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Chapter 10

Teaching Robust Argumentation Informed by the Nature of Science to Support Social Justice. Experiences from two Projects in Lower Secondary Schools in Norway

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Abstract This chapter suggests a set of design principles for science curricula that will enable students to produce evidence-based arguments expressing views related to their own interests. It is based on the assumption that the ability to construct evidence-based arguments strengthens students' ability to promote their own views in the interest of social justice. This is of special importance for students not enculturated into such argumentation through their upbringing. To promote one's own views in a debate means to critique others' arguments, and especially to ensure one's own arguments are resistent to criticism. Insight into the nature of science includes insights in how to construct sound arguments based on facts and research results. The discussion of design principles is based on an analysis of two science projects in two lower secondary schools in Norway (Grade 8). In the first project, students produced scientific claims based on evidence from their own practical experiments. In the second project, the students developed and applied a method for estimating energy use and carbon dioxide (CO_2) emissions. The students used their findings to construct arguments related to local transport plans. The analysis focuses on challenges and successes in scaffolding students at different competence levels to successfully produce evidence-based arguments.

10.1 Introduction

This chapter presents an analysis of two science projects where grade 8 students constructed evidence-based arguments informed by their developing understanding of the nature of science (NOS). In the first project, the students experimented on the toxicity of household chemicals. In the second project students constructed models for energy consumption related to a local transport issue. Based on the analysis, the chapter suggests a set of design principles for science curricula that will enable students to produce evidence-based arguments expressing views related to their own interests. Fundamental to this analysis, is the assumption that the ability to construct evidence-based arguments strengthens students' ability to promote their own views in the interest of social justice. This is of special importance for students not enculturated into such argumentation through their upbringing. To promote one's own views in a debate means to construct arguments that are resistent to criticism. It also requires critiquing others' arguments.

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Several insights about NOS, like the destinction between observations and possible inferences, can guide sound construction and evaluation of evidence-based arguments. Insights into NOS can therefore support students as they construct arguments related to issues of their own concern.

Issues that are relevant to students might differ considerably depending on local context, socioeconomic situations, and personal interests. Students in disadvantaged areas may experience more acute issues than students from wealthier areas. However, all students may experience the need to articulate their concerns and requirements to attract attention to their own situations. Students from different backgrounds might have experienced varying degrees of enculturation into ways of constructing robust argumentation. Arguments based on superficial inquiries or incorrect interpretation of facts may be refuted and may weaken the student's position. To strengthen their cases, they could support their opinions with evidence-based arguments. To support social justice, it is therefore important that schooling develops the ability of all students to construct robust evidence-based arguments based on adequate understanding of the nature of science (NOS).

The core elements of NOS include basing claims on evidence, a distinction between observation and inference, and the roles of creativity, testing, critical thinking, and communication of arguments (Lederman, 2007; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Insight into these elements, combined with experience of how they guide epistemic practices and the development of scientific arguments, might enable more students to construct robust evidence-based arguments.

Science education for social justice places emphasis on student agency and on enabling students to use science for their own agendas (Barton, Ermer, & Burkett, 2003). Basu and Barton (2010) conducted empirical research on democratic educational practices to identify a model of democratic science pedagogy, that is, a science pedagogy aimed at empowering all students to use science in accordance with their own needs. This model has critical science agency, shared authority, and constructions of community as its key principles. Critical science agency implies that students have opportunities to influence the way science is used and to use science in accordance with their own values and perspectives. Shared authority implies that students are free to raise their voices and provide suggestions and critiques, and that students' knowledge is valued. Constructions of community imply the opportunity to work together in a supporting and caring environment that enables all students to learn.

This model emphasises how teaching for social justice should combine opportunities to learn with opportunities to bring forward the students' own perspectives and use science in accordance with their own needs and values. The present study expands this model by focusing on how students' use of science in accordance with their own perspectives can involve evidence-based argumentation, i.e., argumentation involving scientific or other factual knowledge about the material world. Moreover, the study identifies design principles for science teaching to provide experiences with construction of robust evidence-based arguments.

In science, argumentation is linked to knowledge justification, and claims should be justified with logical reasoning and empirical and theoretical evidence (Jiménez-Aleixandre & Erduran, 2007). Lacking awareness of how scientific arguments can be scrutinised might lead to less robust argumentation. Experience and knowledge about scientific inquiry and critical thinking will empower students to construct arguments that better withstand criticism.

One of the central goals of teaching science for social justice, and of the two projects that are analysed in this study, is to 'position students as knowledge-constructors and critics, rather than passive recipients' (Thadani, Cook, Griffis, Wise, & Blakey, 2010, p. 22). Increasing students' ability to construct knowledge and arguments through inquiry is therefore a necessary aspect of teaching for social justice (Garii & Rule, 2009; Thadani et al., 2010).

Teaching for social justice includes 'tying the academic content to students' own lives, recognising that this will empower them within the contexts of their lives and communities' (Garii & Rule, 2009, p. 491). In science education, this aim implies the provision of students with experiences of how science could be used for their own agendas (O'Neill, 2010). This aim also presupposes the fostering of student ownership of content, student autonomy, and student mastery experiences (Barton & Tan, 2009). The aim also requires the inclusion of students' knowledge as legitimate sources of introductory ideas and contributions to class dialogues (Barton & Tan, 2009; Basu & Barton, 2010).

The purpose of this chapter is the identification of design principles that enhance students' ability to construct robust evidence-based argumentation based on their own perspectives. That is, science teaching for social justice focusing on students' construction of arguments that are informed by NOS and critical thinking. To enable the identification of such design principles, this paper analyses two science projects based on two questions:

1. What practices did the students participate in that involved construction of evidence-based arguments reflecting aspects of NOS and critical thinking?
2. What underlying design principles might have contributed to student participation in learning activities where they used facts and scientific argumentation to support their points of view?

The suggested set of design principles are intended as a starting point for design-based research and a guide for curriculum design. The principles are general and do not describe specific teaching or learning activities. This set of principles might be denoted as a high-level conjecture. Sandoval (2014) has discussed design-based research and identified a high-level conjecture as 'a theoretically principled idea of how to support some desired form of learning, articulated in general terms and at too high a level to determine design'. In this chapter's discussion, the design principles are compared to Basu and Barton's (2010) key principles for democratic science pedagogy presented above.

10.2 Theoretical Framework

The theoretical framework for the analysis of the two science projects includes a conception of NOS and a conception of robust argumentation. The nature of science refers to the epistemology of science, science as a way of knowing, and the values and beliefs that are essential to the development of scientific knowledge (Abd-El-Khalick & Lederman, 2000). Lederman (2007) formulated a set of seven NOS objectives for science education, which together represent a condensed formulation of the "consensus view" of NOS. According to this view, students should learn about the following characteristics of science: observation is distinct from inference; scientific (empirical) laws are distinct from (explanatory) theories; science is based on observations of the natural world and involves human imagination and creativity; scientific knowledge is subjective and theory-laden; science is as a human enterprise practised in the context of a larger culture; scientific knowledge is never absolute or certain; and NOS refers to the epistemological underpinnings of the activities of science.

Although the concepts are related, NOS may be seen as distinct from scientific inquiry, which refers to the methods and procedures of science (Lederman, 2007). However, Grandy and Duschl (2008) warned that such a differentiation oversimplifies the nature of observation and theory, and emphasised that inquiry practices are guided by epistemological thinking. This comprehensive view of NOS is echoed in the well known Delphi study by Osborne, Collins, Ratcliffe, and Duschl (2003), which identified nine key ideas about NOS to be taught in school science. The nine key ideas were categorised as ideas about the nature of scientific knowledge, the methods employed in science and institutions, and the social practices in science.

Several authors (Allchin, 2011; Yacoubian, 2012) have suggested that teaching NOS should be aimed at inculcating the use of epistemic understanding to guide inquiry and should focus on the dimensions of reliability in scientific practice. In line with this reasoning, this paper takes the perspective that students' ability to engage critically with science and scientific argumentation might profit from NOS teaching, which is integrated into student inquiry and related to topical issues. One major reason for this is that several aspects of NOS reflect values and practices employed by scientific communities to enable the development of reliable knowledge backed by robust argumentation. Examples in the above-mentioned Delphi study include asking questions and seeking answers; using experimental methods, hypotheses, controls, and critical testing; distinguishing between data and interpretations; using creativity and collaboration; and subjecting new developments to critique through activities such as peer review. Moreover, the Delphi study includes insights about the tentative and revisionary nature of scientific knowledge and the use of reports, for example, to communicate arguments and new developments. Compared to Lederman's conceptual core objectives, the Delphi study represents a somewhat broader picture of NOS and places more emphasis on epistemic practices in science.

Ideas about NOS guide epistemic practices in science and are therefore relevant for students aiming to construct and criticise evidence-based arguments. Using the core elements of NOS identified by Lederman (2007) and the Delphi study (Osborne et al., 2003), the arguments constructed by the students in the two projects, and their epistemic practices, will be analysed for their use of ideas about NOS.

The main purpose of this study is to discuss how to support the development of students' competences in critical thinking and construction of robust argumentation. The analysis therefore includes a focus on instances and characteristics of the evidence-based argumentation and critical thinking students practised and became more skilful in. An argument might be regarded as a justified claim, i.e., supported by data (Toulmin, 1958). According to Toulmin (1958), arguments might also contain elements like warrants, qualifiers, and rebuttals. In a discussion involving several points of view, arguments might meet critique. A main purpose of critical thinking is to decide on what to believe (Bailin, Case, Coombs, & Daniels, 1999), e.g., to judge the quality of arguments. An argument can be viewed as more or less robust depending on its ability to withstand criticism. In the process of constructing an argument, the arguer might use critical thinking to evaluate the strength of different parts of the argument in order to identify element in need of improvement. Consequently, a crucial part of critical thinking is to identify, construct, and evaluate arguments (Facione, 1990).

According to Golding (2011), a critical thinker needs a sophisticated epistemic understanding as, in addition to other elements, 'critical thinking is about constructing and evaluating reasoned judgments' (p. 358). Moreover 'interpreting the reliability of scientific claims requires a broad understanding of scientific practice' (Allchin, 2011, p. 522). However, while critical thinking is an integral aspect of NOS, it is also a separate area of scholarly study. Bailin et al. (1999) have identified five kinds of intellectual resources that are necessary for critical thinking: background knowledge; operational knowledge of the standards of good thinking; knowledge of key critical concepts (e.g., being able to distinguish a value statement from an empirical statement); heuristics (strategies, procedures, etc.); and habits of mind (e.g., open-mindedness and fair-mindedness). Moreover, critical thinking often requires 'imagining possible consequences, generating original approaches and identifying alternative perspectives' (Bailin et al., 1999). Thus, creativity plays as important a role in critical thinking as it does in NOS and scientific inquiry.

Bailin and Battersby (2016) have argued for 'a conception of critical thinking as a practice—the practice of inquiry' based on the need to integrate skilled performance and the acquisition of the virtues inherent to the practice of critical thinking. The claim that critical thinking and inquiry are interlinked practices and competencies is also supported by the seminal Delphi Expert Consensus (Facione, 1990), which has stated that 'critical thinking is essential as a tool of inquiry'. The consensus report goes on to state that 'critical thinking is a liberating force in education and a powerful resource in one's personal and civic life', which is consistent with one of the main purposes of teaching for social justice.

Several researchers have explored how understandings of NOS might support students' critical thinking in socio-scientific contexts (Bell & Lederman, 2003; Khishfe, 2012; Leung, Wong, & Yung, 2015; Matthews, 1994; Yacoubian, 2015). Neither Bell and Lederman (2003) nor Khishfe (2012) have found any impact of personal decisions on socio-scientific issues after NOS instruction. However, Yacoubian (2015) has argued that the students need to not only *understand* aspects of NOS, but also be guided to *apply* their understanding in relevant contexts. Khishfe's (2012) study included such practices. She examined students' justifications and found that more students in treatment groups were referring to NOS aspects; the students were backing their views with empirical evidence and indicating greater awareness of the tentative nature of evidence.

This chapter assumes that experience with NOS in inquiry environments can improve students' abilities to construct and evaluate arguments in socio-scientific contexts. This assumption is supported by several studies that have documented how students' critical thinking could be positively influenced by inquiry-based science teaching (Gupta, Burke, Mehta, & Greenbowe, 2015; Hand, Shelley, Laugerman, Fostvedt, & Therrien, 2018; Quitadamo, Faiola, Johnson, & Kurtz, 2008) and topical socio-scientific contexts (Goeden, Kurtz, Quitadamo, & Thomas, 2015; Merchan & Matarredona, 2016; Wang, Chen, Lin, Huang, & Hong, 2017). These topical socio-scientific issues provide opportunities for students to relate science to life outside school.

10.3 Data and Analysis

10.3.1 The Cress Project

The first of the two projects to be discussed was initiated by a male science teacher at a lower secondary school. He had two Grade 8 science classes and wanted to do an inquiry-based project as some of his students showed a lack of motivation for science. Also he thought the inquiry methods were appropriate for the next topic to be taught, NOS and scientific inquiry. The teacher felt somewhat unexperienced with the topic and with inquiry-based teaching and asked this author to collaborate.

The school is situated in a suburban area where students have varied socioeconomic background, but the average is above that of the local municipality. Varied socioeconomic backgrounds of students are typical of many schools in the area. At the national test in mathematics the year of the project, the school's score was one point below the national average, which was defined to be 50 (www.udir.no/in-english/). Of the five performance levels, only 22% of the students at the school were in the top two, while the national figure is 32%. There are no national tests in science. The students had conducted practical work in science before, but had not experienced inquiry-based teaching at this school.

The main goal in this project was to help students, in the context of an environmental issue, begin to understand how scientific claims are constructed and might be inspected for trustworthiness. Students were asked to imagine that a local environmental organisation wanted to advise people to use less harmful chemicals. The organisation needed reliable knowledge on what types of chemicals are harmful so that people would not lose trust in their advice. The students worked in groups of three and four to test the impact of a household or garage chemical of their choice on the growth of plants. All groups were given 10 pots with garden cress as a model plant to use in an experiment of their own design. Seven 45-minute science lessons were allocated for the Cress project.

The data from the project consist of observational notes from the classroom lessons, including students' oral contributions during class discussions; student experiment plans and experimental reports; and students' written responses to tasks during lessons and to questions on an end-of-chapter test. Data also include planning documents and the teacher's and researcher's written reflections during the project.

10.3.2 The Energy Project

The second of the two projects was suggested by two university teachers and this author as part of a three-year collaboration with a lower secondary school. The project was developed in cooperation with eighth grade teachers in science, social science, and mathematics. All the data were collected from this author's collaboration with the two female teachers running the project in one class. These two teachers showed great interest in the project and thought it was important to raise the relevance of the science teaching for their students.

The school is situated in a suburban area with students from similar mixed socioeconomic backgrounds as the first school. At the national test in mathematics that year, the school's score was at the national average (www.udir.no/in-english/). Of the five performance levels, 33% of the students at the school were in the top two levels that year and 12% were at the lowest level, while the national figures were 30% and 11% respectively. Also in this class, the students had conducted practical work in science before, but had not used inquiry-based teaching.

The goal of this project was to increase students' confidence to use facts to build up their own arguments on a topical socio-scientific issue. There was a local debate on whether to expand an existing light rail system. Due to climate and pollution considerations, the municipality had decided that an existing line was to be extended past the students' school. Students were asked to develop a method to compare light rail and more roads in terms of energy consumption and CO_2 emissions. Then, the students were to apply this method to their own inquiry and write a scientific report presenting their exploration and conclusion. A set of introductory tasks was designed to introduce students to the concept of kilowatt hours and how energy can be measured using different concepts (e.g., gasoline consumption). The scientific report had to be written as a poster and each group presented their report orally to the rest of the class. All presentations were followed by a teacher-mediated class discussion that focused on critical questions and the identification of interesting points. Students worked in groups of two to six students, and the project involved 16 school lessons.

In this project, all 16 lessons were videotaped, using one whole class camera capturing the teacher and blackboard and five GoPro cameras capturing different groups. Relevant passages in the videos were transcribed. Data from this project also included students' written reports and posters; self-evaluations of learning gains, effort, and challenges; and the teacher's and researcher's videotaped oral and written reflections.

10.3.3 Method and Analysis of the two Projects

The analysis of the two science projects focused on student experiences with NOS, evidence-based argumentation, and critical thinking. Such experiences might impact students' abilities to construct and criticise knowledge claims. In addition the projects will be inspected for presence of key aspects of democratic science education. All field notes, videos, and written work by students were carefully inspected and relevant sections, i.e., involving talk or writing of arguments, claims, critiques, inquiries, and NOS, were marked. Marked sections were further inspected, and the elements of NOS and critical thinking involved were described.

The first dimension of the analysis, the identification of situations where students experience NOS, included aspects related to dimensions of reliability in scientific practice. The analysis included instances where students expressed elements of NOS with their own words and where elements of NOS were reflected in the students' practices or where students were challenged by their teacher to do so. In specific, the analysis identified situations where students formulated research questions, designed and explicated methods of inquiry, used controls and critical testing, collected and interpreted observations, experienced relevant critique, discussed assumptions, based conclusions in reports on evidence, discussed the tentative nature of scientific claims, and exhibited other elements of NOS.

The second dimension of the analysis implied identification of students' experiences, discussions, and writing involving construction and critical thinking about arguments, including situations where students were challenged or supported by their teacher to do so. In specific, the analysis identified situations, discussions, and written work where students created or presented arguments; identified questions or comments on possibly weak aspects in plans, experiments, observations, interpretations, conclusions or justifications; suggested or commented on alternative interpretations or ways of testing the correctness of claims; or practised or commented upon dispositions associated with critical thinking (e.g., scepticism, open-mindedness, requests for grounds for factual claims or value judgements). This dimension also included instances where students or teachers questioned the relevance of a claim or expressed the importance of a critical attitude.

These two foci of analysis included descriptions of the tasks and scaffolding that are used in the identified situations and practices. Student participation in such situations was also noted. This inclusion enabled a discussion of design principles informed by challenges and successes in scaffolding students to acquire the kind of practices that are the focus of this study.

Finally, to judge the extent to which the projects supported social justice through providing experiences and insight into the construction of evidence-based arguments, three interlinked key aspects of democratic science education were examined. First, do the students bring their own perspectives and express their own views in discussions and reports? Second, do they use their voices and knowledge to construct their own arguments and critiques? Third, are students experiencing a supporting and caring community enabling all students to participate in activities?

Based on a comparison of results of the analyses along the described dimensions and the characteristics of the projects, a set of tentative design principles was identified.

10.4 Findings from the Cress Project

At the outset of the Cress project, the students were informed that they would learn more about NOS and how scientific claims are made. They were told that they would make a practical inquiry, formulate clear questions and plans, make detailed observations, and use those observations to formulate a concluding claim. As the teaching unfolded, this author and the teachers decided to focus on critical thinking as an important aspect of scientific practice. The final learning goals stated that students should learn the following:

- The nature of scientific research questions.
- The importance of identifying and controlling variables, nonbiased and systematic observation.
- How concluding claims need to be consistent with observations and results.
- How the introduction, method, results, and discussion (IMRaD)-structure of scientific reports and its strict division between empirical results and final claims enables critical inspection of a study.

The central pedagogical idea of the Cress project was to use students' experiences from different phases of the practical inquiry as starting points for discussions and mini-lectures on elements of NOS. Typically, each lesson started with a class dialogue on experiences from the previous lesson that sought to highlight students' reflections and articulate answers on NOS-related questions. Tasks and scaffolding were designed to guide students to use relevant practices, formulate their own ideas, and discuss interpretations of elements of NOS.

10.4.1 Practices that Reflect Ideas About NOS

The first lesson sought to engage students and provide an introduction to a body of ideas. The key idea was that in science, studies need to be designed carefully in order to make concluding claims reliable. Students were shown a provocative claim from a scientific study: ‘If you sleep less than 7–8 hours each night you are more likely to get a cold’. Following a short class discussion, students worked in small groups on the following prompts: ‘Might this claim be correct? How should researchers have conducted their work for us to trust what they find out? Suggest some ideas!” The students had relevant ideas that were shared and written on the blackboard. The methods that were used by the researchers were then revealed and discussed in the class. This process signalled that students’ ideas were valued, and provided students at all levels of abilities a reservoir of ideas for subsequent discussions and design of methods.

Students began to design their own methods of inquiry based on these introductory activities and a template. The students had the freedom to choose chemicals according to their interest. They brought substances like nail polish remover, engine oil, and dish soap to the classroom, and decided how to check whether these would harm cress plants. As an introduction to the planning phase, the teacher led a discussion about the importance of testing hypothesis about toxicity before making claims.

During the Cress project, the students experienced discussions of observations and how observations do not speak for themselves, but need to be interpreted. Before the students began to run their experiments, the teacher initiated a class discussion on whether some observations were possible, such as if the engine oil was toxic. Many students said ‘no’, many said ‘yes’, and there was a discussion over ‘Why [the plant] might have become withered?’ In the next lesson, before students went to observe the effects of their treatments, the teacher picked up again on that issue by asking ‘Will you be able to observe whether your chemical is dangerous?’ Student comments ranged from ‘No!’ to ‘We might have given too small doses’ and ‘It might have got too little water’.

All the groups planned to use different amounts of their chosen chemical on the cress plants. This made the details of the inquiry methods different. In both classes, at least one group had the idea of leaving some pots untreated by chemicals as control, and this idea spread to most of the other groups and became implemented in their plans.

In the last lesson on the project, the concepts of variables and control was introduced and discussed in relation to students’ experiences. The teacher invited students to discuss ‘What could possibly vary in these inquiries?’ Students’ contributions resulted in the following list being written on the blackboard: ‘[Different] substances, amounts of the chemical, mixes of chemicals, amounts of watering, ways to add the chemical, numbers of cress plant, treatment times, light.’ The teacher added the word ‘Variables’ as a heading for the list. The students were then asked to indicate the strategies their group had used to make sure that only the chemical was responsible for the withered plants. Next, the teacher conducted a discussion on the value of using control plants.

In several reports, students commented explicitly on how the use of control plants enabled comparison. The group that tested dish soap stated, ‘We have several cress pots, some with ordinary water and some with dish soap. Then we can see the difference.’

About half of the 15 reports made comments indicating awareness of the value of controlling variables, as in the following example: 'After [treatment was added] they got a bit of water in order not to dry out. We gave them exactly the same amount.'

A final activity stimulated students to reflect on their resulting insights about how to ensure quality of methods and reasoning when using inquiry to produce scientific claims. The students were asked to work in pairs and 'write down four things we need to take into account when investigating a research question'. The 37 responses in one of the classes included the following: 'Have a good plan, thorough method', 'They must vary a lot to see what really affects the plant', 'They observe, one must observe only what is being measured', 'Accurate observation, orderly table', 'Discuss the reasons why this happened'. Each group shared two responses in class, which were written under the appropriate heading on the blackboard (introduction, method, results, and discussion) to support a final class discussion.

The end-of-chapter test included questions about observations, such as 'Why do researchers first write down exactly what they see, and then ask how it might be explained'. In their answers, 22 of 44 students explained that there might be other causes from the one anticipated. Some answers were detailed while others were simpler, as the following two examples illustrate:

> Because then you can decide for yourself if the conclusion is true. You can see how it might fit the hypothesis and whether you will believe it because they explain how they have achieved the results and what they have seen.
>
> It's important that they first write down what they saw, so they did not forget it. And then they can begin to find an explanation and compare.

Seven students gave answers that were not relevant to the question.

10.4.2 Practising Argumentation and Critical Thinking

Students practised scientific argumentation and critical thinking when drafting experimental plans and reports, taking the end-of-chapter test, and in responses to oral and written tasks. Twelve of the 16 experimental plans included the key practice of using the control group to make fair tests. Ten experimental plans also included one or more arguments about qualities or potentially weak aspects of their method. The following is an excerpt from a plan that included both (text from the template in italics):

> *Suggested method:* Different dosage of diesel. Two plants with one drop, two plants with 4 drops of diesel, two plants with 7 drops of diesel and two with a lot of diesel and finally one without diesel to enable comparison. *We will observe:* Does it wither, change colour or become smaller or larger. *The method may be unreliable because*: If we had had too much diesel it could have been drowned because of shortage of oxygen.

All the groups made a plan, started their own experiment, logged observations, and wrote a report. As illustrated by the following example, all reports included a discussion (counting between seven and 181 words) with a justified claim about the harmfulness of the tested chemical:

> In our opinion the answer is that plants do not tolerate juice because the juice has substances that the plant cannot withstand. The observation supported us because the plants withered and we thought the plants do not tolerate the juices. We are sure that this answer is correct because the cress withered and then we have something that can prove that the plants didn't withstand juice.

The structure and logic of the scientific reports, i.e., providing a claim backed by observations and a sound method, were discussed several times during the project. All 15 reports separated results from inferences in the discussion. All but one of the reports made explicit reference to empirical results that supported the concluding claim. None of the conclusions in the reports were judged to be unacceptable. Seven reports demonstrated open-mindedness by stating a different conclusion from the one hypothesised, as in the following example: 'We don't think that charcoal lighter fluid is very dangerous for plants. This we believe because only those plants that received very much fluid [sic] were clearly injured.'

Six of the students' reports included eight examples of creative critical thinking by identifying possible weaknesses in methods, alternative interpretations, or additional tests, as in the following example:

> To make sure they [the cress plants] were really dead, we gave them some water to see if they become fresh and alive again, but that did not happen and therefore we believe that petrol is very harmful to plants.

In the end-of-chapter test, eight students suggested possible reasons why their conclusion might be wrong, including issues related to quality of observations, control of independent variables, and the doses used in the treatment.

10.4.3 Ownership and Critical Science Agency

The analysis above reveals that all groups of students picked a chemical of their own interest, made experimental plans and reports, and constructed a concluding argument backed by their own observations. Within the common general questions, students formulated their own research question, hypothesis, and interpretations. This suggests that students brought some of their own interests and perspectives, although within the constraints set by the project. These findings also show that the students took the fictive context seriously. According to the teacher, most students showed more interest in the writing of the reports than he had seen before, and many groups were actively discussing as they were writing. This indicates that the context involving an environmental concern and the issue of trustworthiness of claims was meaningful for most students, resulting in a situation where argumentation and critical evaluations became natural.

This conclusion is also supported by comments made by the students in a rubric the students were asked to complete to evaluate the project. All groups used word like *fun, interesting, exciting,* or *worked fine* in their comments. Five groups added a comment reflecting the environmental focus of the context of the project. For example, one group commented that 'It was very interesting to work with this. It was very disappointing that environmentally friendly gasoline is not so environmentally friendly.'

Throughout the Cress project students were challenged to discuss in small groups and share their own ideas in class, and often these were written on the blackboard. Such sharing implies valuing of students' ideas. Also, students' ideas were not assessed but used by the teacher as starting points for presenting ideas about NOS. As this sharing and valuing of students' ideas was related to their inquiry projects, it also implied an establishing of an epistemic culture in the classroom where students' epistemic agency was practised and valued.

The use of group discussion and sharing of ideas also implied scaffolding the development of ideas needed to create experimental plan and understand key points of NOS. Most pairs of students contributed in class with ideas as part of think-pair-share activities, and all groups designed an experiment and logged observations. However, fewer students contributed with comments in class discussions that focused on conceptual knowledge. Key points related to NOS and critical evaluation of ideas was in focus in several activities and discussions throughout the project. This repetitive focus probably contributed to positive results at the end-of-chapter test. The teacher did not include activities that stimulated reflections based on examples of critical thinking in students' plans or reports.

To support learning and mastery for all, the overall research question for the project, 'What chemicals might impact the growth of plants?', was deliberately designed to allow for inquiry projects at many levels of complexity. When students were asked to make a research question, design a method using the provided cress plants, do the experiment, and write a report, they solved these challenges differently. An easy solution designed by one group was to put the chosen chemical on some plants and see what happened. Other students used different doses of their chemical on different plants and used each dose on a minimum of two plants for increased reliability, and some additional untreated plants for control. One of these groups also wanted to check the conditions where the plants were stored between lessons, to ensure equal light conditions for all plants. This freedom in complexity of methodology, combined with different types of scaffolding, probably explains why all groups managed to produce plans, experiments, evidenced-based claims, and reports. Thus all students had experiences enabling them to participation in discussions.

10.5 Findings from the Energy Project

The specific learning goals identified for the Energy project included the following:

- Experience how to back up claims with facts and clear reasoning so that those claims are not criticised or ignored.
- Practice the ability to collect the necessary facts, build a model to compare measures in a structured way, and put forward a fact-based argument.
- Understand how energy can be used as a common yardstick for comparison across different contexts.
- Understand the concept of energy consumption per passenger kilometres, and use this concept for fair comparisons.

The project also emphasised how to help the students gain insight on how a report is structured, why the method is explained in scientific reports, and why the results and discussion of those results are presented in separate sections. The purpose was to provide an introductory awareness of the use of environmental impact assessments reports in management and how these might be used to find and critique arguments that relate to issues of interest.

The central elements of the pedagogical thinking behind the Energy project were to engage students, provide for the sharing of ideas, and support continuous improvement of ideas. A real-life context and a driving question were designed to engage students and to allow all groups to develop their own specific research question and method of inquiry.

10.5.1 Practices that Reflect Ideas About NOS

In the Energy project, discussions of aspects of NOS were restricted to ideas that were embedded in the structure and logic of scientific reports and characteristics of scientific methodological thinking. The different sections of a report were presented as the project developed, and examples from students' tentative descriptions of methods, results, and discussions were shared and discussed. During model development and the writing of final reports, students in the Energy project were challenged to explicitly articulate their methods. The following extract from a report is a typical example of how the students did this.

> The method we used was comparison. We mostly compared numbers in [kilowatt hours] Kwh. What we compared was the difference in figures between car and light rail. How did we do that? We first found out how many people took the light rail. If they had not taken the light rail they had most probably driven a car. Then we found out how many percent (%) of those who would have taken a bus (2100), electric car (990), diesel car (5614), petrol car (4400), and so vi multiplied with 1.4. 1.4 is average number of persons in a car.

When discussing how to explicate methods, the teacher explained how the method supports an implicit claim about the quality of data presented and enables criticism of possible weak points. In discussions following presentations of reports, the teacher often challenged the rest of the class to comment, thus stimulating students to apply their developing ideas about the characteristics of scientific reports:

> *Teacher*: What makes this a good research report?
> *Student 1*: There's a lot of order, so we can see where the introduction is and where the method is, and.
> *Student 2*: They have explained very good what they want to investigate and how they did it. And, very well explained, and also they explain at the end, eh, what they could conclude, in a way.

All group reports explicated methods, separated data and interpretations, and formulated an evidence-based argument in the concluding discussion. However, explanations for these practices were not explicitly articulated by students during discussions or presentations.

Although students were not challenged to articulate their understanding of NOS, students were challenged to explain the difference between methods and results, and between results and concluding claims.

The importance of argumentation, quantification, correctness, and explanation of assumptions was discussed on several occasions. As illustrated in the following dialogue, the teachers repeatedly explained how scientific arguments needed to be convincing.

> *Teacher*: If you want to compare, you may want to have some numbers to compare. Just saying 'a bit much', and 'a little more', makes it difficult to compare, in a way. *Student*: Should we make an average, kind of? *Teacher*: ... The question is, in a way, how may I know that what you claim is correct? You have to make it convincing. *(The discussion goes on)*

The idea of fair comparison often came up when teachers supervised groups. Upon being asked by the teacher what they had found so far, the students in one group stated 'It takes nine times as much energy with the city rail.' The teacher then asked if they have thought about the number of passengers. One student replied, 'Yes, so there are many more who take it, right'. Figures were given in energy per person in the final report of this group.

The key NOS idea exemplified here, the importance of designing one's methods in ways that makes the results and conclusion reliable and robust against criticism, was a recurrent theme in discussions.

10.5.2 Practising Argumentation and Critical Thinking

Evidence-based argumentation was evident during supervision of groups and in all reports. Such argumentation ranged from short statements to more elaborate discussions, as the following two examples indicate:

> *From conclusion in report from group two*: It is better to use the light rail lane, and not cars, because the light lane uses only 0.62 kWh per person from Lagunen to Flesland, while the car (petrol car) uses about 3.2 kWh on the same stretch.

> *From conclusion in report from group seven*: Our evaluations are, that when you drive a car in and out of the city, you spend a lot less than the light rail use, but if you think about it, the light rail is actually better because it carries 212 passengers and a car max 5. Early in the morning there are only 1 max 2 in the car while in the light rail there are maybe 70 people, so in the long run the light rail is much better than cars. It uses a lot more kwh than a car but also it carries many more.

Throughout the project, the teachers reminded students of the need to use correct facts to justify claims:

> *Student:* The light rail uses more energy than cars.
> *Teacher:* In order to justify that claim, you need figures.

The video data and written reports made it evident that critical discussions during the project typically involved practical reasoning, fact-based argumentation, and critical discussion of figures used by peers.

The practical reasoning was characterised by students using their everyday knowledge about energy, environmental issues, and transport-related needs to make arguments, as exemplified in the following excerpt from an early discussion in group 2:

> *Student 1*: We could still just use cars [and not build light rail] and build a lot of bicycle and car roads. *Student 3*: But then we will be using more and more energy. *Student 1*: But think about the fact that more and more people use electric cars. *Student 3*: But think also of what kind of source the energy is from. *Student 2*:

> Hydropower? *Student 3*: And? ... *Student 1*: We do not have enough hydro power if all the cars are going to use it. *(Continuous discussion about hydropower, coal, and wind energy from Denmark)*

This excerpt also exemplifies how critical discussions sometimes involved the critical skill of considering alternatives.

Their fact-based argumentation typically included figures about travelling distances and energy consumption of different types of vehicles. These critical discussion of figures included an example of a group being asked by a peer to explain a figure for the number of cars travelling a stretch every day: 'How can there be 2.5 million cars on that road when there are 5 million cars in all of Norway?'. This critical question focusing on a possible inconsistency was resolved when it was explained that the first figure concerned the number of cars passing a counter during the preceding year.

Following the presentation by another group, a question was raised about their use of the figure of 212 seats in the light rail as a basis for calculating energy consumption per passenger. Some students remembered that the light rail was said to often be very full, while others had read that it had 217 passengers on average. One student pointed out that not all passengers take the rail the entire route. The teacher stated 'It's very good you are so awake'. She summarised by highlighting the importance of stating the figures and assumptions used, and that assumptions need to be checked when comparing reports.

Critical discussions among students were most often observed when teachers contacted groups. Typically, the teacher asked for an update and then asked a challenging question, which led to a discussion. Some of these discussions were also initiated by students.

10.5.3 Ownership and Critical Science Agency

In the Energy project, all student groups formulated different research questions and methods of comparison. For example, two groups calculated energy consumption for each person who travelled a certain distance by light rail and by car. The consumption rates were then compared, considering statistics on the number of persons in cars and light rail at a comparable distance. Another group included energy costs of the materials used in construction and CO_2 emissions involved. Yet another group found statistics on types of preferred transport and calculated how many people would use the new light rail. The group also calculated the distance the light rail had to go before the energy construction costs were lower than the energy saved by shifting from cars to light rail. The groups' concluding arguments also varied. While some focused on energy costs only, other groups emphasised other aspects, e.g., that 'We don't think the light rail is needed, as there are buses on that stretch already'. The teachers' positive comments to all groups during supervision and presentations signalled to the students that their diverse perspectives were valued.

The diversity of research question and methods suggest that students made choices based on their own perspectives and competence levels. On several occasions students continued working in the classroom after lessons had ended, and the two teachers commented that the students' engagement was higher than normal. This indicates that the context involving a local topical issue and the focus making trustworthy reports to inform politicians was meaningful for many students, resulting in a situation where argumentation and critical thinking became natural.

On several occasions, the teachers stated that the students were supposed to come up with ideas, find facts, find ways to do relevant calculations, and construct their own conclusions:

> You will come up with ideas on whether city railways are smarter than cars. How might we find out? There are many ways, you should develop your own ideas, develop a method, compare with and without the city rail.

The teachers did not evaluate students' ideas or indicate that there were correct forms of thinking. Instead, the teachers facilitated sharing and mutual evaluation of ideas. One example is how the teacher structured an introductory task: 'Work in groups for 6 minutes: Make suggestions as to what might affect how much energy it costs to carry people by car and by city rail.' After 6 minutes, the teacher called for attention and stated 'I want one idea from each group!' She noted ideas on the blackboard for easier sharing among groups. She wrote two headings on the blackboard, 'Road' and 'Light rail', to enable structured comparison of the ideas.

These teacher practices implied valuing and support of students' ideas and funds of knowledge. A reoccurring activity in the Energy project was the mutual evaluation of students' ideas and critical discussions related to their inquiry projects. These practices constituted an epistemic culture in the classroom where students' epistemic agency was stimulated and practised. Together with several introductory tasks and the simple template for the report, this implied scaffolding of students' practices and learning opportunities for all students.

Throughout the project, the teachers signalled trust in students' ability to practice agency:

> *Teacher:* Now we share ideas. No expectations about finished ideas, but start sharing. Can you start, group two?
> *Student*: We talked about where the power comes from. That the power must come from a source with no pollution.

Typically, teachers would follow up with remarks such as 'Any comments or questions to this group? Any ideas for you to take on-board?'

During the final presentations of reports, the teachers expressed trust in students' abilities to construct a model and a justified conclusion: 'Speak louder, Marit, because what you're saying is smart, so just go for it!'

The use of scaffolding and signals of trust in students' abilities suggested a caring and supportive learning culture in the classroom. Although at different levels of complexity, all groups constructed models, made calculations, and wrote justified conclusions. The presentations and the students' written self-evaluations indicate that the project was an experience in mastery for all groups and for most students. One of the teachers summarised the evaluations by teachers from all the classes as follows:

> The teachers express that they would like to have this project again. The students learned a lot, new concepts, collaboration, and mastered things they did not think they could handle.

10.6 Didactic Principles for Teaching for Robust Argumentation and Critical Thinking

The two projects reveal that it is possible to design science projects for students to practice ownership and use their growing insights in NOS to construct and present arguments and carry out critical thinking. Although this is not a sufficient basis for establishing design principles, it is possible to use the two projects to identify design principles to be used as working hypotheses for further exploration.

Both projects included a social context, and the tasks were designed to have some relevance for participation in such contexts. Moreover, students could make personal choices and engage with issues within their own interests and abilities. Thus, the tasks and situations bear a resemblance to real-life situations for students engaged in issues and discussions where evidence-based arguments are relevant. Differences in opinions on such issues might trigger argumentation from diverse fields of knowledge. However, a focus on trustworthiness of evidence-based arguments can make science, NOS, and critical thinking relevant. The following three design elements are therefore suggested as important to the development of social relevance and student ownership, which are in turn necessary for the motivation and engagement needed for lasting participation in classroom activities:

1. Identify a real-life context that might be meaningful to the students and includes evidence-based arguments with potentially disputed trustworthiness to trigger students' engagement.
2. Design situations where trustworthiness is at stake to give students a natural need to construct evidence-based arguments and to inspect all arguments critically.
3. To enable ownership, mastery, and autonomy for all students, design driving questions and scaffolding tasks which can be interpreted to any level of complexity and adapted by the students to their interests and abilities.

School teaching always aims to support students' competency development. Science teaching for social justice must therefore support intended learning while allowing for ownership and activities that resemble real-life situations. The students involved in the cress and the energy projects have gained introductory insights into NOS and critical thinking as well as experiences in using such insights in their own projects. This indicates that the projects to some extent enabled planned learning while involving the students in practices that resembled real-life activities.

The Cress and the Energy project had few and interlinked learning goals. Moreover, teachers used tasks, presentations, and discussions to challenge students to create, share, and improve ideas and to repeat key ideas and practices. The following three design elements are suggested for their contribution to intended learning through active knowledge construction in science classrooms that are characterised by real-life context and student autonomy:

4. Formulate learning goals which are interlinked, manageable, and represent aspects of NOS and critical thinking that are relevant for evaluating the robustness of arguments.
5. Cultivate an epistemic culture in the classroom that resembles epistemic values in science: all students have a legitimate voice, all ideas are welcomed and explored, and the goal is the evaluation and improvement of ideas.

6. Students repeatedly encounter important ideas and situations to support their development of deep understanding and new knowledge-based habits.

The six principles are not meant for inquiry-based teaching in general, but more specifically for guiding teaching aimed at increasing all students' capacity to construct robust evidence-based arguments, with the ultimate aim of promoting social justice.

10.7 Discussion

This chapter analysed two science projects where students constructed evidence-based arguments related to a real-life issue. The analysis revealed that all student groups constructed arguments and that many students participated in critical discussions of observations, figures, or arguments. Moreover, students participated in practices reflecting key aspects of NOS and focused on the reliability of scientific practices and arguments.

The analysis of students' practices and written reports in the Cress project revealed that the students expressed awareness of the difference between observations and possible inferences and articulated a range of ideas related to scientific methods. In the end-of-chapter test, half of the students applied the distinction between observations and inferences. Furthermore, in their scientifically structured reports, all groups communicated evidence-based arguments. The students also discussed, designed, and implemented methods, tested hypotheses, interpreted data, and made use of, and discussed, the concepts of variables and the control of variables.

In the Energy project, all groups distinguished between data and inference in their reports and communicated evidence-based arguments. The students also discussed, designed, articulated, and implemented their own methods. Several students formulated differences between methods, results, and concluding claims in their own words. Moreover, students participated in discussions about the importance and characteristics of scientific argumentation, the argumentative structure of scientific reports, fair comparison, articulation of assumptions, and the importance of checking information for correctness.

In the two projects, students experienced how using elements of NOS, such as basing arguments on evidence, separating results and inferences, and using their own creativity and thinking when developing methods and inferences, resulted in quality arguments. Moreover, the use of control plants in the Cress project and evidence-based calculations in the Energy project provided an experience of how to make arguments less susceptible to criticisms. Consequently, the two projects showed the students how an awareness of the elements of NOS supports the construction of defensible evidence-based arguments. Increasing students' ability to construct such arguments might enable more students to provide robust support for own views in issues of interest. This suggests that awareness of NOS in the context of argument construction might have a role in supporting social justice.

Practices involved in the two projects were compared with Basu and Barton's (2010) model for inclusive science teaching aimed at empowering all students to use science in accordance with their own needs. Within the chosen contexts, students constructed arguments based on their own perspectives and choices. Their ideas, perspectives, and knowledge were valued, and they experienced support and opportunities to learn.

The present study expands Basu and Barton's model by including characteristics of science teaching that empower students to construct and critique evidence-based arguments related to real-life issues. These characteristics are formulated in a set of six didactical principles. In their model, in order to promote social justice, science teaching needs to ensure access to science for all students and enable the use of science for students' own purposes. Our results imply the possibility of specifying their concept of 'critical science agency', i.e., opportunities for students to engage with science in accordance with their own perspectives, to include opportunities for students to use science in class to construct evidence-based arguments in accordance with their own needs. Moreover, the importance of empowering students to be able to construct robust arguments related to issues of interest implies that epistemological autonomy is an important practice in science class. An explication of this aspect involves a specification of the key element of 'shared authority' in their model.

It is likely that increased insights into issues of reliability will enhance students' ability to construct robust evidence-based arguments. As reliability is a main concern in science, scientific practice has developed appropriate methods, values, and ways of thinking. In the two science projects analysed, key elements of NOS were dominant in one and less prominent in the other. The Energy project had less emphasis on increasing students' ability to explicate key elements of NOS. The development of students' epistemic habits might gain from explicit attention to relevant elements of NOS (Lederman, 2007). At the same time, experience with critiques of evidence-based arguments and discussions of how to make arguments more robust is probably necessary. Autonomous application of abstract tenets of NOS is demanding and needs to be developed through experiential learning. The present study indicates that a combined focus on NOS and critical thinking might help to create classroom environments where students' construction of evidence-based arguments is guided by key ideas about NOS and critical thinking. However, more research seems needed to understand how NOS should be included to support the development of students' abilities to construct robust arguments.

A basic assumption in this study is that science teaching for social justice requires the development of all students' abilities to construct robust evidence-based arguments. The analyses of the Cress project and the Energy project indicate that insights into NOS and scientific practices involving critical thinking might support students in constructing such arguments, thus supporting social justice. However, the ultimate aim is students' autonomous construction of arguments in issues related to their own interests outside school. This probably presupposes trust in their own abilities to inquire into issues and construct evidence-based arguments that are robust to some extent. Consequently, critical science agency does not only depend on the students' scientific knowledge and desire to learn. It also depends on the student's trust in their own abilities to construct knowledge claims and critical comments that are based on their inquiries into issues of concern. As self-efficacy refers to a person's belief that he or she can do what is necessary to successfully achieve a specific goal or task (Bandura, 1997), this might be denoted as *epistemic self-efficacy*. In addition to psychological and affective states, self-efficacy is influenced by mastery experience, observing others' experiences, and social support and feedback (Bandura, 1997). This implies that experience is necessary, but might prove insufficient if this is unsuccessful. An emphasis on mastery for all, sharing and discussions between groups, and a supporting and caring teacher thus seems paramount.

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