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Stein Dankert Kolstø [a]
[a] University of Bergen , Norway
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RESEARCH REPORT

Patterns in Students' Argumentation Confronted with a Risk-focused Socio-scientific Issue

Stein Dankert Kolstø*
University of Bergen, Norway

This paper reports a qualitative study on students' informal reasoning on a controversial socio-scientific issue. Twenty-two students from four science classes in Norway were interviewed about the local construction of new power lines and the possible increased risk of childhood leukaemia. The focus in the study is on what arguments the students employ when asked about their decision-making and the interplay between knowledge and personal values. Five different types of main arguments are identified: *the relative risk argument, the precautionary argument, the uncertainty argument, the small risk argument,* and *the pros and cons argument*. These arguments are presented through case studies, and crucial information and values are identified for each argument. The students made use of a range of both scientific and non-scientific knowledge. The findings are discussed in relation to possible consequences for teaching models aimed at increasing students' ability to make thoughtful decisions on socio-scientific issues.

Introduction

Today's society is continuously confronted with socio-scientific controversies related to health and environment. Several major educational organizations have argued that scientific literacy includes the ability to make knowledge-based decisions on such issues (AAAS, 1989; NRC, 1996; OECD, 1999; Royal Society, 1985). The need and relevance of emphasizing decision-making in science teaching has also been argued by several science educators in recent decades (Aikenhead, 1985; Millar & Osborne, 1998; Osborne, 1997; Zeidler, Sadler, Simmons, & Howes, 2004).

As a response, several teaching models for thoughtful decision-making to be used in the science classroom have been proposed (Aikenhead, 1985; Fullick & Ratcliffe, 1996; Geddis, 1991; Kolstø, 2000; Kortland, 1996; Ratcliffe, 1996a; Simonneaux,

*Department of Physics and Technology, University of Bergen, Bergen, Norway. Email: kolstoe@ift.uib.no

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2001). Teaching socio-scientific issues also involves developing students' willingness to reflect critically on their own values and stance (Oulton, Dillon, & Grace, 2004) and consider a range of information and viewpoints (Aikenhead, 1985). However, the development of curricula involving these aims need to build on knowledge of what currently characterizes students' reflections and arguments related to their decision-making on socio-scientific issues.

The research reported here was initiated to meet this need for more insight into students' ways of using values and different types of knowledge in their argumentation and decision-making. To gain in-depth knowledge a qualitative study was designed in which a selection of students were interviewed about their decision-making on a specific controversy. The controversy was the question of whether overhead power transmission lines should be allowed to be built across residential areas. A central problem in this issue is that some studies have reported a possible increased risk for leukaemia among children living close to such lines (Kolstø, 2001).

Socio-scientific issues often involve expert disagreement on central scientific questions, such as the existence or size of a risk to human health or the environment. In such issues the *student*, and the citizen in general, is confronted with two main questions. First, there is the ethical, personal, or social question related to what scenario to prefer or what actions to take. Second, the decision-maker might need to make a decision on the scientific question involved. In the present study, one part of the issue was concerned with the *political question* of whether to put the lines underground or not. But the issue also involved the question of how to judge a disputed scientific claim. This was the *risk question* on whether there is a risk or not associated with magnetic fields from power transmission lines. In this study the students' arguments and decisions on the ethical/political question is focused on. The students' ways of dealing with the scientific question involved, whether there is a risk involved not, is reported elsewhere (Kolstø, 2003).

Prior Studies on Students' Patterns of Informal Reasoning

There have been several studies within science education on characteristics of students' decision-making on socio-scientific issues, most of them focusing on the role of scientific knowledge in the students' reasoning. In one study (Flemming, 1986a, b) it was found that students used their knowledge of the social world when analysing socio-scientific issues and only rarely used their knowledge of the physical world. Analysing 17-year-old students' discussion of science-based social issues, Solomon (1992) found that evidence of scientific knowledge tended to be absent. However, a simple familiarity with elementary scientific terms nevertheless underpinned and made the discussion work possible. From a discussion about burning of recycled liquid fuel in cement kilns, Tytler, Duggan, and Gott (2001) identified three types of evidence to be used by the participants: scientific, informal, and wider issues related to the framing of the issue. Based on interviews of senior high school students about nuclear energy use, Yang and Anderson (2003) identified three

different groups of students based on their information preference: scientifically oriented, socially oriented, and equally disposed. Zohar and Nemet (2002) found in their study that, following an instruction unit in genetics, 33 out of 66 students referred to (correct) biological knowledge when constructing arguments in the context of dilemmas in genetics. Finally, Simonneaux (2001) identified economics, ecology, genetics, science, medicine, politics, and ethics as disciplinary fields called upon by students in support of opinions on issues involving animal transgenesis. The current study adds to this body of research by identifying information involved in different kinds of arguments put forward by students during decision-making.

The study by Simonneaux (2001) also analysed, in terms of the "orders of importance" attached to the different arguments, the values supporting students' arguments. A focus on values was also included in two studies by Ratcliffe (1996a, b). She identified values and criteria articulated by students working with structured decision-making tasks on different issues with a science dimension. A third study focusing on the value dimension is by Sadler and Zeidler (2004). They found a tendency for a group of students to construe genetic engineering issues as moral problems. However, none of these three studies sought to identify patterns describing the interplay between information and values. In an analysis of interviews with students about genetic engineering dilemmas, Sadler and Zeidler (2005) identified three patterns characterizing student decision-making: rationalistic, emotive, and intuitive informal reasoning. However, they differed between reasoning where students made rationalistic calculations based on available information, where empathy and concern for the well-being of others guided decisions, and where reasoning was restricted to a "gut-level" reaction or feeling. The present study is based on the view that decisions on ethical/political issues are based on arguments involving both information and values/empathies/sympathies. Consequently, the present study represents an alternative way of studying students' decision-making patterns on socio-scientific issues.

Decision-making on Socio-scientific Issues

The focus in this study is on students' patterns of informal reasoning in a decision-making situation. The decision-making context is characterized by uncertainty regarding the outcome of alternative actions, in specific regarding the risk for leukaemia. It is a real-world issue where the problem is unstructured. The situation demands a collective decision, and the potential negative and positive consequences affect others and not, in the foreseeable future, the students themselves. It is also important to be aware that the decision which the issue demands is not a factual one where formal logic might provide a correct answer. The decision demands the use of personal values to weigh between different scenarios that involve both pros and cons. In a context with these characteristics, the students were interviewed about their personal opinion on the socio-scientific issue.

Psychological research within judgement and decision has traditionally employed formal models (Jungermann, 1986; Kuhn, 1991). The basic idea in these theories is to assign a numerical value representing the decision-makers' expected utility to all

possible scenarios or outcomes. Choice is characterized as maximization of value (utility) and this is done by purely mathematical means. The models imply normative claims about how to reason about interrelated values (assign weight measured in utility and multiply with probability, calculate total utility for each alternative, and chose the one with maximal utility). These formal models (e.g., expected utility theory and subjective utility theory) have been employed as normative models for rational decision-making. Empirical research within this tradition has been experimental and based on tasks with structured problems. The main findings have been of deficiencies in peoples' reasoning when compared with the normative models. This research tradition has been criticized based on the claim that the formal models are

> difficult to apply in complex, real world decisions, and they often fail to capture significant aspects of people's deliberations. (Shafir, Simonson, & Tversky, 2000 p. 599)

Research on students' decision-making on socio-scientific issues has taken advantage of psychological research about judgement and decision-making. Aikenhead (1985), Kortland (1996) and Ratcliffe (1996a) all suggest the use of structured decision-making models based on formal models when evaluating the quality of students' decision-making. Formal models are often used as prescriptive models for rational decision-making. A disadvantage with such use is that this research tends to result in the identification of deficiencies in peoples' decision-making. Moreover, due to the complex nature of real-world decisions and the assumptions behind formal models (reductionism, no restrictions on time and other resources), this critique of peoples' decision-making might not be appropriate.

An alternative tradition in the study of decision-making, reason-based choice, focuses on people's reasons and arguments (Shafir et al., 2000). This research, which is qualitative in nature but experimental and uses well-defined problems, seeks to understand how people weight different reasons. One finding is, for instance, that people tend to weigh positive reasons more heavily when *choosing* among alternatives and negative reasons more when *rejecting* alternatives (Shafir et al., 2000). The focus on the decision-makers' reasons is shared with the present study. However, in research on reason-based choice the decisions studied are based on problems structured by the researchers and not real-life unstructured issues. As this study focuses on students' argumentation and decision-making confronted with unstructured real-life socio-scientific issues, reason-based choice as an approach was not appropriate here.

Based on an increased interest in human reasoning in real-world unstructured issues, there has been a trend to focus on people's informal reasoning in everyday contexts (Kuhn 1991). The present study is embedded within this tradition. However, the aim of this study is not to gain insight into peoples' reasoning in general, but their reasoning in relation to socio-scientific issues. According to Voss, Perkins, and Segal (1991, preface), informal reasoning is reasoning carried on outside the formal contexts of mathematics and symbolic logic. It involves reasoning about "causes and consequences and about advantages and disadvantages, or pros

and cons, of particular propositions or decision alternatives" (Zohar & Nemet, 2002, p. 38). Consequently, informal reasoning is concerned with arguments outside the domain of formal logic (Voss et al., 1991, preface) (e.g., arguments involved in public debates).

The present study seeks to identify the arguments, scientific or other, that hold a central position in the students' reasoning about their decision on an issue. This involves a focus on the students' *arguments*. A personal opinion or decision on an issue might be based on several arguments and an evaluation of arguments for and against this decision. However, this study will, specifically, seek to identify which argument emerges as crucial for different students' decisions.

Making a break with the traditional focus on formal logic, Toulmin (1958) has presented a general description of the structure arguments in informal reasoning that has gained wide acceptance. In line with Toulmin's definition of an argument, in this study argument was defined as an assertion accompanied by justification (Kuhn, 1991; Toulmin, 1958). Research on students' argumentation in science education has frequently made use of Toulmin's layout of argument. However, within science education, Toulmin's layout has typically been used as a normative standard, in order to evaluate the *quality* of students' argumentation (see, e.g., Driver, Newton, & Osborne, 2000; Erduran, Simon, & Osborne, 2004; Kelly & Takao, 2002; Osborne, Erduran, & Simon, 2004; Watson, 2004; Zeidler, Osborne, Erduran, Simon, & Monk, 2003). In this study the focus is on *patterns* in students' argumentation and decision-making. Thus the main aim is purely descriptive, although I do discuss the different patterns identified from a more normative perspective in the discussion.

In this study the students evaluated facts and opinions, drawing conclusions about the desirability of different actions. When analysing a decision about what *ought* to be done, it is important to be aware the observation articulated by the philosopher David Hume (Baier, 1998)—that a normative conclusion cannot be deduced from purely descriptive or factual premises. The students' arguments for their normative policy decisions therefore involve appeals to personal or generally accepted values that justify their arguments. In line with this reasoning, the concept of values was defined in this study as those ideas a person appeals to as criteria or warrants when judging the desirability of a certain action or conclusion (Kolstø, 2005).

In order to identify the students' arguments or reasons, a simplified version of Toulmin's (1958) layout of argument was employed. Toulmin uses six elements within an argument: claim, data, warrant, backing, qualifiers, and rebuttals. In this study the focus is on the claim (what ought to be done), the data, and the warrants proposed by the students. According to Toulmin (1958), these are the three elements that constitute an argument as such. As the focus is on policy decisions, the claim is interpreted as the student's decision or personal opinion on the issue discussed. Data are evidence or facts (as viewed by the arguer) appealed to in support of the decision. Identification of data implies explication on what information or knowledge the students consider relevant for their evaluation and decision. Warrants are the reasons, values, rules, or principles employed to justify the connection between data and

claims. According to Toulmin, "data are appealed to explicitly, warrants implicitly" (1958, p. 100). Consequently, warrants reveal the unspoken beliefs and values of the author. In this study the claims involved in the analysis are claims of policy: "What should be done?" (Wood, 2000, p. 160). In such instances, Wood states, both facts and appeals to values and authorities might be used to support the policy claim.

The following example illustrates the use of the theoretical framework in a situation where the student uses a value proof (Wood, 2000) that is, using values as warrants:

> Interviewer: Are you telling me that you thought it was difficult to arrive at an opinion?
> Student: I was not sure, but as long as there is a risk, I think it is reasonable that life itself has to be chosen before money.

In this statement the claim or opinion is that "life itself has to be chosen before money". In the context of the discourse this means that the student thinks it is reasonable that the power lines are made underground in order to reduce the risk for childhood leukaemia, even if the construction costs will be higher. By stating that "there is a risk" (if air-borne lines are used), he provides data or evidence in support of his opinion. The data, "there is a risk", and the claim (which he is not quite sure about)—that the lines ought to be cabled—are linked by the warrant expressing a value: He implicitly states that a health risk involving childhood leukaemia ought to be avoided even if this costs money. Thus, when the values (or criteria) of "avoiding extra costs" and "diminishing the risk for childhood leukaemia" conflict, he chooses the avoidance or diminishing of the health risk. As the values appealed to are only implicitly stated, it is possible to formulate this warrant in different ways. In the example both "risks should be avoided" and "health is more important then money" are possible articulations. However, both formulations point to the order of importance of different values. As a rule the prioritized value will be highlighted in the types of arguments identified.

This student also includes a qualifier: only *as long as* there is a risk, he will have this opinion. However, the focus in this study is on claim (personal decision), data, and warrant, as the aim is to identify patterns describing the interplay between evidence and values in students' argumentation and decision-making.

Power Transmission Lines and Childhood Leukaemia

There have been a range of studies over the past two decades on possible health effects of low-intensity electromagnetic radiation from power transmission lines (Ahlbom & Feychting, 2003). Some studies have found increased risk for the development of childhood leukaemia on residents living near such lines, and these studies have triggered debates on whether one should stop building overhead power transmission lines through residential areas. When the interviews in this study were made, there was no consensus within the scientific community as to whether there is an increased risk or not (Ahlbom & Feychting, 2003). The science involved was therefore non-consensual frontier science.

The "power transmission line issue" was chosen as a focus for this study as it was a topical socio-scientific controversy. The local power company, Bergenhalvøens Kommunale Kraftselskap, situated at the west coast of Norway, had applied for the building of a new power transmission line that passed partly through residential areas. This application had triggered a debate in the local newspapers. There had also been a debate 1 year earlier because of the upgrading of another power transmission line. All students interviewed had heard of the debates, and many of them knew people living rather close to the lines.

In the debate, it was argued that underground cabling provided an alternative to overhead lines. An information brochure made by the power company stated that the magnetic field strength would be weaker if the lines were put underground, but the construction costs would rise considerably (Bergenhalvøens Kommunale Kraftselskap, 1995). The public controversy therefore tended to be a "pro or against overhead lines" debate linked to the question of whether the magnetic fields from the lines could cause childhood leukaemia or not.

Research Design and Analysis

To be able to explore students' ideas in depth, a qualitative methodology was used. The strength of qualitative methodology is that it allows for categories to be developed inductively from data and observations (Eneroth, 1984; Kvale, 1996; Merriam, 1998). In total 22 students (11 girls and 11 boys) from four different districts, schools, and classes were interviewed. To ensure that all students had some basic information of the issue, a preparatory phase was arranged in the four science classes prior to the interviewing. In one science lesson the students were introduced to the issue. In this lesson their science teacher showed them several transparencies with seven copies of newspaper articles and six excerpts from three different research-based reports ordered by politicians. The science teacher read out a short excerpt encircled by a red line from each transparency. The following example was from a local newspaper:

> Power lines might cause childhood leukaemia. Research report establishes that the risk for children to develop leukaemia increases if they live near power lines. "We can expect one additional case of leukaemia every third year among children who lives less then 50 meters from power transmission lines" Professor Harbo says.

There were also three transparencies from the correspondence between a committee of politicians and the applicant for building of the power transmission lines, and one from a folder distributed locally by the power company and containing a quote from a Norwegian researcher. All four science teachers used the same lesson plan and teaching resources. The lesson plan was written in great detail and was adopted by all four teachers. In a second science lesson the students were to discuss the issue in groups of four or five. Each group had to make a decision on the issue and formulate two reasoned arguments and two possible counter-arguments. The transparencies from the first lesson were available in print for each group.

Taped and transcribed group discussions provided the base necessary to select the interviewees. The criteria used to select an interviewee from the four classes were *interest* in relation to the issue together with *variation* in socio-economic background, expressiveness, and opinion. Interest was important because it was anticipated that only students who accepted the chosen socio-scientific controversy as an issue would get their ideas about decision-making and relevance of knowledge triggered. Interest was therefore seen as important to increase the internal validity of the findings (Merriam, 1998, chap. 10). Variation was important to make the findings exhaustive in relation to differences among the students in the four classes. Exhaustive findings increase the potential relevance of the findings for similar contexts, and thus the external validity of the findings (Eneroth, 1984). All respondents were interviewed within 5 days after the preparatory phase.

The preparation phase, where I was present all the time, ensured that the interviewees and I had a common frame of reference. This made it possible for the interviewees to talk within a context they knew the interviewer was aware of. The existence of this common context increases the internal validity of the study as this design made it easier both for the respondents to talk freely and in ordinary (context-bound) language, and for the interviewer to interpret the interviewees' statements in adequate terms.

After the group discussions, and prior to the interviews, the students were asked to tick off on a questionnaire whether they had an opinion in advance, whether they had changed their opinion during the lessons, and what opinion they had after the lessons. Questions about biographic data were also included.

The interviews were semi-structured with ready-made questions. The semi-structured design ensured that all respondents were confronted with a set of main questions. This "common area" across the different interviews was important to raise the reliability of the study. During the interviews, probes were used to invite for clarifications or explanations. In addition, quotations from the discussion in the interviewee's group were sometimes used to contextualize questions. The use of open questions and probes implied an opportunity for the interviewees to introduce unexpected themes and ideas, and was used to strengthen the explorative character of the study.

Several issues were in focus throughout the interviews. The main focus was the respondents' explanation of their opinion on the issue: What were their main arguments? What knowledge did they regard as relevant? What would they like to know more about? What were their personal opinions? There were also questions meant to bring about the students' opinions on how the final decision on the issue should be made. A third focus was the trustworthiness of knowledge claims and different sources of information encountered in the preparatory phase (see Kolstø, 2001). At the outset of each interview the interviewee was told that no information would be handed over to the teacher, that no correct answer existed here, and that I was interested in *their* thoughts about the issue. Importantly, in the preparatory phase the students had been asked to make a decision and to indicate their opinion in the questionnaire. Consequently, the findings presented in this paper are based on

the students' thoughts as these emerge through interviews accomplished *after* they had tried to make their decisions, and not an analysis of the naturalistic or real-time decision-making process.

All interviews were fully transcribed before the structured phase of the analysis. The transcribed interviews were subjected to inductive analysis (Patton, 1991) and imported into the software ATLAS-ti (Muhr, 2003). This software makes it easier to keep track of all emerging codes, quotations, thoughts, and ideas during the analysis. In specific the software makes it easy to retrieve quotations underlying a tentative code or category and thereby facilitating constant comparison between emerging hypothesis and data. The coding of the interviews focused on information somehow mentioned by the students in relation to their decision-making. The analysis differed between specific knowledge claims to which a student implicitly or explicitly related, and topics, knowledge domains, or sources of information that the student indicated a need for or interest in getting more information about. In addition, I also looked for value statements and statement concerning the decision-making process itself. Finally the students' perceptions and views of the potential risk involved were identified together with their personal decision on the political issue.

From the code-and-retrieve process a range of knowledge claims, arguments, topics, and knowledge domains were identified. Single-case findings were then entered into a cross-case data matrix (Miles & Huberman, 1994), which gave an overview enabling the generation of tentative hypothesis regarding differences and similarities between the respondents. Through a closer inspection focusing on the knowledge identified as important to the different students, and also on value statements, risk perceptions, and personal decisions, a set of argumentation patterns were identified. Using the constant comparative method (Strauss & Corbin, 1990), tentative argumentation patterns were tried out against the different interviews and were adjusted several times until the argumentation of each single respondent fitted smoothly into one, and only one, category. As the analysis was based on 22 case studies, each category had to find a resonance in several interviews before being accepted. This "inter-interview" triangulation was done to increase the trustworthiness of the categories developed (Merriam, 1998, chap. 10). The types of arguments identified describes not only information and values emphasized, but also, based on Toulmin's (1958) model of argumentation, how these interact and result in an argumentation-based decision.

It is not possible, from this single cross-case study, to make inferences to students' ways of using knowledge and values in other socio-scientific controversies or other contexts. However, a main characteristic of the "power transmission lines issue" was the controversy around the risk question. This characteristic, which includes lack of consensus within the scientific community, is central in a range of health and environment related issues. The types of arguments identified in this study might therefore have relevance as "working hypotheses" for analysing students' decision-making on risk-focused socio-scientific issues more generally (Merriam, 1998, chap. 10).

I will present the five types of arguments identified in this study by describing the decision-making of five selected students. Each case will serve as a base for the

presentation and discussion of a type of argument. The author has assigned all names on students.

The Relative Risk Argument: The case of Lise

Lise held the view that the power transmission lines could continue to be constructed as overhead lines and she did not have any problems reaching this conclusion:

> Interviewer: Can you tell me something about whether it was difficult or easy to reach a decision?
> Lise: I thought it was easy. I didn't think much about it. I just got that opinion after all the impressions I received.

Her decision was not altered through the group discussion, even though most of the other group members thought the lines ought to be placed underground.

But what knowledge triggered her decision? Throughout the interview Lise emphasized the relevance of specific types of scientific information. Her argumentation centred round the risk question, and she was clear that "if there was a great chance for getting leukaemia from overhead lines, I would have had a different opinion". This point she made several times. Thus her conclusion at first seemed to be based on her view of a risk estimate as she remembered it:

> Interviewer: In general, what do you think one ought to know, concerning power lines and risk of cancer, if other people were to pay attention to ones' opinions?
> Lise: […] As far as I understood, thirty persons get Leukaemia in Norway each year, and only one of these is caused by power transmission lines. And it is very few, it is only one out of 100.000, so it's extremely few that get Leukaemia.

A researcher cited in a leaflet distributed by the construction company reported this research-based risk estimate. But Lise's citation also includes an evaluation of this estimate, saying that one out of 100,000 is *very few*. This evaluation of the risk estimates was used several times in her argumentation, and underlines the importance of scientific information about the risk for her decision-making.

However, a closer look at her argumentation reveals that her decision was not only a simple evaluation of the risk estimates. She was also drawing upon another kind of scientific knowledge; namely, information about the magnetic field strength from power lines and from home equipment:

> Interviewer: What impact do *their* [the committee of politicians] stance against overhead lines through residential areas have on your decision?
> Lise: It has some impact of course, because I think they are a trustworthy agency, but the most important point, which shaped my opinion, was that the radiation was so small.

When asked about what knowledge one ought to have if others were to pay attention to ones' opinions, Lise also replied:

> One ought to know that there are not clear and unambiguous research results on this, and that the researchers argue about the risk question. Then I think one should know that other electric equipment which one voluntarily brings home have greater magnetic radiation, and thus probably have more reason to induce leukaemia than power transmission lines do. I am not sure of this, but I suppose the use of microwave ovens is more carcinogenic than power transmission lines.

This kind of argumentation indicates that, for Lise, small risk meant *relatively* small compared with other risks we accept. This point is supported by her view of those who protested against overhead lines:

> Interviewer: Could you say something about what you learned [in the preparatory phase]?
> Lise: I thought it was a bit too much hypocrisy from people. They made a lot of fuss just for … Well, it might be wrong to say it is a trifle, but still, I don't think it is such a terrible issue worth making a lot of fuss about.

Concerning traditional textbook science she was not sure whether such knowledge was relevant. When asked specifically whether one ought to know the meaning of the words *voltage* and *electric current* she said "yes, I think so, but it's hard to say, I haven't really thought about that in a way". This indicates that knowledge within the science of electricity was not considered important, and this even though this topic had been worked on in science class in the weeks before the interview took place.

In one of the earlier quotations Lise stated that "the researchers argue about the risk question", showing that she also used information about the level of consensus among the researchers. She had the impression that the researchers disagreed, but also that they agreed that if there is a risk, this is below a certain level. As the relative size of the risk was of importance in her decision-making, the information about degree of agreement among the researchers on the risk question was of some relevance to her.

But Lise did not only focus on *scientific* knowledge as relevant for her decision-making. It had been argued by the construction company that the construction price would be much higher if underground cabling was chosen. When asked what the most important arguments to her were, she explicitly mentioned the potential extra costs. In addition Lise also showed some interest in environmental aspects:

> Interviewer: Would it be necessary to know for instance what the opinions of environmental organizations are?
> Lise: Yes of course, for instance the impact on animals and such things. But one thing I have been wondering about is, if you cable the lines, whether this might have an impact on life in the soil.

It seems that for Lise, this aspect of the issue is also an argument for overhead lines to be preferable. She was also asked explicitly what other aspects she possibly would have liked to have more knowledge about before making up her mind.

> I would have liked to know exactly how dangerous the magnetic radiation is, and how this compares to the electrical house equipment which I am accustomed to. (Lise)

Again Lise emphasizes not only scientific information about the risk, but also the *relative* size of the risk. It is worth noticing that Lise only used information from the

scientific knowledge domain in her argumentation, except from information about construction costs.

Decision-making is never only a question of knowledge. It is also value based in one way or other. Lise did not explicitly state any guiding values when explaining her opinion. However, her claim that one additional case each year is "extremely few" is an evaluation that is value-based. She also stated that she would change her opinion if the risk turns out to be "great" (probably compared with electrical house equipment). These evaluations clearly show that values were involved in her decision-making. But in addition there seems to have been a third evaluation involved, one that Lise was not explicit about. There is no direct logical link between "relatively low radiation and risk" and "not worth the additional costs". To establish the link one has to add that cost-effectiveness is desirable. This is a value standpoint, and we will see that not all the interviewees share this point of view.

The Relative Risk Argument for Overhead Lines

A main problem that the students were facing was how to weigh between health and other values when the risk was uncertain. The main characteristics of the case of Lise discussed earlier were shared with three boys and one girl (five in total including Lise) of the other students in this study. These characteristic common aspects constitute an argument denoted as *the relative risk argument*.

Students using this type of argument focused on scientific information about the *relative* strength of the magnetic field and the *relative* size of the possible risk (compared with magnetic fields and risks associated with electric equipment that we usually accept). In addition they focused on construction costs and how much the risk would be reduced if extra costs were accepted. As the relative field strength or risk was low, and the relative costs were high, the decision was unproblematic: the power transmission lines ought to be overhead even if there could be a small risk involved. Figure 1 illustrates the main aspects of this argument. The representation of the students' argumentation is based on Toulmin's (1958) layout of arguments.

An interesting aspect of this argument is that it emerges as a purely knowledge-based decision. This is of course not true. Implicit in the decision lays the value of cost-effectiveness. This value seemed to be taken for granted and was not articulated by any of these students. The reason for the value aspect to be indistinct might be

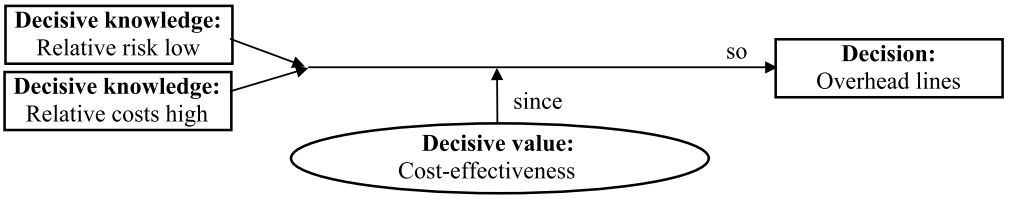

Figure 1. The relative risk argument identified in this study as a prototype for decision-making on socio-scientific issues based on a focus on the relative size of risks

that the emphasis on relative risk makes the whole problem disappear as an issue so long as the relative risk is comparably low.

All students using this argument arrived at the same conclusion, except from one. He did not feel sure about the relative size of the risk, and wanted more information before he thought it possible to make up his mind.

The Precautionary Argument: The case of Synne

Synne did not have any opinion on the issue prior to the preparatory phase, but had no problem deciding that the lines should be cabled when she got some information:

> Interviewer: Could you tell me something about whether it was easy or difficult to reach a decision?
>
> Synne: No, not really, in fact I immediately thought that they should dig them down. That has ever since been my opinion, really.

What information did Synne draw upon to reach her decision, and how was this information used? Before trying to give an answer to this question, I will focus at an interesting difference between Lise and Synne regarding view on, and need for, sources of information.

Several times throughout the interview Synne signalled an interest in the views and evaluations of others, among them knowledgeable researchers:

> Interviewer: Would it have been interesting to know more about how they [the researchers] worked, the research methods, to know whether you could trust them?
>
> Synne: Yes, I guess it would, but in fact, it is not *very* important to me. However, I am of course very curious about, those [researchers] who are knowledgeable, what they have to say about what is reasonable here.

She also stated an interest in getting more knowledge about the local residents' viewpoints:

> Interviewer: Would it have been interesting to know the opinions of environmental organizations, researchers, local residents, or —?
>
> Synne: It would in fact have been interesting to listen to the residents, those living near-by, and listened to their views.

Also when she was asked about the collective decision, she emphasized the need to bring in several points of view:

> Interviewer: I understand that you think it is important that politicians listen to ordinary people. Is there anybody else you think it is important that they listen to?
>
> Synne: One ought to listen to the researchers who have made the research—researchers from both sides, those who have studied this.

She makes one exception, however, as she stated that the politicians should not listen to the power company. The following quotation illustrates that she seems to be aware that her openness and interest in different viewpoints is not "full range":

Interviewer: During the group discussion you mentioned that "Researchers who have results supporting their own side [opinion], they [only] listen to researchers who have results supporting the side which they belong to", thus listening to those results they personally prefer. What do you think about listening to those [researchers] who have findings that fit *your* opinions?

Synne: Ideally you should listen to both sides and get both types of information before you make up your mind about it. But I think, if you have made up your mind to be against it in the first place, then you trust those who bring that [kind of] information the most, and then you think that the others are wrong.

Implicitly Synne here admits that it was not easy for her to have the same openness and freedom from prejudices towards all sources or viewpoints. In spite of her view of the importance of other people's points of view, Synne made her decision right away when she received information about the issue. How was that possible? For Synne the issue did not have any easy solution through an emphasis on *relative* radiation or risk. On the contrary, Synne did not think that information about the size of the relative risk had any relevance:

Interviewer: What do you think of the argument that says that power transmission lines are much less dangerous than many other things we do?

Synne: There are a lot of things that are dangerous, we might get cancer in very many ways. After all it is not necessary [to make overhead lines], when you already have the alternative of making underground lines. And if that decreases [the risk], that is, if that [alternative] don't increase the risk, then I think they should use underground lines.

This quotation also indicates that to Synne it is important to avoid risks. When she was asked "what was the most important arguments to you?", the answer embodied the basic ideas in the precautionary principle. This principle is usually interpreted to imply that one might impose actions that might lead to irreversible serious damage (Hanson, 2003).

> Why I think they should cable them? Actually, what was most important was that they ought to cable them because they don't need to try out whether the number of cases of cancer rises or not. It is not like "Well, if the number goes up, then we will see it when ten years have passed". Then it has already happened. So it was actually the cancer issue and that stuff. (Synne)

This argument, the importance of avoiding unnecessary risks, was used several times throughout the interview. In addition to this argument, she also emphasized the importance of considering the local residents.

Synne held several additional views related to the risk question that elucidated her argumentation. She had the impression that there were research findings supporting "both sides", and that researchers disagreed on whether there was an increased risk. And even if she seemed to conclude that an increased risk was more likely than not, she viewed an increased risk not as proved, but as a possibility:

Interviewer: Those who say they have found an increased risk, don't you think they will regard it as proved?

> Synne: Well, they might be doing that, but I wouldn't say it's proved. I have only heard that it might be that it increases the risk, and that there are no proofs for this. When someone finds that the risk is not increased then it's probably very uncertain.

In total, the decisive argument to Synne thus seems to be that there have been studies that claim to have shown an increased risk. That is, for her to make a decision it was enough to know that there *might be* an increased risk. This conclusion is underpinned by the fact that Synne said she did not remember any of the risk estimates from the preparation phase. Thus neither relative risk nor absolute risk estimates had any essential impact on her decision.

Synne's (implicit) use of the precautionary principle in conjunction with the possible risk may also explain her lack of emphasis on the economic argument. The increased construction cost was only stated indirectly, and her only comment on the economic aspect shows clearly that this was of limited importance to her:

> We do have the underground alternative, and then I don't think this should be an issue at all. They probably have enough money for it if they prioritize. (Synne)

Information from other knowledge domains than science played only a minor role in Synne's decision. Beyond the economic aspect, which she did not think relevant, she did not mention, or use, any knowledge from outside the scientific domain. She said that her parents were in favour of underground lines because overhead lines disfigured the forests where they used to go hiking, an argument fully supported by Synne. She also claimed the importance of listening to local residents although only employing scientific information in her own decision-making. This apparent conflict disappears if we suggest that Synne want local residents, who also shares her view, to be heard when the *collective political decision* is to be made, while her *personal decision* is based on the precautionary principle.

When asked whether knowledge of scientific concepts such as *electric current, voltage, high voltage*, or *magnetic fields* were relevant, her answer indicated this to be unimportant: "Maybe, but not very much. You don't have to be very good at it".

The Precautionary Argument

Nine of the interviewed students, three boys and six girls including Synne, shared Synne's emphasis on the precautionary principle. Most of these students even articulated this value explicitly as a decisive argument and also shared the ideas related to the risk question that we found in the case of Synne. Two pieces of information were emphasized: the knowledge that there existed research that indicated a risk, and that this risk involved a serious damage—childhood leukaemia. In a situation where the potential risk was uncertain, these students solved the problem of weighing between health and other values by giving the precautionary principle a strong precedence over other values. Their decision, which is illustrated in Figure 2 using Toulmin's (1958) layout of argument, then became unproblematic.

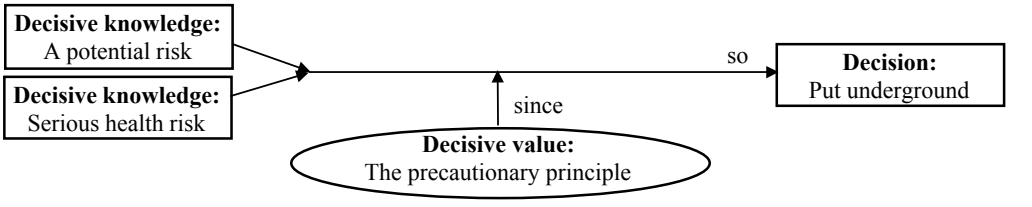

Figure 2. The precautionary argument identified in this study. For nine students this was the main argument supporting their decision on the socio-scientific issue, and it was based on the prioritizing of avoiding risks

In *the precautionary argument* the size of the potential risk was of minor importance. The knowledge that several research reports had found an increased risk was enough to trigger the application of the "safety first" argument. Thus the decisive information was solely from the science domain, with no need for information neither from other knowledge domains nor even of the level of consensus within the scientific community.

The Decision Impossible Argument: The case of Ivar

All students were asked to make a decision during the group discussion in the preparatory phase. Ivar found this difficult, in fact impossible, and his problem with making a decision was still present when the interview was conducted:

Interviewer: Could you tell me whether it was easy or difficult to reach a decision?
Ivar: No, it was difficult. I really don't have any opinion.

Ivar agreed with Lise on the importance of considering the increased construction costs for the cabling alternative. However, he did not share her evaluation of the relevance of information about *relative* risk:

Interviewer: What do you think of the argument that says that living near power transmission lines is much less dangerous than many other things we do?
Ivar: That may be so, but if we remove the overhead lines, then we get the danger diminished anyhow, if it's dangerous. So all overhead lines should have been taken away.

Ivar agreed with Synne that it was likely that there was a risk involved, even if it still was highly uncertain whether this was the case or not:

Interviewer: You ticked the box for the lines to be put underground, and a moment ago you mentioned the precautionary principle, what were the most important arguments to you?
Ivar: No, mostly it is, it might be dangerous, but we don't know.
Interviewer: So it is the uncertainty?
Ivar: Yes. If people die of cancer because we don't put them [the lines] underground, it's a bit stupid. Then we should rather put them underground.

This quotation shows that Ivar agreed that it was important to be precautious, but he did obviously not give that value a strong precedence to all other values. Ivar was

also concerned about the undesirable consequences of putting the lines underground. In addition to the increased construction costs, he also had a concern for the subscribers who he thought would have to pay the extra costs in the end. On the other hand he also wanted to take into consideration the possible problem of decreasing house prices for house owners living near the path of overhead lines. His teacher mentioned this argument in the preparatory phase, as the teacher himself could lose money if this happened.

But instead of weighing the pros and cons and making a decision, Ivar "hit the wall" in the middle of this process. To be able to choose between overhead and underground lines, Ivar thought it was crucial to know whether there really was a risk involved or not:

> It's very difficult to have an opinion because we don't know if it's dangerous, and then no one can—When everybody holds different opinions in a way, and when you don't know [the risk]. If we had known the risk it would have been a bit easier. (Ivar)

But again and again, throughout the interview, Ivar stressed that the risk was not proven, the research results were uncertain and the researchers disagreed on the risk question.

The Decision Impossible Argument

The main characteristics of Ivar and one similarly disposed interviewee, both boys, are sought visualized in *the decision impossible argument* presented in Figure 3.

Students who applied this argument valued both the precautionary principle in relation to health and risk, and avoidance of extra costs. But the main feature of the argument is the problem caused by the diverging opinions on the scientific claim central to the discussion. Knowledge of this situation represented an insurmountable obstacle to Ivar and his like-minded peer. This also implies that it was the social status of the crucial claim within the scientific community, the lack of consensus among the researchers that was the decisive factor.

It is interesting to notice that this situation, the lack of consensus within the scientific community, is a characteristic feature of many socio-scientific issues. And this

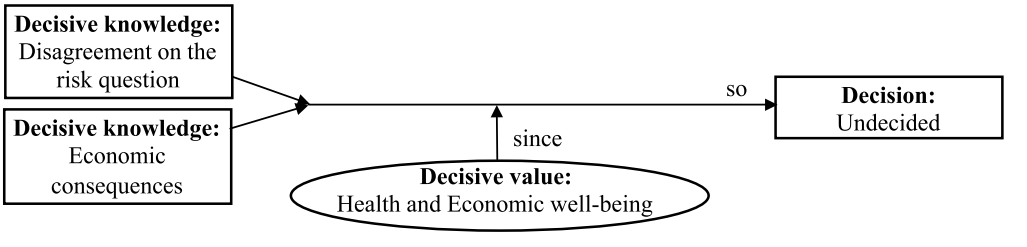

Figure 3. The decision impossible argument identified in this study. For two students this was the main argument supporting their decision on the socio-scientific issue, and it was based on an unalterable demand of factual knowledge about the possible risk

feature was exactly the aspect that made it impossible for Ivar to make any other decision than "don't know".

The Small Risk Argument: The case of Finn

Finn held the opinion that the power transmission lines could be built overhead. However, his argument was not, as in the relative risk argument, that the relative risk was low:

> Interviewer: How do you judge the argument that says that living near overhead lines is less dangerous than many other things we do? …
> Finn: Yes, I think it's true. You [may] drive in more than 200 kilometres an hour—[so] it is a point in a way. But I nevertheless don't think it's a good argument. You know we all live at risk. There is no one who doesn't live risky. You might die any time, so to say. So I don't think it's a very good argument.

In this quotation Finn also expresses the idea that it is impossible to avoid all risks. In fact, Finn seemed to evaluate risks rather different from Lise, Synne, and Ivar. On the one hand, Finn did not only seem to refuse the possibility for a risk to be present. He remembered a risk estimate mentioned in the preparatory phase, which said we could expect one more case each year in Norway, and he referred to this twice with no critical comments. He also stated the view that the lines should be put underground where the trace passed kindergartens:

> Interviewer: Then you had a discussion about kindergartens near overhead lines. One of the girls said: 'It should have been illegal not to put them underground where there are kindergartens". What do you think about that point of view?
> Finn: […] It would have been ok [to put power lines underground] where there are kindergartens, because they [the children] are young, you know. Yes, may be. It's not like—You shouldn't place a power transmission mast where there is a kindergarten. That would have been just stupid. Even I would go against that.

On the other hand, he concludes that:

> Interviewer: Did you think it was difficult to make up your opinion?
> Finn: In fact, I think, to me these overhead power transmission lines really don't do much harm. I'm not sure they are so very dangerous as they [those who want the power lines to be cabled] want them to be.

The general impression from the interview was that he was a bit provoked, not by the risk estimates, but by the fuss other people made just because of a small risk:

> Interviewer: In the group discussion you said: "Who do we listen to?", and one of the girls replied: "Definitely not BKK [Bergenhalvøens Kommunale Kraftselskap]".
> Finn: Well. I don't agree on that. Well, in one way may be, because—I don't know. I would rather have listened to them, because I don't believe in all those people, those who say "Oh, it is dangerous, you might die of cancer".

What characterized Finn was therefore his evaluation of the possible risk. A risk involving one extra case childhood leukaemia was small and to be accepted as a natural part of life.

Finn's evaluation of the risk was understood to build on his values and on information about a risk estimate. In his argumentation he also pointed to the "substantial extra construction costs", and to increased costs related to maintenance. In addition he introduced the question of whether it could be possible to find alternative and less controversial traces.

The Small Risk Argument

Finn's reasoning represents an example of use of a fourth kind of argument, *the small risk argument*. Based on Toulmin's (1958) layout of arguments, the argument is illustrated in Figure 4. Its main feature is the decisive value or attitude—saying that small risks are a natural part of life, and nothing to make a big issue about. This attitude was applied to the information about risk estimates. When the risk question was evaluated as uninteresting, economic or other possible negative consequences of the underground alternative became decisive for these students. In my sample two students, one girl and one boy expressed this argument.

In this argument the answer to the risk question is considered of minor importance as long as the possible risk is small. There might be a risk involved, but the answer to the risk question does not really matter. The decision on the political issue is clear, but inherent in this argument is a view very close to refusal of the issue as a problem worth considering.

The Pros and Cons Argument: The case of Nils

In Nils' opinion, the power transmission lines should be cabled. He repeated several times that overhead lines are ugly, and although not stated as such, this aesthetic evaluation seemed to be his main argument:

> Interviewer: Can you tell me something about whether it was difficult or easy to reach a decision?

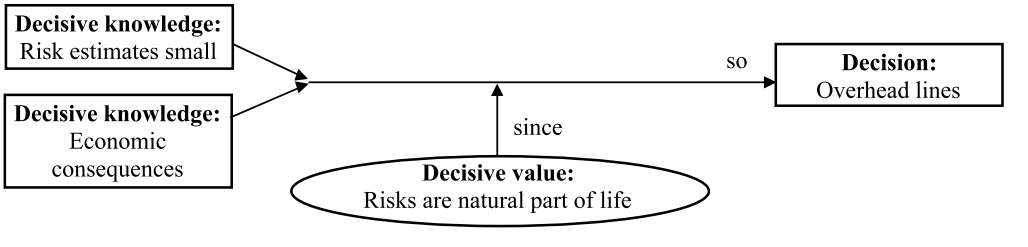

Figure 4. The small risk argument identified in this study. For two students this was the main argument supporting their decision on the socio-scientific issue, and it was based on a view of small risks as unimportant

> Nils: No, in fact I had an opinion in advance. You know, … whether they [the lines] give people cancer or not they are still extremely ugly to look at.

Like the other students, he believed underground lines to be more expensive, but he still thought it to be worth it because "in the long run it might be a significant difference".

But Nils also showed an interest in taking other additional factors into consideration. He mentioned the importance of knowing "consequences of different actions", and pointed to the lowering of residents' house prizes. He also pointed to the residents' uncertainty and fear as an independent argument. Finally Nils also stated that knowledge of wider societal consequences were important:

> Interviewer: What do you think you, or others, should know before making up an opinion for instance in this issue?
>
> Nils: If one wants to make up ones' opinion one should know how this decision will influence society, or one should know what consequences it has. One should know what there is to be done, what they want to do, what the others want to do. I'm not sure how to formulate this—one has to know why it's right.

Concerning the risk question Nils remembered that a Norwegian researcher had found no additional risk. He perceived him to be a single researcher though and argued that, if five or ten different studies had yielded the same result, he might have started to tip towards that view.

When it came to scientific information he mentioned that the information about the magnetic fields as a possible cause for leukaemia was interesting, that the information about the risk was important, and that information about research methodology was relevant if there were methodological weaknesses. Nils never explicitly mentioned science learned at school as being relevant, but stated that "afterwards my teacher said that if you increase the voltage, then in fact the magnetic field will diminish, but I thought that was a bit strange". The argument about the relative risk to be small he found difficult to use:

> Interviewer: What do you think of the argument that says that living near power transmission lines is much less dangerous than many other things we do?
>
> Nils: It is absolutely possible, but one also sees research results which show that it's not. It's a bit difficult to say. We are close to such magnetic fields all day, but still it might not be magnetic fields that cause it [leukaemia].

The Pros and Cons Argument

In total, Nils seemed to take into account a wider range of knowledge than Lise, Synne, Ivar, and Finn. There were indications in the interview that he wanted to consider possible consequences, and he made an "on the one hand …, but on the other hand …" kind of evaluation when he commented the construction prizes. The argumentation expressed by Nils and also some of the other students interviewed therefore had some of the characteristics of a "pro et contra" kind of process. The argument used by Nils and his like-minded peers to explain their decision is therefore

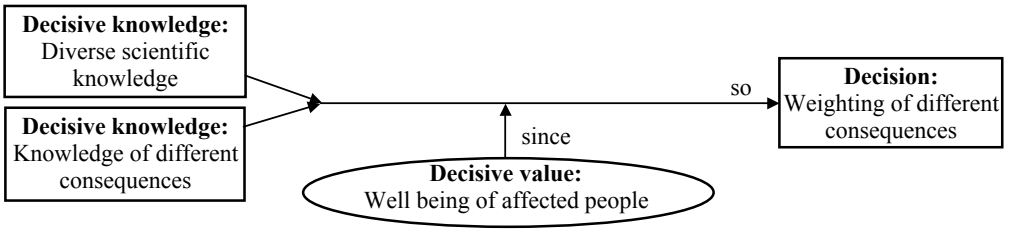

Figure 5. The pros and cons type of argument identified in this study. Four students used this type of argumentation, and it was not based on a specific attitude towards uncertain risks

called *the pros and cons argument*. In this argument the pros and cons of different alternatives are listed and considered before a decision is made. An important characteristic, which distinguishes this argument from the relative risk argument, is that the former one does not include an idea on how to handle the risk question. The pros and cons argument is illustrated in Figure 5.

In this study four students used this kind of argumentation, two girls and two boys. Three concluded finally on underground cabling, and one of the boys was undecided.

Discussion

This study set out to reveal insights into students' use of knowledge and values in arguments expressed in support of their decision-making on a controversial socio-scientific issue. As the case studies showed, students handled the ethical question and the scientific issue involved, the risk question, in different ways. All the students interpreted information about research and researchers' view on the risk question as implying expert disagreement. For two students this interpretation made it impossible to make a decision. The key features of these students' informal reasoning were conceptualized in the uncertainty argument. This line of argumentation echoes the reaction to a decision-making situation denoted as *defensive avoidance* by Janis and Mann (1977). Defensive avoidance implies that the person in a decision-making situation avoids making a decision but defends this avoidance by claiming, for example, lack of time or information.

For nine students, the knowledge that some researchers said there *might* be a risk involved was decisive, and these students' decision-making was identified in the precautionary argument. Their focus on avoiding a risk due to possible catastrophic consequences resembles the safety-first models identified within economic research (Wik, 1996). The idea in safety-first models is that the decision-maker demands a risk not to take on a value less than some critical minimum or disaster level. Only if the risk is above this level will maximizing of the expected utility guide the decision. The two students using the small risk argument judged the size of the possible risk as *negligible*, and decided that airborne power lines were acceptable. The presence of this argumentation indicates that the risk avoidance (Beck, 1992) often said to characterize today's society is not shared by all students.

Information about the *relative* risk, compared with other everyday risks, was decisive for the five students employing the relative risk argument. In the pros and cons argument, identified by four students, no specific piece of knowledge where decisive. The uses of these two types of arguments resemble formal decision models with their emphasis on comparing alternative actions. However, it was only the relative risk argument that involved a guiding principle, cost-effectiveness, which made these students' decision straight-forward. This principle is similar to the principle of maximizing utility used in formal decision-models.

In this study, more girls than boys (six versus three) used the precautionary argument, and only boys used the uncertainty argument. However, due to the low number of interviewees, these differences do not necessarily represent any interesting dissimilarities between girls' and boys' reasoning about the issue.

Several of the main arguments identified hinged on information related to the risk question. Thus the students used scientific information in their evaluations and decision-making. However, scientific theories or scientific content knowledge offered in school science was not employed, echoing the findings of Flemming (1986a, b) and Solomon (1992). Only factual claims about the possible risk and the size of the magnetic field from different equipment were important, even if a few students also made us of scientific content knowledge in their reasoning (Kolstø, 2001). Information on the additional costs associated with the underground alternative was crucial to some students. The students also considered other types of information, but none of these were found to have had a crucial influence on any students' decision-making.

In relation to a discussion of the so-called democratic argument for scientific literacy (Millar, 1996), Sjøberg (1997) has posed the important question of whether students' decisions on socio-scientific issues are more value-based than knowledge-based. The crucial issue here is whether science education has a role to play in education aiming at thoughtful decision-making if adolescents' decisions are primarily value-based. However, Toulmin's structure of argument implies that arguments always include both data and warrants, and furthermore, in claims of policy, values might be used as warrants (Wood, 2000). The analysis in this study shows that this model of how knowledge and values are related in a policy argument is meaningful. The question is therefore not whether knowledge is relevant for policy arguments, but what kind of knowledge is regarded relevant by different people holding different values. Interestingly, in this study information based on scientific research, namely information about the possible risk, was crucial to all interviewees' judgement or decision-making.

Consequences for Science Education

Oulton et al. (2004) argue that the purpose of teaching socio-scientific issues should not be to enhance students' decision-making *per se*, but rather to understand the nature of controversial issues and to develop students' open mindedness, thirst for more information, and ability to identify bias and reflect critically. In this study the students were found either to provide arguments based on the information present,

or, as in the uncertainty argument, to argue for postponing the decision until they had received further information on some specific aspect. What all students had in common, however, was that they did not look up further information during the days between the preparatory phase and the interview, even when they viewed further information as desirable. The situation is probably the same for most of us when dealing with issues outside our area of special interests. This finding indicates that frameworks for argumentation, decision-making, or the critical examination of information to be used in the science classroom should include an easy access to an appropriate range of information and viewpoints. An example here is Ratcliffe (1996a), who placed decision-making tasks towards the end of teaching units with science–technology–society (STS) profiles. Kolstø (2000) has proposed that groups of students might obtain information within different topics of relevance, thus making all students "experts" within a domain prior to a class-discussion where arguments and claims are critically examined.

When teaching thoughtful decision-making and evaluating what is an appropriate range of information to be provided to students, one should be aware that students might have different needs. This study has revealed that some students used a relative risk argument and wanted to compare risks and expenses across issues, and thus need information that makes such comparison possible. Furthermore, there were students who used the precautionary argument and were concerned about psychological reactions on affected people due to uncertainty and anxiety, and thus this aspect should be included if possible. There were also students who were interested in opinions and evaluations held by different actors in general, and knowledgeable or neutral researchers in particular. Their decision-making might also get more thoughtful if such information is included. All students used information about the scientific risk estimates, but some were also concerned about the level of consensus within the scientific community. If we are to train students in knowledge-based argumentation in decision-making situations and at the same time respect their values and evaluations, we need to include the kind of knowledge they probably consider as relevant.

However, this study also showed that many students' decision bases were limited to research-related information and the economy of the involved power company. Some students thus drew upon a very limited range of knowledge domains. Thoughtful decision-making involves consideration of information from a range of potential relevant social domains (Aikenhead, 1985), including consequences of different alternatives for the wider society. If we want students to consider such information, it is probably not enough to include it in information made available to them. Frameworks for thoughtful decision-making ought also to include tasks or "mechanisms", which ensures that the students are confronted with this information. Such confrontation might make students aware of aspects not thought of before, and thus enlarge the range of aspects included in their decision base. Students using the precautionary argument did not, for instance, emphasize the size of the risk as they focused mainly on possible negative consequences for children. A closer consideration of possible consequences for various affected actors is therefore

desirable regarding students whose decision-making resembles the precautionary argument. As an example, politicians are worried about the slippery slope argument: that if one power line is to be cabled due to the precautionary argument, the possible economic consequences for the construction of all future, and perhaps also existing lines, will be enormous.

In complex issues with several arguments involved, it is important to weigh, and thus to prioritize, different alternatives. Students using the precautionary argument had a prioritized ethical value, making the decision straight-forward. However, the students using the uncertainty argument and the pros and cons argument weighed scenarios and arguments, but had more problems coming to a conclusion. For students who find it hard to prioritize and thus to decide what argument to guide their decision, it might be valuable for them to become more aware of their personal values and get more experience in prioritizing among values when these are in conflict. Such awareness and experience might be developed in the science class, for instance through the inclusion of decision-making tasks where also clarification of criteria or values is emphasized (Ratcliffe, 1996a).

The students' use of *different* arguments in support of their decisions might be used as a resource when teaching science for citizenship and thoughtful decision-making. The relative risk and pros and cons arguments identified indicate that some students, to some degree, do include a wider range of knowledge domains in their decision-making. These students' views might be used as a resource in the science classroom, and also in science teacher education, when exploring the relevance of different kinds of knowledge. The other types of arguments present among students might be used to make evident that there are different ways to reach a conclusion, and that there is a range of aspects that might be judged to be crucial. Such exemplification, based on the different evaluations already present in a class, might have an impact on students' consciousness regarding the possible relevance of a wider range of information than initially considered. The five main arguments identified might also be used to analyse and characterize ones own argumentation, and thus to become aware of strengths and weaknesses of that argumentation as well as of alternatives to that argumentation. In sum, they provide a possibility for making students' or science teacher students' argumentation and decision-making more reflective.

Consequences for Science Curricula for Citizenship

It is desirable that students' examinations of information crucial to their decision-making, namely research-based risk estimates, are based on an understanding of the different aspects of this information. This study therefore implies that science education has an important role in developing students' understanding of the concepts of risk and uncertainty, and characteristics of research on risk-related issues. All the five main arguments identified somehow involve the concept of risk and uncertainty. Consequently, a change in a students' thinking about risk and probability will probably involve a change in their decision-making. However, it is probably wrong to

conclude that deeper scientific insight into these two concepts will favour one specific of the five main arguments. The reason is that also personal values are involved in our thinking about risk and uncertainty. A deeper insight into the concepts of risk and uncertainty might increase students' appreciation of the relative risk argument, but an understanding of societal aspects is probably equally important. I will argue that students who use the precautionary argument need to increase their awareness of possible societal problems concerning application of this argument to socio-scientific issues in general. Increased understanding of the fact that "no decision" also is "a decision" in its consequences might stimulate those students who hesitate in making a decision to make one. Nevertheless, one should also appreciate the ability to postpone a decision due to awareness of lacking insight into an issue.

In this study none of the interviewees viewed the textbook science they had learned at school as crucial knowledge. During the interviews, the students were asked what topic they would like to have more information about, and whether they considered it correct that it is the current in the power lines that gives rise to the magnetic fields. In a final question the interviewer reminded the interviewee that they had learned about electricity in science class the last few weeks before the study was conducted, and asked whether this knowledge somehow was relevant for their decision-making. Some students agreed that an understanding of scientific concepts such as *current*, *voltage*, *high voltage*, and *magnetic field* was desirable. However, no students used such knowledge in their arguments during the interviews. Some students thought 300,000 volts sounded scary. Nevertheless, no student asked why the voltage, for a fixed power transmission, was not made even higher in order to reduce the necessary current, and consequently the magnetic field. (This possibility follows from the expression saying that the electric power transported by a line is given by the voltage times the electric current.)

The kind of science they had met through the content-centred Norwegian science teaching was thus of minor relevance. Concerning knowledge from the scientific domain, the students considered the risk estimates, the magnetic field strengths from different kinds of electric equipment, and information about researchers presenting views on the risk question. Consequently, important scientific information and claims in the issue was from the frontier of science. Frontier science is usually characterized by diverging research findings, discussions among involved scientists, and absence of consensus within the scientific community (Driver, Leach, Millar, & Scott, 1996; Ziman, 1991). Inclusion in the science curricula of knowledge of scientific research methodology and the nature of frontier science is therefore relevant if we want to make the students better equipped to cope with expert disagreement and uncertainty in science.

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