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Teaching Teachers NOS: Practical Examples and Classroom Experiences

PETER DEKKERS *(dekkersp@ul.ac.za) University of the North, South Africa*

ABSTRACT *This paper presents a range of examples of teaching/learning activities for learning outcomes pertaining to nature of science (NOS). The activities have been tried out with different groups of pre-service and in-service teachers of science in professional development programmes at a 'historically Black' South African university in the Limpopo Province of South Africa. Most of the activities serve as both learning activity and model lesson, and are equally appropriate in secondary school – some, with suitable adjustment of level, even in primary school. The student-teachers in the programmes generally have a limited understanding of the concepts, methods and nature of science. They tend to have understandings of NOS that are very similar to views reported from across the world. Science teachers in the region typically, but far from uniquely, tend to believe quite strongly in witchcraft and magic, which play a major role in local society. Many adhere strongly to religious, generally conservative Christian, beliefs. Many see conflicts between these three 'ways of knowing' (science, magic, Christian). and reject some or all tenets of one or more of these systems of thought. Others see no conflicts at all and seem to be able to reconcile views that are mutually exclusive or contradictory. The activities described here use a practical, challenging and often surprising approach to elucidating contemporary views of NOS, eliciting traditional or popular views of NOS, and confronting these different kinds of views with each other. The central question underlying these activities is: how do scientific knowledge claims come about, and how sure are scientists, and everybody else, about these claims? The paper describes how students engage with these activities and what they generally learn from them.*

KEY WORDS: *nature of science, teaching/learning activities.*

Background

Science teachers in the Limpopo Province of South Africa use very little practical work. As purposes of practicals, they recognize only confirmation and verification of theory, and rarely development of skills and understandings related to problem solving, inquiry, nature of science, or the role of science in society. The teachers' own skills and understandings in these areas, too, are modest. In designing in-service programmes, I therefore decided to prioritise developing in teachers a sense of the purposes, meanings, methods, strengths and weaknesses of science. This accords with the new South African curricula for the Sciences at primary and secondary level. The new curricula (Department of Education (DoE)., 2002; 2003). present the view that a person who is scientifically literate has an understanding of basic science content (facts, principles, theories, laws etc.), but also needs understandings and skills associated with development of scientific knowledge through inquiry, and adequate attitudes and understandings regarding science as a human enterprise: its cultural, political, historical, economic and societal role, its philosophy, status and significance. These 'human' aspects of science are known as aspects of 'nature of science' (NOS) (though in the literature, 'NOS' is not clearly delineated and often refers to only one or a few of these aspects, not all).

This paper describes the tentative development of a basis for science teacher education that explicitly includes developing an understanding of epistemological aspects of science, sufficient for secondary school. Scientific epistemology involves the basis of scientific knowledge claims, their status, and the factors that influence them. Abd-El-Khalick, F., Bell, R.L. & Lederman, N.G. (1998) argue that philosophers of science do not agree on these matters, but that there is sufficient agreement to decide on outcomes for secondary school science teaching. Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003), in a Delphi study among experts in the UK, confirm these areas of consensus and add others. A summary is given in Table 1. These understandings may be seen as the 'skeleton' of NOS. Each teaching/learning activity for NOS that is reported in this paper includes at least one, but often several of these aspects. Descriptions of the activities refer to these aspects with the letters a.-k. as given in Table 1.

Table 1
Aspects of Adequate Understanding of NOS for Secondary School, as Given by Abd-El-Khalick et al. (1998; aspects a.-g.). and added by Osborne et el. (2003: aspects h.-k.).

An appropriate understanding of NOS reflects that scientific knowledge is:

a. tentative (subject to change).;

b. empirically based (based on and/or derived from observations of the natural world).;

c. subjective (theory-laden).;

d. partly product of inference, imagination and creativity (involves the invention of explanation).;

e. socially and culturally embedded.

Also required are knowledge and understanding of:

f. the distinction between observation and inference, and their relevance to scientific development;

g. the functions of and relationships between scientific theories and laws.

h. the historical development of scientific knowledge,

i. the methodical and structured experimental approach as key characteristic of science,

j. the difference between established and frontline science in terms of reliability and trustworthiness, and

k. the moral and ethical dimension to the conduct of science and use of its products.

NOS-based learning outcomes are not restricted to a particular age group, all can learn from (and enjoy) the activities sketched in this paper. Here, I discuss activities that were used with prospective and active (though not necessarily qualified) teachers of science in the Limpopo Province, South Africa. The reason should be clear: if we fail to assist these science teachers in developing adequate understandings of NOS (understandings that were never part of their professional development) *and* an educational practice that matches these new outcomes, the beautiful plans and dreams of curriculum reform are beyond our grasp.

Outcomes of NOS are regarded as *regular* subject matter, just like Newton's Laws of Motion. Research elsewhere has shown that students do not acquire understandings of NOS, if these are taught implicitly. For example, students who are immersed in scientific inquiry do not become aware of the tentative nature of its products - that is, scientific knowledge claims - unless they are explicitly confronted with information and intellectual challenges regarding this aspect of NOS (Bell, Blair, Crawford, & Lederman, 2003). Knowledge and understanding of NOS should be taught *explicitly*. But unlike Newton's Laws, NOS permeates *all* aspects of science knowledge and inquiry processes, so that NOS should be reflected in all science teaching/learning activities. However, that is rather a challenge if one intends to introduce NOS for the first time to students with a substantial educational background in which NOS was missing. In our programmes, we therefore *begin* to expose participants to aspects of NOS by including little science content, since participants have a varying but low level of content mastery (Dekkers, 2003). Later activities have more science, but rarely go beyond Grade 9 (ideally age 16, the end of compulsory education in South Africa).

Teachers need to understand NOS themselves before they can teach it. Satisfying this pre-condition is what the activities described in this paper aim to accomplish. The activities have other purposes too, and serve a variety of additional educational aims as is specified below. Naidoo and Savage (1999) argue that 'a better use of existing resources' is needed in science education, which should :

> *"Be cheap enough for all educational institutions, thus promoting equity. Be more soundly based on current learning theories, thus promoting understanding rather than rote learning. Empower students to contribute better to personal, community, and national development, and participate more actively in the democratic process. Present a more accurate view of science than traditional courses portray" (p. 167).*

The activities presented in this paper are an attempt to contribute to this programme.

Context

The activities described here have all been used in the so-called ACE (Advanced Certificate in Education) programmes for science educators at the University of the North (UNIN), in the Limpopo Province of South Africa. The region is best known abroad for the fact that the Kruger National Park is situated in it, but in addition to tourism has mining and agriculture as main economic activities. The region is very rural, very poor, with high unemployment rates. The University of the North was a Black university during the apartheid era, and was then situated in the 'homeland' Lebowa. Ten years of democracy have seen improvements in many areas, but clearly there are still very many obstacles that need to be overcome. The situation in education, and science education in particular, is among the problems that receive a high level of governmental and academic attention.

The ACE programme provides a qualification for teachers who teach science, have a 3-year teaching diploma, but are not necessarily qualified to teach science. Since 2001, I have used the activities with about 100 student-teachers, while colleagues have used them with between 50 and 100 more teachers. Some of the activities were used in 2004 with Year 1 students in our B.Ed. (First Degree) programme, for 20 of them as part of Physical Science, for about 70 students as part of a 'Scientific Literacy' module. The first group intended to become science teachers, the second group did not.

Activities depending strongly on linguistics (type 5 below) were used initially, but found to be academically rather demanding. Some were simplified, others are now used in our Honours Degree (Science Education) programme, with up to about 70 students so far.

Teaching strategies and activities for NOS

Below I describe six types of activities. Though not exhaustively (see e.g., also Linneman, Lynch, Kurup, Webb, and Bantwini, 2003), this paper presents a variety of teaching approaches, strategies, intended outcomes, and uses of local opportunities. The activities may well be used to pursue pedagogical or content objectives for science that are not NOS related. However, the instructor should clearly choose and articulate main goals and not pursue too many objectives at once. The six types are described in the following rather arbitrary order:

1. Small Group Practical

These activities model hands-on, learner-activating approaches, demonstrate a range of opportunities for low/no-cost practicals and improvisation, have a low threshold in terms of science content, but involve surprising and provocative phenomena. Teachers love them.

2. Teacher Demonstration

These activities resemble the practicals even though only the facilitator handles equipment. Participants are encouraged to forward views, debate, explore, compare, evaluate etc. They are very much minds-on. Teachers often comment, in response, that science is like magic.

3. Visits to researchers

Many of our students see science as something that belongs not to them but to 'others', is done not by them but by those 'others'. Science is seen as something that belongs in schools and laboratories with no bearing on real life. UNIN has a range of fascinating science research projects and educational resources. We send students on visits during which they interview available research scientists on aspects of NOS. Scientists and science educators do not agree on all NOS matters, but the challenge for student teachers is to critically develop their own position. Teachers tend to be very impressed and experience a reduction in the 'distance' between science and themselves.

4. Debate and Discussion

Science issues that are relevant to society rarely have clear-cut objective solutions. Yet in the science our teachers teach, all questions tend to have exactly one correct answer. Debates on controversial statements are meant to encourage student teachers to identify various perspectives on societal issues that involve science, to explore and compare arguments pro and contra *all* sides of the issue before coming to a conclusion or judgement. They are meant to exercise their reasoning abilities and to highlight human aspects of science, both in terms of society's responsibility for the scientific enterprise and the impact of science on people's lives. Students tend to enjoy the debates but have a tendency to choose sides too soon.

5. Literature and Internet study

Literature and Internet provide rich sources of accounts 'from the horse's mouth' about the work and accomplishments of scientists and the views and arguments among philosophers of science. Reading with comprehension, identifying main points in a text, summarising, relating a text to one's own situation, critically evaluating views expressed in texts – all these cause great problems for our students. Activities of this kind provide appropriate training.

6. Integrated NOS

NOS should become an integral part of all science teaching. Activities of this final type model an integrated approach, aiming for teaching of content and/or processes in addition to NOS (and tend to support, furthermore, several of the intentions mentioned in the types above).

Examples and Experiences

The activities described below can be used for various NOS aspects, but rather than aiming for all (with the risk of hitting none), it is important to choose a focus. The text below specifies these foci by referring to NOS aspects (a through k) listed above, but many other choices are possible.

1. Small Group Practical

1.1 Dinosaur (NOS aspects a to f).

Students form groups of 4-5 and receive pictures of bones, see Figure 1. (Source: N. and J. Lederman, activity carried out during NOS workshop at UNIN. Figure 1 is reduced in size, but it really fills four A4 sheets. The reconstructed skeleton, top right, is of course not yet given).

They carry out the following task:

Reconstruct the skeleton of the animal of which you received the 'bones'. Ask yourself: can scientists ever be sure that they have found the correct solution to this puzzle? Or is it more likely that different groups of scientists tend to find different solutions?

Students cut out the 'bones' and reconstruct the skeleton by pasting it on a flipchart sheet. They present their results and explain what kind of animal they think this was. The results are compared with each other and with the solution palaeontologists have found (top right: a bat-like dinosaur called "Scaphognathus Rassirostris").

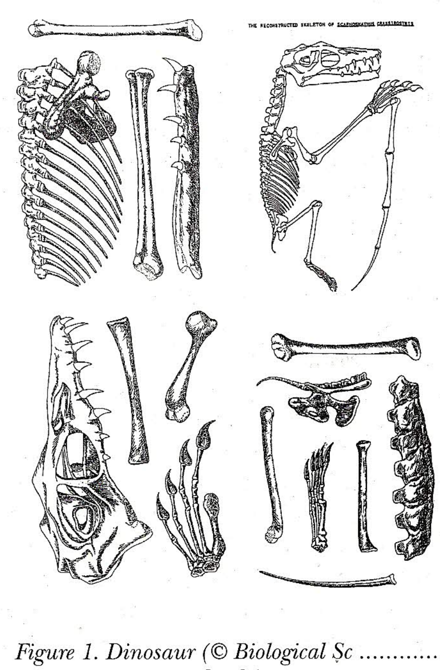

Figure 1. Dinosaur (© Biological Sc .... Study)

Discussion highlights the tentative

and subjective aspects of the solution, the role of creativity and imagination in addition to empirical evidence, the importance of the social and cultural background of the scientist involved, and the distinctions between observation and inference.

Some students think that they must 'find the correct answer' and miss the point. In the 'Science Literacy' class, disregarding all I said, groups did nothing at all until one student went through the course outline, found the 'answer' at the top right of Figure 1, and had all groups copy his group's work! However generally the activity 'works' wonderfully, and students themselves develop most of the arguments regarding NOS. (Note that 'science literacy' is a compulsory subject for all who want to become teachers but *not* teachers of science. In view of their most probable school experiences with science, it is unlikely that they see it as an enjoyable subject, or one in which they can achieve competency. Therefore, the course tries to help students develop basic concepts and understandings of the methods and nature of science, but first has to address their attitude towards science. To change that takes time, as illustrated above, but I believe that change does eventually take place for most students).

1.2 Merry Go Round (NOS aspects b, d and f).

While 1.1 is an introductory activity, the following is used to help teachers design their own NOS lessons. The activity is based on a phenomenon found, for example, in Liem (1992). Cut a spiral paper shape (Figure 2). Attach a cotton thread to the dot in the center, suspend the spiral, then place a burning candle under the shape (leave about 5-10 cm space to avoid overheating). The shape will rotate due to hot air rising from the flame. Student teachers work in groups and use this activity to design and (micro) teach a lesson to develop understanding of one or two aspects of NOS.

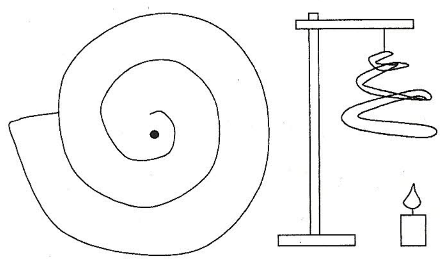

Figure 2. Merry-go-round.

Students ought to come up with a mini-lesson focusing, for example, on the questions: 'what do you see?' and 'why does that happen?' The NOS-related discussion could then focus on observation and inference. You *observe* a paper shape rotating. You *infer* that the flame causes the rotation, by heating up air that rises. You cannot observe the rising hot air, or the force it exerts on the shape (at least not in this set-up), but it makes sense to conclude this in view of your existing knowledge and experience.

Especially in in-service programmes, activities that show low/no cost opportunities for demonstration and practicals are very popular with teachers. However, they find it very difficult to focus on NOS, the majority find it hard to avoid a teacher-centred, expository mini-lecture about rising hot air.

1.3 Rising Water (NOS aspects b, d and f).

This activity clarifies NOS aspects different from those in 1.2. The event is well known (e.g., Liem, 1992). A burning candle in a saucer with water (food colouring enhances the observations) is covered by a glass jar (Figure 3).

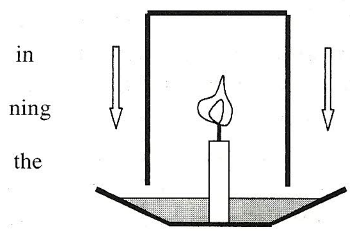

Figure 3. Beaker placed on burning candle in water-filled saucer.

This can be carried out nicely as a POE (Predict-Observe-Explain: White and Gunstone, 1992) activity, and student teachers often choose that approach. They do find it difficult to carry this through carefully, and often aim directly at the scientific explanation, while forgetting NOS.

One might let observers write up their observations, and then compare these. This will highlight the subjectivity and theory-ladenness of observation. All will see that the flame is extinguished, but many will not note that the flame becomes smaller gradually, not suddenly. Most will see that the water rises, but not all will note that it only starts to rise when the flame is gone. Only some will see smoke coming from the wick after the flame dies, and few will see the condensation forming on the glass.

People also tend to differ in their explanations of why the water rises. Many think this happens because oxygen is 'used up' when the candle burns, and forget that a virtually equal amount of carbon-dioxide is formed. Few tend to come up with the notion that when the air cools off, its pressure will tend to reduce, resulting in the outside air pushing water in until a balance of pressure is reached.

2. Teacher Demonstration

2.1 Mystery Tube (NOS aspects a.-g.).

The 'mystery tube' of Figure 4, an activity designed by Lederman and Abd-El-Khalick (1998), is a cardboard tube closed at both ends, with a piece of string sticking out (B), and three more knots (A, D, C). The demonstrator manipulates the Tube, pulling knot A, then B, D, then B again. Every time, the piece of string that sticks out is pulled into the Tube, and where you pull, some string comes out.

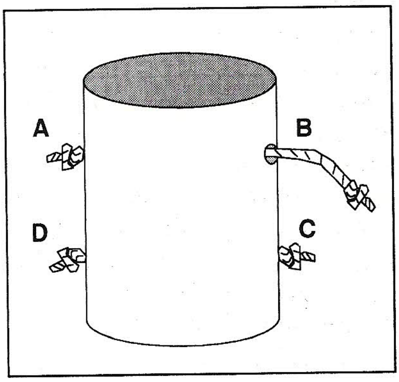

Figure 4. The Mystery Tube

Students are asked to write up their observations and to draw a model of what they think is inside the tube. (I sometimes use a practical, where students build and test models using string and toilet rolls). Using the model they hypothesise what will happen if C is pulled, and test the hypothesis. Models are compared. It is found that many models fit the observations. Students then consider whether their model is the only correct one, whether they are now certain about what is in the Tube, and whether their model describes all future observations with certainty.

This is an activity typically used at the start of a module, it includes no science content. Most students get the drift of the activity, and different people will come up with different models for what is inside the tube, all matching the observations. As long as it remains closed, we can never be sure which model describes what is inside, nor that all future observations can be predicted with one's model. The analogy with science can then be explained. In cases like gravity, the atom or evolution a scientist cannot look 'inside' to see how it works, only the external, empirical consequences are directly accessible. It is therefore not unusual to find competing scientific theories that all describe the observations equally well.

In accord with the vernacular meaning of the word, many student teachers understand the word (scientific) 'theory' to mean a guess or assumption, akin to a personal opinion or preference. They think that a 'theory' can easily be changed or replaced, while, again in accord with the vernacular, a (scientific) 'law' is something forever fixed and certain. A 'theory' that has been 'proven' in 'experiments.' The Tube can create clarity, and show that a law and a theory are both tentative, but categorically different. Laws express *relations* between events, e.g.; no matter which end you pull, the bit that sticks out moves in and the end where you pull comes out. A theory is a tentative *explanation* of events, just as the (material, graphical or verbal) model of the Tube explains the observations.

Somehow one out of every 5 or 6 students tends to insist that since their model matched all observations, they are sure that it is the only correct model, and that it predicts with certainty all future observations. Differences with models of others are seen as irrelevant. The urge to find the single correct answer to a question seems to be incredibly strong among our students.

2.2 Cartesian Diver (NOS aspects b through e).

An example of a Cartesian Diver (see e.g., Liem, 1992) is shown in Figure 5. The demonstrator explains, for example, that this experiment will demonstrate the power of the human mind. By 'willing' it, an object (a piece of drinking straw sealed off on both ends with paperclips) in a bottle of water is made to float or sink at will. And indeed, holding the bottle in his/her hands, by apparently doing no more than thinking, the demonstrator lets the object float or sink or be suspended. Members of the audience are asked to test the power of their mind – some always infer that squeezing the bottle does the trick.

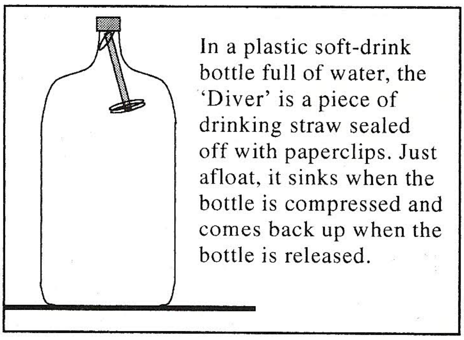

Figure 5. Cartesian Diver

Crucial questions during the demonstration are:

- *Do you believe that mind-power really makes the object sink? Why (not)?*
- *Do you believe that an explanation based on mind-power is scientific? Why (not)?*
- *What makes an explanation to be scientific? What distinguishes it from a non-scientific one?*

These questions are obviously very difficult, even for those who have studied them in depth. The discussion is meant to sensitise students to NOS questions, definite answers are not pursued or reached. (With B.Ed. students, this was used to introduce density in Physics).

Students and teachers like the activity. It sometimes instigates some to remark that science is just like magic, and to discuss what they mean by that. As a result, I have, on other occasions, *claimed* that I was using magic. Yet, students who did believe in magic refused to accept my claim. On that occasion, we discussed what enables them to decide whether situations or events do or do not involve magic. Usually, these discussions do not provide much clarity. Many students', not surprisingly, are reserved in their statements. Also, students views in these matters seem to vary widely. However, it is quite clear that science teachers in Limpopo tend to believe in magic and witchcraft, and tend to find it very difficult to delineate science and magic, or to identify the similarities and differences between them. This is a great activity to introduce NOS and invite students to explore these issues.

2.3 Hole in paper (NOS aspects a and b).

The facilitator cuts a hole in an A4 paper and sticks his hand through: that is easy. Would it be possible to cut a hole, in a sheet of paper of this size, that is big enough for the *whole* facilitator to pass through, possibly together with some students? The audience is generally adamant that this is not possible. However, an A4 paper cut as shown in Figure 5 (see e.g., Liem, 1992) will form a *very* large paper ring, which is quite big enough.

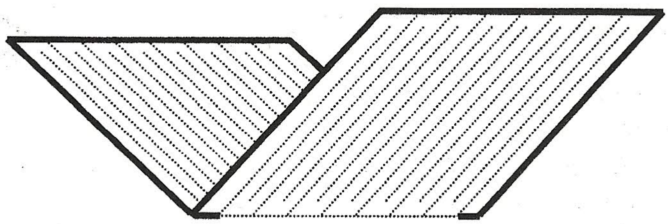

Figure 6. Very big hole in paper (cut along dotted)

Students readily accept that scientific knowledge changes in that it *grows*: as more research is done and technological advances are made, scientific knowledge accumulates and expands. However, the *tentative* aspect of scientific knowledge is something students find very hard to accept. Even when they accept that multiple theories can describe a single data set, they tend to reject the idea that accepted science ('laws') may, at some stage, turn out to have limited or no validity and may change by being *replaced* by other, equally tentative, science.

This activity clarifies that even when we are certain that we know the 'truth', a problem may be seen in a whole new light that changes all we thought we knew. If presented well, this activity models the tentative character of scientific knowledge extremely well.

3. Visits to researchers

On their visits to research units at UNIN, students in our in-service programmes work in pairs, collect information and write an essay to answer the following main questions:

1. What is the topic of this scientist's research? (What is the subject, what are the main questions, what is it all about?)
2. What is interesting in this research? (Why is it worthwhile for the researcher, you, society?)

3. What are the main accomplishments of this researcher's group? (How far is the researcher's group in answering their most important questions?)
4. According to this scientist, what is science? (Where does knowledge come from? How do we know what is true? Is accepted scientific knowledge fixed or can it change?)

For (prospective) science teachers, visiting research projects and scientific exhibitions at the University shows that in their "backyard" their friends and neighbours, so to speak, perform scientific work of high quality. This is one reason why student teachers enjoy the excursions. But there is *added* value to the visits if teachers ask scientists NOS-related questions in addition to questions about their work and accomplishments.

Scientists may view scientific epistemology differently from science educators. As science educators, we prepare learners for a world in which people have to make sense daily of 'frontline science,' to distinguish sense from nonsense in a rapidly developing technological world, and be part of an informed, responsible citizenry that takes decisions on use and abuse of scientific knowledge. This requires a NOS as described in aspects a, k. However, scientists tend to focus more on aspects b, i and j, stressing the reliability and validity of established scientific knowledge and its correspondence with an objective reality. It is difficult to see how else they could make sense of the work they do. Their view, too, is valuable.

Exposure to different perspectives of NOS can help teachers develop a critical understanding of the intended outcomes of the new curricula (DoE, 2002; 2003). In organising these visits, I therefore told our hosts what questions students would ask, but not what my own answers would be. I did not always accompany students, but when I did the contrast between the two perspectives was quite evident to me. If students have difficulty in coming to grips with NOS, the tension between the two perspectives may elude them. However, other students who are more critical are kept on their toes when they pick up the challenge of synthesising the views.

3.1 Electron Microscope (NOS aspects a, b, d, e, i).

UNIN's Electron Microscope Unit (EMU) has recently acquired a more powerful instrument that opens up new avenues of research. The impact of technological progress on scientists' research is illustrated lively, as is the ingenuity and creativity of scientists in designing ways to extend the range of observations accessible to the senses. Much of the EMU research is of commercial value and instigated by community needs, clarifying some aspects of the ways the scientific enterprise is embedded in society and culture. The research done at the EMU is almost entirely experimental, which is clarified and stressed quite strongly in the demonstrations by the units' experts.

3.2 Zoology Museum (NOS aspects a, b, h, i).

UNIN has a great Zoology Museum with local but rare species. It shows how methodological categorisation of species has enabled zoologists to establish historical and genetic relations between very different groups of animals. However the overview of this categorization, on the walls of the museum, was recently overhauled and adapted to newer understandings. Thus, the presentation stresses historical development of science knowledge and its tentative character.

Many of our science teachers are critical of evolution theory and palaeontological accounts of the history of the world. The Zoology museum depicts both; e.g., it has some ancient fossils, and our hosts discuss carbon dating. For many science teachers this may be the first time that they are exposed, be it superficially, to the arguments and methods scientists used to establish these theories. Teachers may discover that more is involved than opinion or dogma alone. (In many examples in this paper, but here in particular, there are obvious opportunities to elaborate on NOS much further and deeper than is done here. Evolution theory and its rivals are a marvellous challenge for educators working with science teachers in this region, where teachers have weak science backgrounds and strong religious commitments).

3.3 Aquaculture Unit (NOS aspects b, e, h, i, and j).

UNIN's Aquaculture Unit is involved in many activities, most directed at optimizing fish farming. The research seems highly applied, hardly fundamental. It focuses strongly on commercial activities and needs of the local community, involving exclusively locally relevant species and ecosystems. In many ways, the research is experimental, methodical and structured; paradigm shifts seem to be very rare in research of this kind. Scientists do tend to stress how similar research is done all over the world and how researchers depend on each other and the work done previously. Visits to the Unit make it abundantly clear how science can be put to work for the community, revealing the power of established science.

4. Debate and Discussion

Activities of this type model debates in society about the value and role of science and its applications. Ideally, students use their existing views and knowledge, augmented with understandings of NOS developed in the programme, to debate different viewpoints regarding that value and role. In groups of 4 or 5, they identify arguments against and in favour of given, controversial statements. They discuss various sides to the issue and try to establish a consensus view or, if that is impossible, to establish the group's views. The group writes a summary of the discussion and reports back to the class.

Initially, I used contemporary controversies on science applications, e.g., debates on whether HIV causes AIDS, on nuclear energy, or on he merits of IVF. However students had an insufficient grasp of the themes to be able to debate pros and cons. Generally, they have limited information regarding the issues and the different views existing in society. The more general statements I list below 'work' better, because they require less science-based information. However, students still tend to reach positions based on hearsay, sentiment and rhetoric rather than on information and reasoning. Students enjoy the activities, but it is unclear whether they develop understandings of NOS here. There is enough space for improvement.

4.1 Science and other knowledge systems (cultural, religious, IKST). (NOS aspects a, e, h, i, k).

Students discuss statements about the relation between science and other forms of knowledge:

1. *Traditional medicine is not science. We must make laws against it.*
2. *Witchdoctors are able to make lightning strike a person of their choice.*
3. *Science and technology make it possible to genetically change organisms, for example, by making maize resistant to drought. This can help reduce hunger. However, changing organisms is against the will of God and should be forbidden.*
4. *Science will in the long run answer all our questions.*

4.2 Science and Society (NOS aspects a, e, h, i, k).

Students discuss one of the following statements about the role of science in society:

1. *Scientists know more about some things than others do. They can be trusted. So, if they recommend something, we should do it.*
2. *Scientists spend billions on research that benefits nobody, for example, by sending people into space. At the same time, others do not even have jobs, shelter or food. Society should make sure that scientists do research that is useful.*
3. *Scientific knowledge is tentative, it can have changed tomorrow. Therefore, we cannot rely on it, it is just an opinion like all other opinions.*

5. Literature and Internet study

After an introduction to aspects a to k of NOS in some of the activities described above, students in our programmes compare these with the writings of philosophers of science and of scientists themselves. They then write an individual short essay about their findings.

This is the most challenging of all activities in this paper, or perhaps the most complex combination of challenges. Teachers battle bravely with these tasks, and some manage to prevail. However, the question as to whether the positive effects of this type of activity can be attained in more comfortable and enjoyable ways is still open.

It is certainly attractive, also for teachers, to have the opportunity of studying the writings and ideas of these philosophers and scientists first-hand. Experience suggests that conceptually, most can handle this in the case of the specific examples listed below. We should explore ways to reduce the linguistic obstacles.

5.1 Philosophy of Science (NOS aspects a to e).

Students are given a very brief overview of some main streams in philosophical thought, including descriptions of Plato and Aristotle's rationalism, Bacon's empiricist inductivism, Hempel's confirmationist and Poppers' falsificationist hypothetico-deductivism, and Kuhn's paradigms and scientific revolutions. (First chapters of Popper's (1959). *The Logic of Scientific Discovery* and Kuhn's (1970), *The Structure of Scientific Revolutions* are provided for those who want to dig deeper). Students determine for each of the NOS aspects a to e whether these philosophers would agree or disagree with it, and explain why they think so.

5.2 History of Science (NOS aspects a to f, and h).

A great site for autobiographical accounts of scientific developments is the Internet Modern History Sourcebook (http://www.fordham.edu/halsall/mod/-

modsbook.html). The following excerpts are taken out of context, with the risk of distortion. The texts from which these clips are taken themselves, however, are extensive enough to avoid that risk.

I. Marie Curie (1867-1934).: On the Discovery of Radium: "*...when radium was discovered no one knew that it would prove useful in hospitals. The work was one of pure science. And this is a proof that scientific work must not be considered from the point of view of the direct usefulness of it. It must be done for itself, for the beauty of science, and then there is always the chance that a scientific discovery may become, like the radium, a benefit for humanity.*"

II. Isaac Newton: Optics *[on Atomic Theory]*: "*...the* Aristotelians *gave the name of occult qualities... to such qualities only as they supposed to lie hid in bodies... to be the unknown causes of manifest effects: ...of gravity, and of magnetic and electric attractions, and of fermentations, if we should suppose that these forces or actions arose from qualities unknown to us, and uncapable of being discovered and made manifest. Such occult qualities put a stop to the improvement of natural philosophy, and therefore of late years have been rejected. To tell us that every species of things is endowed with an occult specific quality by which it acts and produces manifest effects, is to tell us nothing...*"

III. Charles Darwin: *The Origin of Species* (1859).: "*...Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that... from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.*"

IV. Joseph Priestley: The Discovery of Oxygen: "*...this section will furnish a striking illustration of the truth of a remark which... can hardly be too often repeated, as it tends greatly to encourage philosophical investigations: viz. that more is owing to what we call chance, that is, philosophically speaking, to the observation of events arising from unknown causes, than to any proper design or preconceived theory in this business. . .*"

6. Integrated NOS

NOS should become an integral aspect of science teaching and learning. Conversely, an exploration of aspects of NOS involving the relation between science and other forms of knowledge requires the integration of IKS and indigenous technologies into the teaching of science. Activities of that kind involve much more than simply teaching NOS. Below follows a description of two teaching/learning activities of that kind, used with science teachers. The activities are not described in full, we focus on the NOS aspect and how it is integrated.

6.1 Thumb Piano – Science processes (NOS aspects a to d, and i).

In this activity, participants first explore a 'thumb piano': a traditional musical instrument consisting of a series of thin metal strips attached firmly to a wooden board at one extremity, that produce sound when struck with the thumbs. Students determine the economic, cultural, technological, traditional, and scientific values of the artefact. They also note how it is played, and that shorter keys of the instrument produce higher notes. A key is then modelled by a ruler clamped to the table, made heavier with a 500 g mass-piece attached to its tip. If the ruler is hit it vibrates (see Figure 7); the vibration is now so slow that it can be seen with the naked eye and counted. If the protruding end is shortened, the vibration is quicker, corresponding with a higher note.

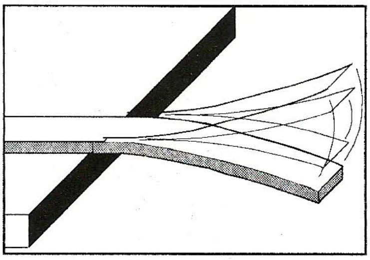

Figure 7. Model of thumb piano

In groups, students design an investigation of the thumb piano to establish how the length of the ruler and period of vibration are related. Doing so, a number of 'concepts of evidence' (Duggan & Gott, 1995) are introduced and clarified, including, e.g., reliability and validity of data, range, precision and accuracy of instruments, fair measurement, experimental error, etc.

Measurements of the relation between length and period typically render results such as given in Figure 8a. Measurements for larger lengths are not possible (rulers are 1 m long) and for smaller lengths not feasible (vibrations are too fast to count).

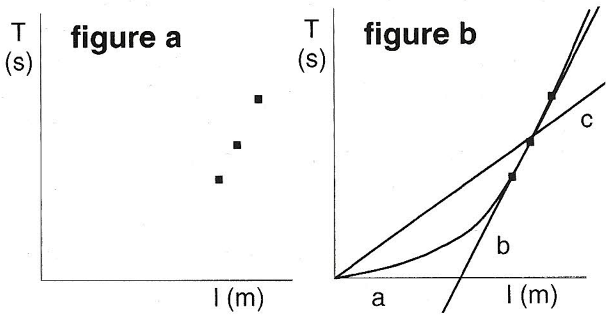

Figure 8. Which line fits the measurements best?

The question then is which of lines a, b and c describes the 'real' relationship, and what arguments we use to decide. The answers depend on many issues, including the researchers' confidence in quality of data, prior knowledge about this or a similar phenomenon, creativity of the researcher (e.g., seeing that b cannot be correct). In other words, NOS aspects a to d and i are pertinent, and clarify why there is a best answer, but no certain or definite one.

6.2 Presentations IKS and T and Science (NOS aspects a to e, and h).

So as to integrate IKST and science, teachers need to gain access to IKST. Textbooks provide a limited resource for teachers because knowledge, beliefs and technologies vary substantially across geographical areas and cultural backgrounds. Below follows a task that is a first step to help teachers gain access, in that they find examples of IKST in their own home and codify the associated knowledge, be it in a subjective and unsystematic way. This is the task:

> *In each culture and civilisation people come up with their own solutions to daily life problems related to food, artistic expression, health, etc. The practical solutions to these problems can be called 'technology.' Indigenous technology in any particular place is the technology that has been developed at that place. So in Limpopo Province, 'indigenous technology' indicates the technology that was developed by the people who live here. Often, there is a lot of exchange between cultures; it is easy to forget that e.g.,*

maize and tobacco are South American in origin, not African. It is often also difficult to decide exactly who invented a particular technology, e.g. which people were the first to start brewing Chibuku [traditional, sorghum beer]. *We are not going to be too worried about these issues. What we will be worried about is: how can we bring the indigenous technology of the Limpopo Province into the science classroom, so that our learners can begin to appreciate the accomplishments of their own people, develop an understanding of the wealth of their culture, and come to see technology and science as their own rather than imported?*

Look around in your own house and that of friends. Find a typical, interesting bit of indigenous technology. Please prepare a 20 min presentation about this item of technology. Discuss for example: who makes or uses it, what is it for, how does it work, how is it made, what is it made of, what is its cultural importance and meaning, etc.

A group of 24 teachers presented lots of calabashes, all showing almost identical uses of indigenous flora, but also a fascinating range of local indigenous technologies on production of food (fermentation: marula beer, mageu), drugs (snuff), traditional building, uses of indigenous plants (marula seed oil), weapons (hunting bow and arrow), clothes (traditionally produced leather garments), woodcarvings, musical instruments (drums, Kudu horn), etc. Teachers presented these to each other and, eventually, to a general audience of relatives, colleagues and principals in a closing conference. They truly outdid themselves, surprised as they were at the value and magnitude of their own cultural wealth.

New ideas under construction

The activities described above result in better understandings of NOS among the vast majority of our student teachers. However, not all outcomes of learning are as intended. The development of understandings, concepts and insights is not trivial. Constructivist and conceptual change approaches of the past decades acknowledge that even when teaching is based on learners' existing ideas and designed in accordance with our best strategies, the learner will make his/her own sense out of the experiences, and the results of learning cannot be precisely predicted. However, I deviate from the constructivist perspective of Driver and Oldham (1986). who say that we cannot be 'tightly prescriptive' about what we *want* learners to learn. On the contrary, we *should* specify precise learning outcomes, but should also accept the burden: if learners do not learn what we want them to learn, it is up to us to devise better teaching. That is why it is worthwhile to explore the unintended outcomes of learning. I do that, here, by presenting and interpreting statements of student teachers collected informally after they completed several or all of the activities described above. As a facilitator of these NOS-activities, I have become attentive to the occurrence of these or similar statements as they provide a formative kind of instrument. By giving time to discussing statements such as these, one may re-direct the learning process towards the intended aims. The following statements are among the most relevant and interesting:

- *'Every scientific claim will some day be shown to be incorrect.'*
  The student has over-interpreted the falsificationist argument, there is no need for an extreme relativist view. We all rely comfortably and securely on valid, established science in our daily lives.
- *'There are no correct answers in science.'*
  From a view that each question has exactly one correct answer, some stu-

dents switch to the exact opposite view. It is worthwhile to recognise that although science does not aim to describe an absolute, Platonic truth, there still are answers of better and lesser quality to very many scientific questions.

- *'It is alright to make mistakes in science.'*
  Some students understand the tentative character of scientific knowledge not as a fundamental consequence of science as human, but of the errors and mistakes scientists make. While that is rather a misrepresentation, the statement may reflect an acceptable pedagogical principle ("*Do not despair if you make mistakes, scientists do too*").
- *'Science is just a guess.'*
  Students who have no personal experience of scientific inquiry do not always recognize the rigour and fastidiousness required in scientific research and underestimate the effort involved in it and in getting ones results accepted. Lack of understanding of NOS-aspects i and j can be reflected as easily in nihilist relativism as in naïve empiricism,
- *'Science is just like magic.'*
  Occultism and witchcraft have a great enemy in science, and are essentially very different from it (in view of, e.g., Newton's quote above, methods of persuasion, and considering public accessibility). Yet, this statement needs closer examination. There is some sense to the statement, and exploring that sense may inform us about the relationships between science and other systems of knowledge.
- *'Everything people do is science.'*
  The notion that science can be applied to all facets of human experience and that it can help us cope in all aspects of life can easily be over-extended. However, the fact that there are similarities between science and technology, religion, art, to name but a few areas of human activity, does not make them identical. Exploring what separates these areas is a useful part of developing NOS.
- *'Science teachers are scientists.'*
  Student teachers often see themselves as scientists. Discussing this view and the wide range in kinds of scientists that exist may highlight that teaching science might perhaps be seen as one form of applying science.

The development of understandings of NOS is not a jump from one level to another, but rather a gradual process of piecemeal and ongoing change. The activities described in the preceding sections should not be judged dichotomously in terms of whether they 'work' or not, but in terms of how and where they can contribute most favourably to this process. The present section suggests how the process may evolve between and after these activities.

Conclusion

There is an enormous gap between the teaching that actually goes on in schools and the expectations of teachers (and others) in the envisaged OBE-dreamscape of science education in South Africa. As in so many other places in the world, rote learning and mindless memorization are strategies that are far more common than a learner-centred, challenging and entertaining approach. Imagine a teacher chalking NOS-aspects a to k on a blackboard in front of 80 learners. Learners dutifully copy and memorise, and all can recite them faultlessly, in choir, during the next day's period. It is easy to envisage a multiple-choice test or exam that rewards the learners generously for their efforts. Our programmes attempt to open teachers' eyes to far more enjoyable, inspiring and relevant alternatives to this all-too-likely realisation of the new curriculum, in the hope that our concerted efforts may prevent this nightmare from coming true.

Developing balanced, acceptable views on the value and trustworthiness of scientific knowledge is not easy, because these views are highly complex. There is a distinctly 'human' side to scientific knowledge, in that it is tentative, dependent on creativity and imagination, and to some extent subjective, socially and culturally determined. And yet in its attempts to develop universal, consensually agreed knowledge that applies always and everywhere in the same way, humanity has never been more successful than in the field of the natural sciences. Should we really bother these teachers (and their learners), who have a limited exposure to 'hard' science and shaky understandings of the scientific enterprise, with such complex issues? Is there not a real risk that they will come to understand scientific knowledge as uncertain, weak and no more reliable or valuable in addressing questions and problems than any other personal view or opinion? Well, even if there is that risk, a place like the Limpopo Province, rural, remote and underdeveloped as it is, is as radically influenced by the rapidly developing scientific and technological applications, permeating all facets of life, as all the rest of the world. As an aspect of scientific literacy, an acceptable contemporary understanding of NOS is at least as important as an understanding of, say, how to deal safely with electricity in the house. In order to be part of a modern society that takes responsibility for the development and application of scientific knowledge and addresses abuse and excess in the scientific enterprise, a naïve faith in an all-powerful benevolent science is as dangerous as an outright dismissal of science as inhumane and evil. In short, we simply cannot afford *not* to include NOS among the aims of science education, even when that is difficult, because a contemporary flourishing society cannot afford a scientifically illiterate citizenry.

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