A 6-week Nature of Science module incorporating social and epistemic elements

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ABSTRACT: The module is designed for six double lessons (6x90 min). As opposed to prevailing textbook practice the module attempts to incorporate epistemic issues and the traditional NOS material in a sociological framework. This naturally means that less time is devoted to traditional NOS issues (demarcation criteria, the scientific method, induction, deduction, falsification), as nearly half of the module is on grounding the sociological starting point. The novelty of the module is in bringing the social to the fore, and restructuring the (more or less traditional) epistemic aspects in a way as to utilise resources available to students, thus decreasing teaching time devoted to these elements. The module has been tested in three consecutive years for high school students (17-19 years-old), at a Dual-Language School in Hungary running an IB Diploma Course (Karinthy Gimnázium). The students are average to high ability, and studied the module in English, which was for nearly all a second language.

Keywords: history of science, sociology of science, philosophy of science, NOS,

Description of Case Study[1]:

Teaching NOS is clearly an important pedagogical challenge for today's science education. A major problem with current treatments of the nature of science in the classroom is the separation of "philosophical" from historical / sociological insights. The discussion on the method of science all too often boils down to simplistic logical insights when a module on NOS starts with epistemic criteria. Furthermore, starting with epistemic considerations does not allow for the natural introduction of social factors, which at some point need to be mentioned. The rather negative role social considerations generally play in NOS modules (and the fear of educators from "social constructivist" approaches) is the result.

To remedy these problems the module embeds the epistemic in the social. Science is portrayed as a social institution, and as all institutions, science also has norms. The necessary existence of these norms is investigated and their role in maintaining the proper functioning of science as an expert system both in knowledge-production (i.e. epistemic norms) and in the proper functioning within society is stressed.

The aim of the social starting point is therefore not to replace the epistemic considerations, but to find place for them. The epistemic norms are not shown as decontextualised, abstract criteria, but rather as the results of historically contingent developments that gave rise to a very special social institution in Western Societies starting from the 17th century, an institution that is the primary knowledge-producing organ of these societies. Science, while still often portrayed as an isolated enterprise in search for pristine knowledge, is in fact an embedded system that has specific functions in modern societies.

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[1] More details about the background and the literature are given in: Zemplén, Gábor Á. 2009. Putting Sociology First—Reconsidering the Role of the Social in 'Nature of Science' Education. *Science and Education* 18 (5):525–559.

Once this social starting point has been established, norms of science can be discussed – some ethical, some epistemic. As opposed to the prevailing textbook conventions, the approach proposed here reverses the order (the social comes before the epistemic) but does not dispose of the epistemic criteria.

Historical and philosophical background including nature of science

The general textbook-convention in science courses – if at all focusing on NOS – generally introduces science as characterisable by a distinct and specific method, reliance on empirical data and logical reasoning (as *opposed to* other social institutions). Many textbooks stopt at his point, the ones that go further gradually „soften" this view, admitting that there is no clearly definable scientific method, and that there is no guarantee to cut nature at its joints. In general, textbooks use decontextualised epistemic criteria separately from social considerations, in ways that the latter are seen to be hindering the fulfilment of the former.

The approach outlined in the article runs counter to the above model. Starting from „soft", social considerations, stressing *similarity* to other social institutions, and problems that students can easily understand in their own life-world, one can better appreciate the never ceasing attempts of scientists to tackle sources of errors and acquire knowledge (that is as reliable as possible) about the natural world. By shifting the position of the social in NOS modules and embedding epistemic criteria in a social framework, a radically more constructive role can be given to sociological considerations without a major change in the contents of the course. By giving up unreasonable expectations about science, sociological insights can help students appreciate science as the main knowledge-producing organ in our society, and help them become science-friendly. As opposed to traditional curricula, this approach is closer to how historians, sociologists and philosophers of science think about science today. The sociological starting point helps students understand the presence of values in science, the biases that scientists at times are criticised for, and still appreciate science as a privileged form of knowledge-production.

The module offers a way where both the rational and the social can be seen as indispensable for knowledge-production. The social level of interaction among experts (who generally accept and at times change the relevant norms of the community) ensures that empirical evidence and the beliefs of individual scientists *can become* knowledge shared by the community. This approach also supports the view that the public understanding of science should be an interactive process between technical experts like scientists or educators and lay people like students, rather than a unidirectional or narrowly didactic passing down of information (Wynne 1991). Taking social considerations into account and bringing NOS issues closer to the lifeworld of students help to sidestep the "cognitive deficit" model of scientific literacy that characterises much of science education (Gregory and Miller 2001; Ziman 1991). Social considerations also appear to be successful in separating science from non-science in the classroom. And, as stressing the social by no means equals neglecting the epistemic, it does not lead to the much feared extreme relativist positions.

Target group, curricular relevance and didactical benefit
Target group:
Age range: 17-20 years old. Higher years of academic secondary school or early undergraduate studies.

Institution: Academic high school, college, university

Curricular relevance and didactical benefits: There is at present no generally accepted approach to teach Nature of Science (NOS) for high school students, but there is a growing demand for it from curriculum developers in an increasing number of countries. Teachers, who themselves had little training in NOS are therefore finding it hard to live up to the curricular expectations. The problems are various: what are the key elements of NOS that high school students (usually between 17-19 years of age) should be familiar with? How to teach these in an interactive manner, to further general abilities like critical thinking, and improve on the students' approach to Socio-Scientific Issues (SSI)? The module described here offers a novel alternative approach to satisfy these needs.

Didactical benefits in more detail, with regard to general textbook-practice:

A general belief is that for students first a "simple" view of science should be given, and more complex, social considerations can come into play at a later stage to modify earlier views. An unrecognised problem with this view is that it treats earlier, mainly logical positivist and Popperian views as unproblematic and easy to grasp. It implicitly endorses the 'statements view' of science, where the job of the scientist is to come up with statements that have certain characteristics (can be verified, falsified, corroborated, reduced to other types of statements, etc.). For most students, however, this is a non-trivial view of the natural sciences. Not only is this alien to what and how they learn in science classes, but also alien to most science teachers, generally little educated in the philosophy of science. Further, this statements view requires non-obvious notions of truth, truth value, etc., and therefore can hardly be considered a "natural" starting point. For most students these notions are not "at hand". This general, "simple" view of science utilizes a very specific view of language, one that has strict requirements about syntax, mostly idealised views about semantics of the language, with almost total neglect of pragmatics. The scientific method, if introduced in this framework, seems simple on the surface, but in fact implies views that are not at all easy to grasp for high school students.

Not only is the epistemic starting point more complex than is believed by many of its supporters in science education, it is also more remote from the students' lifeworld than a social starting point. In science classes students directly face (some of) the complexities of laboratory work, they see instances of error handling, and are accustomed to trust their teachers, when e.g. she explains why a specific experiment did not work the way it should have. They are also faced with science as a socially embedded institution in television news, hospital encounters, or when they see experts arguing for specific positions in open scientific controversies. These are readily available resources that are generally neglected when NOS modules focus nearly exclusively on testability criteria and the like. Yet they could easily be utilised when the social dimensions are given a greater role, as the approach outlined here shows.

Activities, methods and media for learning

Grounding the social

The module introduces the concepts of expertise, expert systems, and social institutions.

LESSON 1

Expertise and expert-systems were introduced during the class.

- The first double lesson starts with "The expert game" a setting resembling a quick in-class test, common to many school systems, but the answers are not graded (30 min.).
- While one student adds up the results of the expert-test, the class discusses their response to the mini-essay questions in small groups.
- This is turned into a frontal discussion, and key concepts (social institutions, expert systems) were introduced (15 + 10 min.).
- After this the results of the „expert-game" are discussed (15 min.).

The form of the game is used to contrast "knowledge" that school-tests usually test and other forms of knowledge important for the students' everyday lives. The discussion highlights the fact that students have expertise in a number of areas, and they treat each other as experts in social, educational, and various other matters.

After this, the formal and informal ways experts can be picked are contrasted, a short introduction is given to the development of science, and the gradual institutionalisation of science is presented through examples (frontal method).

- The differences between trusting and individual as an expert (e.g. my neighbour as opposed to e.g. a doctor) and an institution (e.g. science) is discussed. Both advantages and disadvantages of individual versus institutional trust is discussed. The class is asked to give a rough classification of how experts gain acceptance (usually similar to Weber's tripartite grouping of the nature of legitimating into 'charismatic', 'legal', and 'traditional') (15 min.).

LESSON 2

The second lesson focuses on the difficulty of constructing expert-systems, the many ways social institutions can fail, and how norms are instrumental in these systems for their proper

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The Expert Game

At the beginning of the class students are asked to take a paper and pencil, put everything else away, number lines on the paper from 1 through 10 (a setting resembling a quick in-class test), and are asked to answer two questions first:

1., Does science provide us with better, more reliable knowledge for important questions than everyday knowledge or other traditions do?

2., If yes, why and where (e.g. healing, physics, environmental issues, risk management, etc.)? If no, why and what *does* provide us with the most reliable knowledge in your opinion?

The students have about 15 minutes to answer these questions

For the rest of the questions they are then asked to write names of their class-mates who

3. knows best parties

4. can help with physics HW

5. can trust which movies to see

6. tell which medicament to take in case I feel unwell in school

7. help in an emotional crisis

The students could pick the last 3 questions that they were interested in (if it was accepted as appropriate by all members).

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functioning.

- Warm-up game. Each individual has to write three questions to which she/he personally would like to know the answer for. After this students are asked to find a pair and their partner has to look at the questions and decide *who / which institution* is best suited to give an answer. They have to be reminded not to answer the questions themselves, but find "experts" on whom to rely. (15 min.)

The warm-up is used to rehearse key concepts of the previous lesson (expertise, trust in individuals and in institutions).

- The class is divided into 4-5 groups. Each group has to devise their ideal expert system (made up of fallible humans) that can provide as reliable knowledge as possible for important questions. During the instruction the word "truth" should not be used, only more neutral terms, like "producing knowledge". At this stage students are not told that science as an institution is one solution, and they are basically asked to invent this institution. (35 min.).

The groups have to present their findings and defend their views.

- Each group has 3 minutes to propose their solution, and in 3 minutes has to respond to objections. (40 min.).

As homework, students are

◊ asked to list 5 different scenarios (as diverse as possible) that can hinder "scientific understanding", and where science / the scientist can go wrong (HW 1).

◊ asked to write 2000 characters about the following question "Why do we follow extremely complex scientific methodologies, even in cases where much simpler methods could yield similarly (im)precise answers? Is this good practice or not?" (HW 2)

The Class-discussion on the best possible expert system

As the discussions can be heated, it is important to make sure all students realize the necessity of time-limits. Short, precise questions are encouraged. During the discussions students recognise in each proposal the difficulty of finding

a) motivation for experts to go after knowledge (as opposed to cheating, etc.)
b) means of control (and control of controllers, etc.),
c) ways to increase the significance of the most successful experts without turning the system into a despotic oligarchy (i.e., to balance both the meritocratic and the democratic elements of science).
d) the trade-off between "certain" knowledge and time and resources used to gain that knowledge

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LESSON 3

The third lesson starts with discussions on the homework

- Depending on their position in HW 2, the class is split into two groups ("Is this good practice or not?"), and both groups has time for preparation. (20 min.)
- The groups have to present their strongest arguments in 3 minutes. The short speeches are debated, and the teacher highlights key elements in both positions. (20 min.)
- HW 1 is discussed in small groups, and students are asked to provide a typology of error sources into which all their examples could be meaningfully integrated. (20 min.)

Group 1	Group 2	Group 3	Group 4
Human misinterpretation/ fallacy	scientist	human	Language/physical limitation
	sample	specimen/environment	Mental limitation
lack of technology	method/equipment	equipment	Placebo effect

1. Summary of some student error-typologies from one of the assessment-classes

The lesson ends with a frontally coordinated discussion. This is used to connect HW1 and HW2. They appear to have little in common, but the discussion is directed to lead to the following conclusions

- even if today an expert system (using complex methodology, as in HW 2) is unable to have a good understanding (and control) of phenomena, without joint effort (and invested money) the possibility of improvement is small. There are many historical examples (like astronomy, storm-forecasting, infections etc.) where a group of expert struggled long and hard to develop methods and conceptual tools to understand phenomena. Past examples are not a guarantee, but yield strong inductive support that some of the present efforts will be successful in the (near?) future.
- Errors can never be fully eliminated. But knowing how things can go amiss, one can be prepared and try to reduce the sources of error. If a set of experts consciously work on reducing chances of making mistakes, the reliability of the outcome increases.

The discussion is used to introduce the problem and necessity of *norms*. This is plugged back into the design of the expert system, and students are asked to rethink their expert systems

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The most important arguments for and against an expert-system

Important arguments made by the "pro" group (in square brackets the key issues raised):
- ◊ We need to tolerate science in areas where they are not too successful to allow for the development of these fields [chance for developing expertise].
- ◊ It is a society's choice to empower a group of people with authority for an area, and there is no reason trusting the laymen more than the experts in these cases, plus we have to trust the people who are best at something to do as they wish [epistemic dependence].
- ◊ Expert-systems offer more jobs [science as institution connected to socioeconomic problems].
- ◊ We need expensive experiments, as we want to be sure or as sure as possible [error-avoiding].

Important arguments were made by the "contra" group (in square brackets the key issues raised):
- ◊ Funding of science as a highly problematic area that takes money from important issues [relevance, public opinion].
- ◊ The problem of unidirectional trust: society puts trust in scientists but cannot control them or check if they manipulate citizens [highlighting problematic nature of maintaining expert-systems].
- ◊ The recognition that the better the science is, the better it is for the society, and raising the question of how can one ensure that science is becoming better? [The question and significance of norms.]

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as systems that provide norms for the community, checks and balances (no written HW).

Incorporating the epistemic

The lessons incorporate well-known NOS elements into the social framework.

LESSON 4

The fourth lesson builds on the earlier sociological background, and develops the students' understanding of norms. With this epistemic aspects of NOS are introduced in a sociological framework.

- The lesson starts with a discussion of a short text from Thomas Weller "Economics meets science" (see http://www.besse.at/sms/smsintro.html). Most students find the text funny, and as some already have vague ideas about induction and deduction, a very simplified answer is given as to what the two terms "really" mean. (These are later discussed in lessons 5 and 6). (20 min.)

- After this, students are asked why they found the text funny. Soon they point to the discrepancy between what scientists should (and they say they) do and what they really do; how methodology is used on the one hand to gain knowledge, and on the other to create an image of the scientist that legitimates her in the eye of the public. (10 min.)

So issues of ideology, self-image, and public image are raised, and students are asked to formulate what they think the communicated image of science was, and what the actual aims of the scientists are.

- After collecting ideas, the students are asked to figure out how society (including the group of scientists) can ensure that the individual scientist does what is expected of him by society or by the scientific establishment (See reduced blackboard-image). This discussion revises some of the findings of the previous lesson. (20 min.)

Once science is been located as a historically developing social institution and a system of experts and expertise, the historically changing borders of science are discussed.

- In a frontally coordinated discussion the class is aksed to list branches and modes of knowledge production, and is asked to classify them. Accepted and rejected science, pseudoscience, and fringe-science were suggested as categories[2]. (15 min.)

Well-known examples like astrology and other divinatory techniques are usually mentioned, and the historically and culturally changing position of these modes of knowledge-production in the given scheme of classification can easily be pointed out. Radical shifts (introduced as paradigms) in norms need to be mentioned, their effects considered, and this flexibility can be contrasted with the relative stability of the tasks of science as a social institution.

- The discussion on the norms leads to the introduction of methodological and ethical (Mertonian) norms. The "scientific method" is introduced as an historically changing set of methodological norms, which were seen in different periods as describing successful knowledge-gaining procedures[3]. (25 min.)

Once the epistemic elements of NOS were thus embedded in the social, the end of this lesson as well as the last two lessons are used to cover the more traditional material on induction, deduction, falsification, etc.

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[2] Rather simplistic differences between pseudoscientists (mimicking the norms of real science) and fringe scientists (striving to conform to the norms of science) were proposed. This is in line with recent interest in the pseudoscientist as opposed to pseudoscience. In addition the problems of the approach were also hinted at.

[3] These were consciously not separated. If there is time, an excerpt from Rudner's famous article can be given to the class (Rudner, R. 1953 'The Scientist Qua Scientist Makes Value Judgements'. *Philosophy of Science* 20 (1):1-6.), or the class can be asked to comment on the sentence: "How sure we need to be before we accept a hypothesis will depend on how serious a mistake would be" (This is the last sentence of the article). This can be used to underline that even for the purely epistemic considerations one should not disregard the social.

◊ The first side of a worksheet (on the Wason-task) is handed out to students as homework (see Appendix, HW 3).

LESSON 5

The fifth lesson is designed as the most demanding 90 minutes in the module.

- The lesson starts with a pair-work, where the first side of the handout (part of this was HW3) is completed by the pairs (this includes checking and correcting each other's responses and solving the other's problems). (20 min.).

The students are reminded that the right solutions (p and ~q, i.e. to check the other side of the first and fourth card) coincides with the logically valid forms. With this the possibility of errors in reasoning can be highlighted (see box).

- The same pairs together fill out the second side of the worksheet (30 min.)
- The results are discussed with the class (30 min.).

The class is introduced to 'the scientific method' in this indirect way, with the teacher frequently referring back to the formalisation of the Wason-test and the truth table of the conditional. Deduction is shown as moving from hypothesis (H) to observation (O), while induction as moving from observation to hypothesis.

The earlier formalisations are used to highlight the 'problem of induction', and the fact that falsification is a deductively valid method (i.e. a *modus tollens*).

◊ The students are asked to write a 2000-character-long descriptive essay based on the class work and their individual research with the title: "Compare induction, deduction and falsification. Summarise the method, the potential benefits and pitfalls. Try to give one-one real life example." (HW 4)

LESSON 6

The previous lesson is conceptually difficult, and time is taken to rehearse the content. If all are confident:

- The problem of underdetermination is introduced, using the same basic forms of conditional arguments. (25 min.)

- The conditional H ⊃ O is extended to include auxiliary hypotheses: $(H \& A_1 \& A_2 \& A_3 \& \ldots \& A_n) \supset O$, and students are asked to give specific scientific test-situations and explicate what is to be tested, and how underdetermination is significant in the given situation (This is connected to HW 1) (20 min.).

As underdetermination is often perplexing for students, they are introduced to some simplified ideas of Duhem, Neurath, and Quine. Importantly, none of these writers considered underdetermination as an insurmountable problem of science (see more in my articles at the end).

Argumentation – logic – nature of science

Depending on the class the truth table can also be given. The truth table of the conditional is:

p	q	p ⊃ q
1	1	1
1	0	0
0	1	1
0	0	1

The module works without this as well. It is, however, important that students become familiar with conditional sentences, and how fallacies can result from denying the antecedent or affirming the consequent.

To practice this the students can be asked to devise as contrived examples as they can, and they have to be as quick as possible in supplying the correct answer to as many partners as possible. If they get confused, they are instructed to think about the simple examples, and use this knowledge when tackling the more complex ones.

At first, many of the students giving the example fail to solve the task correctly (at times even their own examples), but after approximately 15 minutes and lots of heated debates, most become confident and get used to using the logical structure in devising and answering the problem.

The students who have difficulty at this stage should receive extra homework and are asked at the beginning of the next class to share their examples with the class. This is also used as an introduction and rehearsal.

- The rest of the lesson is spent on revising the topics of the previous lessons, according to whether they belong to the "inside" or the "outside" of science

The aim of the lesson and the discussion on the "insider" and "outsider" views of science is to wrap up the course, and to revise and consolidate the content of the previous lessons. As a final homework assignment, students have to write a 3500-character-long essay on

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Looking at science from the inside and the outside

Problems of methodology and controlling error sources would belong to the "inside", while the picture of science in the media, complex interactions of science, society, policy-makers, etc. to the outside.

The students are asked to compare their primary and secondary school education to what they know about university and pot-graduate education.

They clearly see the gradual move towards the "inside" of science from the "outside", even though the names of subjects have stayed the same during their education. In primary school, science had for them an unquestionable authority, but during their High School years they meet more and more of the intricacies of scientific activity. As their knowledge of science increases, the extreme complexity of the issues became clearer and clearer.

The two categories help students to place their experiences concerning the popularisation of science, as well arguments they are already familiar with either strongly supporting the scientific establishment (scientism) or strongly critical of it and seeking for alternatives ("romantic" attitudes).

Their common impression they reach is that, just as in the case of demarcating science, these general attitudes help little when a decision is to be made or action is to be taken in case of a specific complex problem. It also helps them to appreciate in a new light the personal trajectories they are taking – some moving more and more "inside" science, and planning to continue their studies at university science faculties, others remaining "outside", but still facing science-related issues every day.

As students progress in their studies their position is constantly changing, and this change needs to be addressed and explicated, especially in courses that focus on the gradual development of reflective thinking and responsible citizenship.

"science as a social institution and the scientific method" (HW 5). They are urged to use their HW 4 (which was not graded only handed back with corrections) as a starting point. HW 5 is later graded to provide a grade for the module.

Obstacles to teaching and learning:

The rationale behind teaching NOS (often expressed in course descriptions) heavily relies on teaching reflective and critical thinking to students so that they can appreciate and evaluate multiple standpoints and balance them. This ideal, however, does not necessarily take into account the cognitive development of students. Some studies suggest that developing this level of reflective thinking may only be open to a small proportion of students, and is very much a function of their age (King and Kitchener 1994). In general, it is little known how good students *can* be at understanding and utilizing the complex NOS issues. It is reasonable to believe that not all the skills and sub-skills relevant for critically appreciating various standpoints in controversial issues (that often characterize NOS or Socio-Scientific Issues (SSI)) are fully developed[4].

This is a general problem for any module targeting these skills. More specifically and pertaining to this module, there is no evidence that it would pose greater difficulties for students than other similar modules, in fact they found it comparatively easier and "more fun" (from assessment of two consecutive yeargroups, based on anonymous questionnaires).

Pedagogical skills

As the module is presently organized, the aim was to minimize expertise required of the teacher concerning history and philosophy of science (though such expertise might be a benefit when moderating and channelling discussions). As it stands, however, the module requires class-management skills that at least in some countries are not included in science-teacher training (but generally present in e.g. teaching language teachers). This might therefore appear to science teachers as unusual first. The guided discussions, groupworks, etc. are, however, not totally alien to science teaching, yet there extent and the open-endedness might pose inconvenience for teachers not used to inquiry-learning.

Research evidence

The existing evidence is summarized below, but as no benchmark exists for NOS, it is difficult to properly compare the module proposed in this article to any other module.
As the sample size was small (one class of 15 students in 2006 and another one with 22 in 2007), I only offer a meaningfully detailed analysis that relies on a number of qualitative and

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[4] Experts in the Delphi report found good critical thinking to include „both a skill dimension and a dispositional dimension. The experts find CT to include cognitive skills in (1) interpretation, (2) analysis, (3) evaluation, (4) inference, (5) explanation and (6) self-regulation." (Facione 1990) Many of these skills develop well into adulthood , and even adults show weaknesses in certain areas, as specific patters of non-correct, "fallacious" reasoning are common, whether directed by "hot" or "cold" biases (Griffin et al. 2002; Holyoak and Morrison 2005; Kahneman et al. 1982; Kahneman and Tversky 2000).

quantitative aspects without statistical analysis. A major concern about stressing *sociological* aspects in the classroom is that while such accounts can avoid unwarranted scientism, they pave the way for unfruitful relativism. So it seems crucial to see whether the module actually leads to sceptical and relativistic views. It *is* thoroughly social-constructivist − not by introducing such models explicitly, but by treating all epistemic norms of science as constructed through a social process.

The general impression was that the students realised that historical contingency does not lead to extreme relativism, as the cultural background at any given time period will have more or less clear norms according to which decisions are made within a tradition, even though these norms themselves are subject to change. The fact that stressing the social did not lead to seeing accepted scientific knowledge as a matter of politics was − as discussions revealed − mostly due to the insights that students gained in the group-work that focused on designing an ideal social institution for the production of knowledge. Not *ending* a module with the introduction of contingent social factors (as most textbooks do) will result in a less negative role being associated with the social. To check this informal insight, a written 2000-character home assignment (HW 6) was given with the title: "What does it mean that science is a social institution? Describe some of the implications of this view (ones that you consider to be important)."

The analysis of the essays showed markedly positive appreciation of science as a social institution. None expressed "dangerous" relativism, yet all portrayed science as "embedded" in society. Typical conclusions were "The various social institutions cannot exist and work without the knowledge and the help of others. Science is also a field of knowledge which is needed in many cases to let other institutions operate or function in a better way", or "To sum it up, science is a system which was created by people for people to gain more information about the world around us", "...a social institution ... that serves the needs of the society, the needs of the people". A third of the essays stressed that science is an institution that serves "us", "humans", more than two-thirds of the essays stressed the importance of science for other social institutions, and half of the latter group also stressed interaction with other social institutions (with one essay stressing *mutual* interaction of various social institutions and science). Science was seen as important in health care (5 essays), school science (3), economical-political-environmental issues (2), jurisdiction (1), architecture (1), and religion (1, science and religion were portrayed as conflicting social enterprises). This shows that when writing the assignments, students primarily utilized their knowledge about medicine (generally seen as the 'paradigmatic' example of science for lay people (Gregory and Miller 1998)) and science as taught in schools. The fact that the majority of the examples were not related to school-subjects like Physics or Chemistry, suggests that one of the main course aims was achieved: the course was centred around the student as knower, and not around specific subjects.

These results strongly contradict the claims that social constructivist views lead to extreme relativism. Even the most "relativist" of the essays (stressing the mutual interaction of institutions) concluded:

"In short, society can ensure funds, equipment and trained manpower to make a particular discovery possible, but at the same time it can prevent an advance by diverting sources and manpower elsewhere or establishing an intellectual atmosphere in which a particular question will not be asked. This way the most basic science that is done today is a product of our society, it is a social institution."

Although both the methods and the results of science were seen as contingent by the student, the essay cannot be considered "dangerously relativistic", even if it might not be what many science educators want students to believe.

These essays also positively strengthened the view that the sociological approach is not too difficult. The conceptual apparatus was easily handled by the students, they could readily connect the theoretical insights with their own experiences and even though some essays showed conceptual weaknesses, this was rather rare and partly due to difficulties in handling English, a second language. (But note that the students were average to high ability!)

Are not the epistemic issues compromised by spending a disproportionate amount of time on social ones? The module certainly offered more concerning the sociological aspects of the NOS than most current textbooks devoting a similar number of contact hours to NOS. It also attempted, however, to cover approximately the same material in traditional philosophy of science as other textbooks explicitly addressing NOS (indeuction, deduction, falsifyability, experiments, hypothesis-testing, etc). So a natural question is whether the epistemic aspects have been compromised in ways that this module offers *less* than other approaches. But if traditional elements of the NOS curriculum can be "condensed", the module can prove to be useful even if the original aim, to devote more attention to a sociological approach, is not endorsed.

To introduce the epistemic aspects of NOS, the module relied on some previous knowledge about argumentation theory and formal fallacies, and introduced concepts through a specific formalism. The students had some background knowledge about zero-order logic, truth tables, and simple formalizations, but the material relevant for the module can be restructured so as not to require these. As expected from the literature and from earlier experience, the crucial part of the material was to understand the conditional structure. For this the well known Wason-task was used, and at first the students did rather poorly on the task, even though they had already covered the material earlier in the year. Many of the students gave an incorrect answer to the first exercise (see Appendix, the responses for Q. 1. and 2. were 16, 11, 9, 11 and 17, 1, 0, 18, respectively for p, ~p, q, ~q for one group, for another 10, 3, 6, 4, and 9, 0, 3, 9), and question 3. yielded only slightly better results. However, as grasping the truth-function of a conditional was a crucial step in introducing the "scientific method", emphasis was laid on making sure that all students are at ease with the conceptual framework. Results improved significantly in question 4., when each student had to devise as contrived examples as they could, and was asked to test their partner, who had to be as quick as possible in supplying the correct answer. At first, though the theory had become clear for all, many of the students failed to solve correctly even their own examples. After approximately 15 minutes and lots of heated debates (and some extra examples by some of the pairs), all became confident and got used to using the logical structure in devising and answering the problem[5].

The next lesson started with a revision (question 1. on page 2. of the Appendix). After spending ample time on the formalisation, the epistemic insights derived were more or less straightforward. The students generally had no difficulty filling out the second sheet on the "Scientific method". Question 3. (page 2, Appendix) was used to test what already existing background knowledge the students have as well as to see if the logical validity of forms and

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[5] There was one student in the 2006 class but none in the 2007 class who at this point had difficulties, and who received extra homework. By the coming week the student was confident enough to share her examples with the whole class, and this was used as a warm-up repetition for the class.

the Wason-task were in fact connected (identical answers in columns 2 and 3 were seen as a positive indicator, if column 4 contained correct and matching answers). About half of the groups correctly identified induction, deduction, and falsification; so introducing the scientific method via this specific formalism seemed to have caused no major problems. Students were already familiar enough with the terms to be able to match formalisms and concepts. This reinforces the view that in NOS these issues need not be frontally introduced, as 17/18-year-old students have sufficient resources to tackle the problem in question 3. Only few individuals (4 out of 22) failed to correctly connect the logical validity of forms with the Wason-task, and the conceptual difficulty was again discussed in class. By this time several of the students felt competent enough at tackling the question to offer one-on-one tutorials to classmates. In general, it was found that once the conceptual difficulty of properly appreciating the formal properties of conditionals was overcome, the rest of the insights were easily grasped. Even understanding and using complex NOS issues like underdetermination posed no problem (all students could easily and correctly identify and 'design' relevant situations), once the general formalism was understood. On this latter point, however, individual differences were – again, as expected – very significant. So cognitive development seems to be decisive on how successfully the epistemic aspects on the NOS can be condensed this way.

A homework assignment (HW 5) was designed to check whether this condensed approach to epistemic aspects of the NOS was sufficient to yield understanding comparable to that coming from standard textbooks (note that as no benchmarks exist, students' achievements were compared not to other students, but to the official curricula and textbooks). The general impression from the essays was very positive. Initially, one obvious worry was that the introduced formalisms would push students towards giving simplistic logical examples for the scientific method, and not "real life" ones. This worry proved to be unfounded, the number of real life examples superseded the simple logical ones (9 as opposed to 6 for 10 essays). While some non-scientific examples were given (4), most students gave scientific examples as well (8). Interestingly, and as opposed to HW 6, the examples here matched school subjects much more closely, with topics in Physics (4, 3 of these astronomical), Biology (3), and Maths (1). Medical issues received significantly less attention (2), and there was no conscious reflection on school-science, unlike HW 6. This difference is noteworthy, even though the sample size was very small.

The same homework was also used to check what the results of incorporating the epistemic into the social were. Again, none of the "hyper-critical" relativistic view that social approaches are feared to evoke appeared, though every essay stressed the relative applicability of induction, deduction, and falsification. Fallibility was addressed in most essays. About half of the essays were optimistic in tone, while the other half pessimistic. The optimistic ones argued for a mixed use of methods, sometimes claiming that all three properly combined can yield infallible knowledge. None of the essays with pessimistic conclusions attacked science: the ideal of certain knowledge was found wanting, but this was always worded as a critique of certain epistemic expectations, and never directed against science.

What is the general offshoot of the module? The final question of assessment addressed here is whether the module was suitable for the students and the specific course. An end-of-year questionnaire was used to obtain feedback from the students (questions including: What was good/bad in learning about Theory of Knowlede? How much did it help you to prepare for presentation and essay writing? Suggestions for the coming year? Did the course

help you in other subjects? Do you have ideas to make the course more interesting/useful/profitable?)

One student explicitly criticised the module "because topic was sometimes ununderstandable", and continued in general about the whole course "The topics also sometimes boring and difficult to pay attention [to] in 6th-7th lessons." Apart from this, and the general demand to get more feedback for their written work (esp. HW 5 and 6, used for the evaluation of the module, but not graded and discussed in class), the responses connected to the module presented here commonly included appreciation of the importance of critical thinking skills, and of the fact that the course helped students to improve in these skills. Many students thought that their presentation and/or writing skills improved, but would have preferred even more feedback. The emphasis on reflective and critical thinking was not always applauded, as one student wrote, "The only message that I discovered from our lessons was to look critically at everything. But this rather caused some kind of confusion in my mind instead of clearing the meaning of concepts." But even though this can be seen as a sign of frustration on the student's side, this again is not an endorsement of extreme relativism. While many students found the course unconnected to their other courses, a minority pointed out that the course-related knowledge could often be used (not just in the modules corresponding to the subjects) in other subjects.

The module gives a less distorted view about science than some alternatives, as it provides students with a view of NOS that is more in accord with the current understanding of science in history and philosophy of science (HPS) and science studies communities than the many other approaches. Further, the social dimension can be included in NOS without weakening the epistemic element. The module successfully utilizes resources and assets that students already have, and manages to bring students closer to critically understanding their surroundings as well as to connect the school curricula to their lifeworlds[6]. Students often made use of the numerous class discussions to openly share their experience and questions. Most notable were the discussions on demarcation and pseudoscience (several of the students came from "scientistic" backgrounds, but some had parents actively pursuing Reiki, Silva's UltraMind System, following astrology-columns, etc.), and the final discussion on science from the "inside" or "outside"[7].

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[6] To cite just one example: students were assigned to read a one-page text with the title "Economics meets science". Even though in this text induction and deduction were displayed as simply different strategies to obtain grants, apart from one single student in the two yeargroups, all students clearly realised that the position taken in the text is not meant to be true (this was tested via an end-of-module questionnaire in the first year, and the 2000-character-long HW 5: "Compare induction, deduction and falsification. ... " in the second). This shows that students have (at least in certain cases) the ability to differentiate between reliable and non-reliable sources, even if a non-reliable source is offered by a teacher. By discussing their reaction to the text, students could reflect on their own attitudes, on how they could openly criticise a source given to them by an authority, why this was difficult, and how similar situations can be handled effectively.

[7] These discussions allowed students to bring up and debate issues in a classroom or group setting where improving critical thinking skills was admittedly one of the main aims of the course. One very positive finding was that identifying the weaknesses and strengths of positions (as opposed to a "black or white" view of issues) also strengthened students' willingness to practice these skills in a number of other areas. This is not a trivially achievable aim, as the famous Delphi report on critical thinking states: "RECOMMENDATION 4: Modeling that critical spirit, awakening and nurturing those attitudes in students, exciting those inclinations and attempting to determine objectively if they have become genuinely integrated with the high quality execution of CT skills are, for the majority of panelists, important instructional goals and legitimate targets for educational assessment. However, the experts harbor no illusions about the ease of designing appropriate instructional programs or assessment tools." (Facione 1990).

The scientific method – and the uses of arguments

I. Arguments

1. Solve the problem and measure the time it takes for you to come to a solution you believe is right!

You have a set of four cards each of which has a letter on one side and a number on the other side. The visible faces of the cards show E, K, 4, and 7. Which cards should you turn over in order to test the truth of the proposition that if a card shows a vowel, then its opposite face shows an even number?

Solution: Time needed:

2. Solve the problem and measure the time it takes for you to come to a solution you believe is right!

You are in a bar where four costumers are consuming beverage. You either know the type of drink they drink, or their age. In this case you know that the customer drinks beer, carrot juice, is 20 years old and 4 years old. Which customers should you ask for the other piece of information, in order to test the truth of the proposition that if someone drinks an alcoholic beverage in the bar, then she has to be over 16?

Solution: Time needed:

3. A crucial part of both exercises above is a conditional sentence with the if...then... structure.

   a. Did you notice this when solving the problems?   YES   NO

   b. Are your two solutions identical?   YES   NO

4. Make two problems that have an identical structure. Write them down here, **but do not write down your own solution yet!**

1st problem:
   If..

   , then..

   The four options: Partners solution:
                                                   My solution:

2nd problem:
   If..

   , then..

   The four options: Partners solution:
                                                   My solution:

5. Show a classmate your own problems. Write down your solutions and his solutions!

II. Scientific method

1. The above exercises had similar structures. The four options can be formalised as follows:
   ~ means "not" or "not true that" [so ~p = not p or p is false]; p and q stand for the first and second halves of the conditionals,
   ⊃ means that the relation between p and q is a conditional one [so p ⊃ q = if p then q]

   1.   2.   3.   4.

Further user professional development

Provide links to further self-study sources, and appropriate readings in personal subject knowledge, historical knowledge, and philosophical knowledge.

Written resources

Appendix:

Form:	$p \supset q$	$p \supset q$	$p \supset q$	$p \supset q$
	$\underline{p}$	$\underline{\sim p}$	$\underline{q}$	$\underline{\sim q}$
	q	$\sim q$	p	$\sim p$
	modus ponens	negatingaffirming antecedent	modus consequent	tollens

1st ex.	E	K	4	7
2nd ex.	Beer	Carrot juice	20	4

Please also circle here which of the options you found necessary to check!

2. Now imagine a scientist who tries to use the previous game to see how one can draw inferences in science. p will be substituted be H hypothesis, q by O observation.

   So the sentence will be something like: if H hypothesis is true then we observe O. (H $\supset$ O)
   How could you reconstruct the four options above?

   1.   2.   3.   4.

3. In science, one can use different methods to arrive at general statements (laws) concerning nature. Fill in the table working with a partner!

	Resembles option (choose from 1-4 above)	Did you choose this option as necessary for deciding truth of conditional?	Logically valid? (circle what is correct)	What can you know conclusively following this method about H or O?
Deduction		YES / NO	YES / NO	
Induction		YES / NO	YES / NO	
Falsification		YES / NO	YES / NO	

4. Formulate your findings and the connections you noticed between scientific method, argumentation and logical validity. Also write down any other observations!