to develop aspects of EC, it could be a valuable tool for science teachers. The aim of this study is to explore SSIBL's potential for developing Environmental Citizenship in lower secondary students.

For this purpose an exploratory Lesson Study (LS) was carried out. During a LS, teachers collaborate with researchers to research educational practice. The current LS could offer illustrative examples of effective education for EC, which are labeled as 'missing' by Sinakou and colleagues (2019). This chapter first describes the study approach, including a description of the lesson design. After that, the main findings are discussed. Finally, we draw conclusions and discuss implications for research and classroom practice.

11.2 Study Approach: Lesson Study

To look into SSIBL's potential of fostering EC, an exploratory Lesson Study was carried out (Fernandez & Yoshida, 2004). During a LS, teachers and educational researchers collaborate to develop and test teaching strategies, focusing on student learning of specifically selected case students who are observed in classroom practice. The research question for this LS was: What potential does SSIBL have to develop Environmental Citizenship in lower secondary students?

The LS-team consisted of four biology teachers, two chemistry teachers, and three educational researchers. Six design sessions of 2.5 h each were organized. After these design sessions, one of the teachers taught the lesson module, during which the rest of the LS-team observed specifically selected case students. Case students were selected from the group based on their ability to work independently, since this is an important skill when learning about open-ended issues. In each group, two very independent students (who hardly need any teacher guidance at all), two averagely independent students (who sometimes need teacher guidance, but otherwise are able to work on their own), and two more dependent students (who almost always need teacher guidance, because they struggle with most tasks) were selected. Afterward, these six case students were interviewed. Experiences of the teacher and of the observers were shared during the post-lesson discussion. This discussion led to some minor adaptations of the module, after which the module was taught by another teacher with a new group of students. After the second post-lesson discussion, findings were discussed in the team.

The teachers who taught the lessons were both members of the Lesson Study team. This means they were involved in codesigning the lesson materials, which gave them a deep understanding of the teaching and learning activities, the decisions made during the design process, and the underlying assumptions and theoretical

underpinning. Both teachers were male chemistry teachers, with Teacher 1 being 59 years old with 20 years of teaching experience, and Teacher 2 being 55 years old with 18 years of teaching experience.

11.2.1 Participants

In total, the lesson module contained one lesson of 50 min and one lesson of 100 min, which were taught to two classes ($n = 45$ students total, one group pre-university level, the other higher general education, F:23, M:21, average age 14.6) of lower secondary students in the Netherlands. Informed consent of parents and guardians was sought before the study.

11.2.2 Data Collection and Analysis

During the LS, data was collected from several sources (see Table 11.1). Design sessions were audio recorded, which enabled us to look back on decisions made during the design process. Audio recordings were made of the lesson and of the case-student interviews after the lesson. Student materials were collected after the lessons, including their booklets and their summary schemes of the selected SSI. Observation sheets of the observers were collected and the post-lesson discussions were audio recorded to provide an entry point into the data and to look back on first impressions of the observers. Together, these data sources provide a rich and detailed image of the learning processes of the students during the lesson module.

The audio recordings of the design sessions and the post-lesson discussion were analyzed for key moments in the decision-making process and for exemplary remarks

Table 11.1 Lesson study phases, collected data sources during those phases, and their analytic purpose

Lesson study phases	Data sources	Analyzed for
Design sessions (six, 2.5 h each)	Audio recordings of design sessions	Choices made during design process
Teaching (two classes, 3 lessons per group)	Student materials (booklets, schemes)	Reaching learning aims
	Observation forms	Key moments during the lessons
	Audio recordings of lessons	Student reasoning
	Post-lesson student interviews	Reaching learning aims
Post-lesson discussions (two, 1.5 h each)	Audio recordings of discussions	Reaching learning aims, effectiveness of lesson design, key moments during the lesson

by teachers and observers. The student summary posters were analyzed using the three main dimensions of sustainability, people, planet, and prosperity, and their occurrence. Answers in their booklets were categorized by the main researcher and analyzed for the sustainability dimensions, the main sustainability competences, and problem context, subject matter information, and mentions of complexity of sustainability issues, since these were learning aims of the module. Audio recordings of the lesson were analyzed for student reasoning, and the student interviews were transcribed verbatim and analyzed for the different learning aims.

11.2.3 Lesson Design

The LS-team based the design choices for the lesson module on experiences from the teachers and on research. This section discusses the design choices, the sources they were based on, and the resulting lesson module.

First, the central goal for the students was defined. Based on experiences from the teachers, we decided to look into how to support students when meaningfully and thoroughly forming an opinion on sustainability issues. Selection of this central theme led to formulation of the following learning aims for the students:

- The student is able to describe that sustainability issues are complex, multifaceted, and open-ended;
- The student is able to form a scientifically and socially funded opinion about sustainability issues.

These learning aims implicitly contain elements of the five key competences. Mapping controversies and realizing complexity requires systems thinking and normative competence. Forming a scientifically and socially funded opinion requires normative competence (desirability of opinion), systems thinking (mapping the issue), anticipatory competence (futureproofing the opinion), and strategic competence (dealing with the action aspect of the opinion). Interpersonal competence is included in the lesson design by the choice for collaborative teaching activities. The lesson module was designed in such a way that it includes activities aimed to foster all of these five key competences for EC.

After discussion with the LS teachers, issues related to the production and use of smartphones were selected as the theme for the module. Based on previous experiences of the teachers, this topic was thought to be closely linked to the students' daily lives, and would be both recognizable and appealing to them. This personal connection is an important requirement when discussing sustainability issues (Blatt, 2014).

SSIBL was selected as the educational approach for the lesson module. SSIBL-based educational materials generally consist of three phases: 'ask', 'find out', and 'act' (Levinson, 2018). During the 'ask' phase, the SSI is introduced, creating a need-to-know for the students. This way, the lesson prompts students to ask questions about the SSI. They try to find answers to these questions in the 'find out' phase,

during which students map the controversy, and perform scientific (experiments, measurements) or social sciences (questionnaires, interviews) research. Finally, during the 'act' phase, students make decisions based on their inquiry and take action accordingly.

The ask phase of the developed lesson module starts with a commercial video of a new smartphone model. To record their primal reaction to the subject, students are asked whether they would buy this model, and why (Table 11.2). The teacher

Table 11.2 Description of the lesson elements of the smartphone lesson, with links to the three SSIBL phases and the five key-competencies for sustainability (Wiek et al., 2011)

Lesson module element	SSIBL phase	Key-competences*
1. Smartphone commercial video, followed by smartphone deconstruction	Ask	Sy
2. Introduction on adapted periodic table of elements, showing which elements are present in smartphones, their availability, and which elements are from conflict areas		Sy, A
3. Writing down initial reaction to the dilemma, including questions raised and emotional response		N
4. Group work: each group looks into mining and its effects for one particular smartphone element; finding sources for the inquiry phase, checking their reliability, and listing stakeholders	Find out	N
5. Mapping the controversy: summarizing initial findings about mining, looking into people, planet and prosperity aspects, effects in the Netherlands and elsewhere, and effects now and in the future		Sy, A, N
6. Lesson two: forming new groups with members from all four elements, discussing findings from lesson one		Sy, I
7. Summarizing information from element schemes into a simplified life cycle scheme, with attention for influence of time and possibilities for change		Sy, A, St
8. Starting with individually thinking of the most desirable option for change, then discussing this in the small groups, then formulating one clear statement about the developed strategy	Act	A, N, St, I
9. Arguments in motion activity with the whole class, discussing the different statements, students take a position in the classroom, indicating whether they are for or against, and whether they came to the conclusion based on ratio or gut-feeling		A, N, St, I
10. Evaluation questions and looking back on initial reaction to dilemma, thinking about what has potentially changed		N, St

* Key competence codes: Sy—Systems thinking competence; A—Anticipatory competence; N—Normative competence; St—Strategic competence; I—Interpersonal competence

then deconstructs a smartphone, while the students pass around the parts. The LS-team thought this hands-on approach would elicit a stronger enthusiastic response from the students. Subsequently, the teacher shortly introduces an adapted version of the periodic table, which shows what elements are present in smartphones, their availability, and whether they are mined in conflict areas (European Chemical Society, 2019). Taken together, this introduction is expected to raise questions and provoke an emotional response. First steps toward developing systems thinking, anticipatory, and normative competence are made (Table 11.2). Students individually write down this first reaction, noting what questions they have and what emotions they felt during the intro. Paying explicit attention to emotions and intuitive reactions is pivotal during moral reasoning, since they often show underlying values and form the basis of moral reasoning (Haidt, 2001). Thinking through an SSI individually before discussing it in small groups is desirable too, to ensure safety and stimulate reasoning for each student (Waarlo, 2014).

During the find out phase, students work in small groups (Table 11.2). Each group performs inquiry into one of four elements: cobalt, copper, tantalum, and tin. These elements were selected for their diverse environmental, social, and economic impacts, the backgrounds of areas where the raw materials are mined, and the diverse processes of acquiring these elements. The students look up information about the elements, think about the different stakeholders, and summarize their information in an element scheme. This process is guided by questions which are aimed to broaden their scope, for instance, making them explicate implications in their surroundings and elsewhere, and on different time scales.

The following teaching and learning activity takes place during the following lesson. Groups are mixed so that each new group at least covers all four elements. Students perform a stripped-down version of a life cycle analysis based on the element schemes from the previous lesson. With constructing these schemes, students have strived to form a holistic overview of the issues associated to mining smartphone elements. Holism in the case of sustainability entails the three different dimensions of people, planet, and prosperity, effects in the past, the present, and the future, and a focus on local, regional, and global effects (Öhman, 2008). Employing a focus on holism during sustainability education can promote student knowingness of the complexity of sustainability issues (Boeve-de Pauw et al., 2015). Additionally, offering opportunities to discuss multiple sides of environmental dilemmas is important for students, since this makes them feel taken seriously (Blatt, 2014). Overall, the find out phase aims to make students realize how complex their sustainability issue is through performing inquiry. This combination of inquiry and explicating complexity is one of the main driving forces behind SSI-based reasoning (Sadler et al., 2007). The find out phase contains elements of all five key competences for EC (Table 11.2).

The act phase of the lesson module started with individual opinion forming, this time asking students to pinpoint the most desirable option for change in their life cycle schemes (Table 11.2). Students discussed their ideas in small groups, and prepared one single statement about what they as a group would change in the system. These statements were used during the arguments in motion activity (Van

der Zande, 2011). During this activity, students position themselves in the classroom, according to what they think about a statement. One wall represents for, the one facing it represents against. After taking place on this line, the teacher introduces the other axis, with one wall representing their ratio, and the other their intuition. Students move along this axis accordingly, showing their principle motivation behind their choice. Subsequently, the teacher asks students to provide reasons for their position, to take another position in the room and imagine why people would stand there, and other questions that might show empathy and diversity of opinions. Explicitly showing different perspectives is essential for fostering SSI-based reasoning (Sadler et al., 2007).

After the arguments in motion activity, students answered a set of evaluative and reflective questions, referring back to their initial reaction at the start of the first lesson. Would they for instance buy the smartphone from the commercial of the first lesson after the module? Again, the act phase contains links to all five key competences for EC (Table 11.2).

After the first round, some minor adaptations were made to the lesson module. The main difference was that we provided a filled-in example of the element scheme for the element gold. This was deemed necessary because students struggled with deciding what to write down, and we expected this example to speed up the process. We also decided to provide the students with information sources a bit earlier than during the first cycle, since this process too took more time than expected or desired. Despite these small changes, the lesson module remained virtually identical during the first and second round of classroom testing.

11.3 Findings

Analysis of the data led to the following findings. They are ordered along the different learning aims of the lesson module: fostering EC in general, raising awareness of the complexity of sustainability issues, and student decision-making.

11.3.1 Fostering EC in General

The module's potential to foster EC was analyzed based on different data sources. In the booklet, we asked the students what they had learned and what was new for them during the lesson. The most common answers here fell in the category of the problem context (Fig. 11.1). These answers dealt with elements becoming scarce or running out entirely in the near future. Subject matter related answers were popular as well, related for instance to all the elements that are used for smartphone production. The third most common category was a bigger appreciation for how complex the issue was.

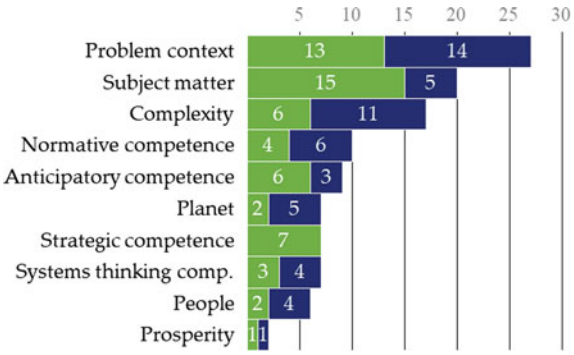

Fig. 11.1 Main categories found in written answers from student booklets ($n = 45$), in response to a question asking what they have learnt during the lesson module. Categories represent the general learning outcomes, developments in the five key competences for sustainability, and the three dimensions of sustainable development. Green bars represent group 1, blue bars represent group 2, with numbers in the bars representing the number of students whose answers fell in the corresponding categories

In their answers, students occasionally mentioned aspects of sustainability competences as learning outcomes. Normative and anticipatory competences were the most common among these. These, for instance, included students being surprised by the variation of opinions about the issues among their peers, and worries about the future. Strategic competences were only mentioned in the first group, with common comments revolving around recycling their used phones. One student shows signs of anticipatory and strategic competence when they strongly remember "That elements are running out and that people have to find new ways to replace them" (Student 14). Commenting on the strategic competences of the students, during the post-lesson discussion the teacher from group 1 said:

> What also stands out to me is that they [the students] do go deeper at a certain point, most of them, not all of them, and that they then think through the issue more thoroughly. But when I then look at the statements, I think yeah, I had expected a little more from that. These are the kind of things you could have come up with after fifteen minutes as well. And not after three lessons—Teacher 1

According to the teacher, the discussion during the lesson was surprisingly deep for what he expected from his students. According to him, this was one of the key moments. However, this deeper level of insight in the issue did not end up in the statements that the students formulated. It appears students experience difficulty with converting their findings into practical ideas, or, in other words, their strategic competence was still lacking. Examples of systems thinking competence in student answers usually referred to the summaries that they made of the issue, for instance, from their element scheme or life cycle analysis. Students did not mention learning anything that could be interpreted as interpersonal competence.

Concerning the three dimensions of sustainability, planet and people aspects were by far the most common in student answers in the booklet (Fig. 11.1). Examples of

these include effects on the environment, child labor involved in mining operations, and rising CO_2 emissions. Prosperity elements were mentioned only by one student from each group, which shows that these are among the least recognizable for the students.

The post-lesson interviews with the case students showed many of these same trends. The problem context, about the elements running out, was similarly commented on, as this example illustrates:

> Well, I have learned more about which elements are used in phones, how you can use your phone sustainably, and how you can improve that, how you can use it more sustainably, and what the government can do about that as well—Student 2

This quote also illustrates that some students were able to think about these issues in both private sphere behavior as well as in public or collective action taking. These are clear signs of students developing EC competences, where private and collective actions are important. Another student also commented on action taking after the lesson:

> I think this is a very relevant subject, because actually nobody knew anything about this before, and what I said, it is very much something that happens now, very relevant, this way we will know for the future, what we can do, of course not exactly how we can do everything, what we can change ourselves, but we do know now what the government can change, and when we are allowed to vote later on, if somebody then has an opinion about this, and then we can see do I agree with that, then you could vote for this person—Student 45

Other students specifically referred to different sustainability competences they developed, comparing this lesson with their regular chemistry lessons:

> Yeah I think that this is a little more important than just stupidly knowing how molecules are formed or something, because this is actually the future, and it has, it concerns the future of the planet, and of course, molecules are also important for the planet, but this is the future and what is happening now […], I did not really think before that this would be covered during chemistry, I know it really has to do with chemistry, but on my own, I did not think it would have that much, impact—Student 34

Despite this clear appreciation for discussing EC during science lessons, a sentiment that should not be ignored is the one voiced by this student:

> It is perhaps something that can be done once every while. Yeah because you hear so much about it all the time, and sometimes I am like, can you for one minute stop whining about how bad everything is for the environment?—Student 39

11.3.2 Complexity of Sustainability Issues

One of the main learning aims of the module was to show students how complex sustainability issues can be. All but one of the observers said during the post-lesson discussions that the module was effective in making their observed students aware of this complexity. Similar to the observers, the student booklets also showed students appreciated the complexity of the issue. As can be seen from Fig. 11.1 from the

Table 11.3 Occurrence of people, planet, and prosperity aspects in student summaries of smartphone production (the element scheme and the life cycle) for group 1 and group 2

	People	Planet	Prosperity
Element scheme group 1	9	4	4
Life cycle group 1	6	7	0
Element scheme group 2	17	19	13
Life cycle group 2	36	30	16
Total	68	59	33

previous section, 17 students mentioned complexity of the issue around the production of smartphones as main learning outcome of the lesson series. Elaborating on this, one student writes:

> [I have learned] That the problem is way more difficult than you maybe think, because there are more effects caused by smartphone production and there are so many problems in the phone industry to begin with—Student 27

The lesson module prompted students to use the three dimensions of sustainability during the find out phase. From their element and life cycle schemes it follows that the people perspective is the most prominent, followed by the planet perspective (Table 11.3). Despite it being explicitly asked for in the assignment, the prosperity perspective was used only occasionally, and then mainly by the second group. Overall, the second group used overwhelmingly more dimensions of sustainability than the first.

During the twelve post-lesson interviews (six per group), some students mentioned an increased appreciation for the complexity of the issues around the smartphone as a result of the lesson module. This was mainly caused by students seeing how complex a device such as a smartphone is, as this student describes:

> I have mainly learnt that phones are way more than I previously thought, that there is way more behind them, and that you can look at them from totally different ways, more than just this is an electronic device—Student 17

Sometimes, students perceiving the complexity of the smartphone issue could be inferred from what they thought was important about the lesson module. For instance, this student says:

> That you could reflect on, that there is a shortage of some elements and that we really are forced to think of a solution or something, otherwise […] we cannot produce anything anymore. And that there are some elements that, when mining for them, this causes extreme environmental damage, and for the people who live there, there is no nice living environment anymore because we want smartphones. […] We need to think about what it is made out of, which elements or something, and if it can be recycled, if it is good for the environment. Yes I think that it is important, that we, we want to keep the world as beautiful as possible for our, for the generation after us, and we have to think about this from our youth onward, that we can do something about this ourselves—Student 7

This student also commented on intergenerational effects of our behavior. One other student mentioned this in their interview.

As can be seen from student 7's quote, students explicitly referred to the three sustainability dimensions of people, planet, and prosperity during the post-lesson interviews. For instance, this student says:

> Yes, I thought it was pretty informative actually, because I did not know there was so much pollution, and so much child labor also, involved during the production of smartphones, that is pretty interesting—Student 34

During the interviews, planet aspects were the most commonly used of the three sustainability dimensions (occurring 12 times), closely followed by people aspects (10 times). Prosperity elements were only used 3 times in all the student interviews, further solidifying the image painted by the student posters and answers to the questions in the booklets that prosperity is the least immediate dimension of sustainability for these students.

11.3.3 Opinion Forming About Sustainability Issues

Fostering meaningful opinion forming, ultimately leading to decision-making, was one of the main learning aims of the lesson module. After the lesson, the observers felt that students did not yet make enough progress during this module in developing their meaningful decision-making skills. During the first group's post-lesson discussion, Teacher 1 comments:

> It occurs to me that they [the students], actually very quickly, I even have to pull the breaks on them, are going head first into drawing conclusions, without going […] really much deeper into it. They very quickly know, well, polluting, and we are running out, and that is so early on in the process, […] they are very quickly occupied with conclusions—Teacher 1

One moment later, this same teachers said:

> And then, yeah, the opinion forming, I think that, yes I have a good feeling about it actually, the difference between answering something individually, and then in a group, and then in the class, the way this was structured, and I think that they did think about it very well, […] they did think about it, but not about their own impact, it is, they think only about what others should do about it, such as governments—Teacher 1

Judging from these quotes, the teacher felt that his students made progress in their decision-making skills, but there was still a way to go before they truly reach this learning aim. The observers and teachers still felt students did make progress during the lesson in developing their opinion forming and decision-making skills. These developments were mainly due to the arguments in motion activity, one of the clear key moments in the lesson design. The teacher of the second group explains:

> Well, I think it is amazing to hear that, the arguments in motion, that students think this is useful, and that they enjoy it, that something happens there after all—Teacher 2

Other data sources show the importance of this key activity as well. In the booklets, students overwhelmingly pinpointed the arguments in motion activity as the most

useful during the lessons (22/45 students), only behind the element and life cycle schemes (23/45 students). During the discussion about the statement 'A maximum yearly tin production is set for each mine', students use different dimensions, as this excerpt illustrates:

Student 13: Yeah, there is less pollution because of this.
[…]
Student 12: It is better for the people, because they have to work less in the mines.
[…]
Teacher 2: Why are you standing here?
Student 14: Because I don't want phones to become more expensive!
[…]
Student 16: If there is less tin available, then it stimulates companies to become better in recycling, so there is more tin available this way and we stimulate reuse.

Answers from the student booklets paint a similar picture. Opinion forming related learning outcomes were among the most commonly mentioned in the booklets (Normative competence, Fig. 11.1). One student writes: "During the statements activity, there were opinions from students that I did not expect" (Student 32). To them, this was the most lasting impression of the module overall.

Looking at student reasoning about the issue, some students paid explicit attention to the three dimensions of sustainable development. For instance, in one of the student interviews, when describing their decision-making process, one student says:

> With that statement, if we have to start spending a lot of money on waste processing, then you can maybe you can spend that money first on improving the working conditions first, before you start working on recycling and those kinds of things—Student 39

This student is using different dimensions of sustainability when forming their opinion, in this case the prosperity and the people dimension. They are thinking strategically about their preferred solution to issues related to smartphone production. Going further, students also reasoned using future generations and their needs, as this quote illustrates:

> It is also important for our future, because the elements are running out, and how are we going to solve this in a few decades? Our children, our grandchildren will be left behind with this, so how can we solve this, what are the possibilities? What materials will we use then? So yeah, I think this is something to think about, and to come up with new things—Student 1

However, some aspects of decision-making remain difficult for students. For instance, during the post-lesson interviews, we asked the students what steps they think they take when forming an opinion. It becomes apparent that most students are not aware of specific steps they take when forming an opinion. The most common answer related to thinking about the question, and forming an initial reaction in their heads. One student describes:

> I think that you should always first think about what sounds like the most logical, and then you have to think about can you ask the question in another way in your head, because you will then see if you are for or against different aspects of the issue, because sometimes it sounds very much like you are for or against, but that you of course also think for a while if that is actually the case—Student 43

At the start and at the end of the lesson, the student booklet asked what students would do with their old phone when they buy a new model. Twelve out of the 45 students said they would do something else than before the lesson, with most of them responding that they would now recycle their old phones. Doing good for the environment was the only reason given for this change of strategy, still showing a relatively shallow argumentation, discarding all the people and prosperity arguments used during the lesson.

11.4 Discussion and Concluding Remarks

The lesson module we developed aimed to foster EC by making lower secondary students see the complexity of sustainability issues on the one hand, and by enabling them to make well-funded decisions about issues on the other. SSIBL's phases of ask, find out, and act were used as an educational framework for the module.

Judging from the data, it becomes clear that some of the main competences of sustainability were at least partially developed by the module. Students learned about the problem context and the subject matter, elements becoming scarce and what elements are used in a smartphone. Mainly their normative competence, related to the opinion forming elements in the module, and their anticipatory competence, dealing with possible future effects of the issue, were stimulated by the module. Students were highly motivated during the lessons, with multiple students wanting to continue even during the break. Some students were still discussing issues on taxes on smartphones during the breaks, entirely without teacher interference. Multiple students mentioned they truly enjoyed discussing real-world issues, they felt it was important what they were doing. It seems SSIBL does indeed create moments of genuine enthusiasm in students.

Based on previous studies, the image arises that students strongly focus on the planet dimension of sustainability issues (Benninghaus et al., 2018; Sinakou et al., 2019). Furthermore, the intergenerational view is most commonly found, with students mostly looking into effects on future generations instead of effects on their own generation (Benninghaus et al., 2018; Sinakou et al., 2019). Surprisingly, in our study we found that people aspects were used at least equally as often as planet aspects, with some sources even showing a stronger representation of the people dimension in student answers. In addition, participants in our study more commonly use the intragenerational view as opposed to the intergenerational view. This inclusion of an intragenerational view is a clear sign of EC development (Benninghaus et al., 2018; ENEC, 2018). In contrast, what is in line with previous findings is that in most of our data sources, prosperity aspects were hardly mentioned at all.

An explanation for the shift in student focus might come from the smartphone context, which clearly features examples of child labor and adverse working conditions in our present time. This could have led to an overemphasis of the people dimension, and thus promote an intragenerational view as well. However, mining also causes severe ecological damage, which means that planet aspects were not underrepresented in the context. We do not know why these planet aspects were less impressive to the students, and why the people aspects were overrepresented in their answers.

One of the teachers commented on the fact that many students in our study placed their solutions not on the individual, at home level, but looked toward governments and other large institutions for solutions. This was a common finding across the various data sources and indicates anticipatory and strategic competence development. Contrary to the usual neoliberalist view on individual actions that some researchers describe (Schindel Dimick, 2015), our students show that SSIBL has the potential to enrich their action taking, with a shift toward more collective or public sphere actions. A focus on both individual and collective action taking is a strong sign of true EC (Dobson, 2007; ENEC, 2018). SSIBL seems effective in promoting that aspect.

Concerning the learning aims of the module, student appreciation for complexity of sustainability issues was fostered. This required students to develop both normative and systems thinking competence. Time and time again, students showed this both in their written and spoken form. Observers and teachers also felt this learning aim was reached. A difference was noticeable between the first and second group, mainly in the richness of their element and life cycle schemes. The adaptation between group 1 and group 2 might have added to this, by strengthening ties between the first and second lessons. Additionally, the second group was pre-university level, whereas the first group was higher general education level, which might explain this difference.

The decision-making learning aim was only partially met at best. The arguments in motion activity, and other activities during which the students discussed their opinions and ideas together, were among the highlights of the lesson for many students. The actual decision-making process was less smooth. One of the teachers mentioned that he had to stop students from drawing conclusions immediately, making them consider multiple sides before making decisions. Furthermore, although students did manage to develop a relatively rich overview of the sustainability issues during the find out phase, this richness was not found in their strategies toward a more desirable situation. This indicates a lack of strategic competence in the students. Teacher guidance seems pivotal during these processes.

Another point that should be explored further is the decision-making process itself. Students are unaware of the specific steps they take when forming their opinion about sustainability SSIs. Paying explicit attention to these steps might make them realize what is important during opinion forming and decision-making, perhaps simultaneously enriching their conclusions.

What can be seen from these results is that the phases of ask, find out, and act have potential to foster student appreciation of the complexity of sustainability issues on the one hand, and can provide a starting point to develop their opinion forming skills

on the other. In doing so, SSIBL can support students during development of EC competence at lower secondary level. Student EC most strongly flourished during those phases in the lesson design where they approached the dilemma from multiple different perspectives, during activities where they could formulate their own opinion but also when they had the ability to hear the opinion of their classmates. Following studies should explore SSIBL's EC fostering potential more in-depth.

Taken together, this lesson was a step in developing EC competences through science education. Of course, developing higher order thinking skills takes time (Guérin et al., 2013). It would be too much to expect students to become problem solvers after this three-lesson module alone. Despite this, the steps that the students took in developing the competences needed for solving sustainability issues can still be seen as successful. With this, our study identified an educational approach for teaching EC through science education at lower secondary level.

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