

## Reconstructing the Creature – Exploring design criteria for teaching NOS

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### Abstract

This case study explores design criteria for teaching understanding of Nature of Science, implementing salient aspects of South Africa's curriculum reform in rural, disadvantaged schools. Grade 7-9 science teachers carried out classroom activities that model some aspects of scientific research. Learners constructed and described an unknown animal based on pictures of its bones, then reflected on the scientific characteristics of the knowledge they obtained. Learners ought to see that in science, experiments are not the only way to knowledge, furthermore that creativity and imagination play a role in interpreting data and drawing conclusions and finally that one scientific question can have several equally acceptable answers. Data from nine teachers and 79 learners show that lessons ensued in which learners engaged in genuine inquiry and reflected sensibly on scientific processes. Implementing the design criteria resulted in clarity of purpose of the task, independence from subject matter, creative responses to a challenge perceived as attainable, freedom from pursuit of a correct answer or method, and free use of means of expression other than English. Support for teachers on management tasks and provision of ample resources also contributed to coherence between design intentions and actual classroom events.

### Introduction and background

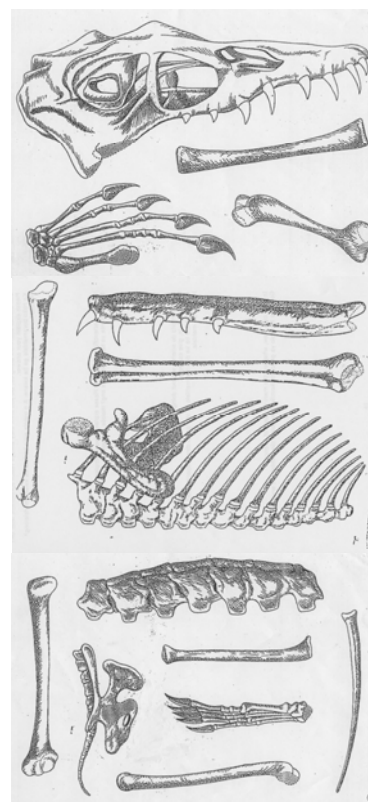
In most South African science classrooms questions are given, not generated, answers are transmitted, not constructed, and each question has exactly one correct answer. Understanding counts for less than marks there, and practical work is non-existent (Rogan, 2003). Meaningless, irrelevant subject matter is memorised merely to pass exams. This science is about *having correct answers*. South Africa is far from unique in this respect. Its new post-apartheid curriculum for the subject 'Natural Sciences' attends to the associated problems, e.g. learners should henceforth develop a richer understanding of the nature of science (NOS) (Department of Education, Government of South Africa, 2002). 'NOS', here, refers to epistemology of science, i.e. the purpose, origin and status of scientific knowledge. However the curriculum does not specify *which* understandings of NOS should be taught, nor *how* they ought to be taught. This classroom based, developmental case study explores practicable answers to these questions.

While philosophers of science disagree on many aspects of epistemology (e.g. Chalmers, 1999), Lederman and Abd-El-Khalick (1998) argue that there is *sufficient* consensus to establish 'understandings of NOS' adequate for secondary school: the ideas that scientific knowledge is "tentative (subject to change); empirically based (based on and derived from observations of the natural world); subjective (theory-laden); partly the product of human inference, imagination and creativity (involves the invention of explanation); and socially and culturally embedded" (p. 418). Research (Dekkers and Mnisi, 2003) showed that South African science teachers have alternative views, similar to those found elsewhere (McComas, 1998). Most believe that science progresses through experiments in which knowledge is proved, so that theories become laws. Experiments then are the sole, reliable basis of scientific knowledge, and proved knowledge is secure, irrefutable, non-replaceable. The possibility of disagreement among scientists about the interpretation of data or the validity of claims is negated. Roles for creativity and imagination, and influences of social and cultural backgrounds of scientists are recognized, but how these roles and influences play out is unclear. On the assumption, to be verified in the study, that learners would share these views, lessons were designed to develop the views that: scientific knowledge is based on various kinds of inquiry, not only experiments; interpreting data and drawing conclusions are not straightforward, depend on creativity and imagination of researchers; there often are several,

contested answers to a single scientific question. Learners first engaged in inquiry, then evaluated their findings in comparison with the work of scientists. The activities provide a starting point for activities towards developing understanding of NOS.

### Methodology

Teachers in an in-service program received, for a sequence of 4-5 lessons, a manual (providing guidance on planning, assessment, and language issues) and low-cost materials for a class of 60 learners. The teachers completed, then taught the activities, monitoring learners' views on NOS using an open-ended questionnaire before and after the lessons. Learners received pictures (Figure 1) of a set of bones that, supposedly, were found during excavations. They were asked to reconstruct the skeleton of the creature, then write a story about it (its appearance, diet, habitat, etc.), and finally to draw it. The combination of reconstruction, story and drawing encourages learners to mobilize different aspects of their knowledge about animals, and to express themselves creatively and imaginatively. The task models a scientific investigation, and invites learners to explore the problem collaboratively and in depth. There is no single correct answer yet all serious responses have merit.



The scientific reconstructions from these bones (Figure 2) were withheld until after the lessons so as to keep the learners' inquiry authentic and avoid teaching to the 'correct answer'. However, the scientists' views were important, validating the inquiry as 'science' and showing the scientists' solution – a late-Jurassic, fish-eating pterosaur, with a wing span of about 90 cm, named *Scaphognathus Crassirostris* (meaning Thick-beaked Tub-jaw).

Learners' reflections on the results of these activities were guided by questions such as what they had done, why, what they had learned, how 'good' the new knowledge was, in what sense they were doing science, and whether their claims held as scientific knowledge. They evaluated whether creativity and imagination were used and explored variations in reliability of their inferences. They discussed related characteristics of scientific knowledge.

The design criteria of Table 1 derive from consideration of the specific circumstances and ideas described above, the research literature on the relation between inquiry and NOS (e.g. Khishfe & Abd-El-Khalick, 2002) and general educational principles pertaining to the importance of motivating and activating learners and enhancing metacognitive understanding. Learners' work was translated by their teachers if it was written in the local language (Northern Sesotho). Teachers kept journals to describe how learners engaged with the activities. One sequence was monitored by the author. Data sets consisted of complete, representative sets from nine teachers and 17 complete groups of, in total, 79 learners. Details on methodology and data analysis are discussed in Dekkers (2006). This paper focuses on a comparison of design intentions with experiences, activities and products.

### Results and discussion

#### *Feasibility of the teaching approach – support for teachers*

Criteria 2 (c)-(f) deal with assisting teachers in support of their teaching and resource management. Data on whether support was adequate can be derived from teachers' journals.

Table 1. Design criteria for the activity 'Reconstruct the Creature'

Intentions	Criteria applied : The task should...
1. Activate learners: shape inquiry followed by reflection.	(a) Be perceived as an entertaining, attainable challenge; (b) Make minimal demands on learners' (or teachers') content knowledge; (c) Be of an obviously (potentially) scientific nature; (d) Make use of daily life process skills (that can become the basis for developing scientific process skills); (e) Have no correct answer, nor one that can be memorized or copied from the board; (f) Invite and reward creative, divergent and imaginative input; (g) Require reflection on concrete, practical issues, naturally linked to the learners' own actions, experiences and thoughts; (h) Challenge incomplete understandings of NOS ( <i>viz.</i> that all scientific questions have a straightforward, single correct answer, obtainable only through experiments, and that imagination and creativity have no significant role in that process); (i) Stimulate cooperation, collaboration and debate on non-trivial on-task issues.
2. Take local circumstances into account: teachers, learners, resources, habits.	(a) Place minimal demands on English language skills; (b) Encourage use of mother tongue and other, non-verbal means of expression; (c) Take over issues of selection of learning objectives, planning, management and assessment from the teacher; (d) Remove the problem of lack of resources; (e) Provide assistance with issues involving large groups; (f) Provide the opportunity to abandon in a non-threatening way the habitual expository, transmission based, teacher-centered approach.

The teachers (Dekkers and Mnisi, 2003) developed most insights they were meant to teach by doing the activities themselves, but remained convinced that only experiments provide the certainty that makes knowledge scientific. Teachers considered the lessons outlined in the materials to be learner-centered, properly resourced, motivating and enjoyable. They appreciated the assistance in planning. Learners were said to have produced creative and imaginative work. The few comments about insufficient class time were contradicted by learners' complete and adequate written responses. Field notes indicated, though, that much time was spent on cutting, pasting and drawing, and relatively little on reflection and discussion.

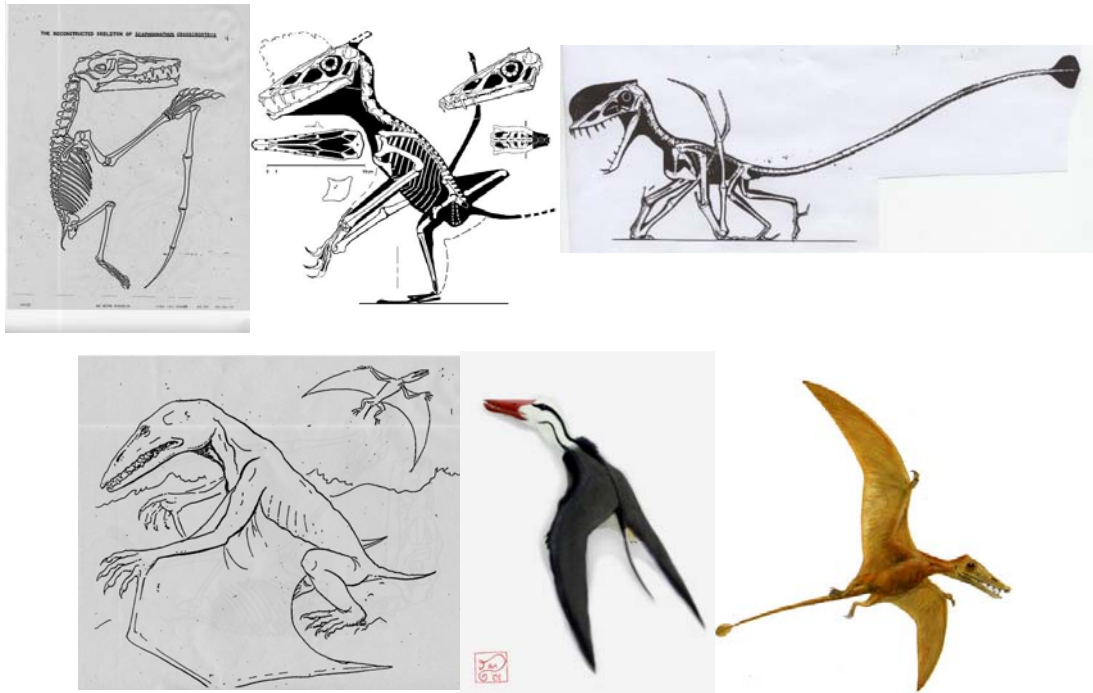
*Feasibility of the nature of activities – support for learners*

Criteria 1 (e), (i) and 2 (a), (b) of Table 1 ought to support learners in engaging with the inquiry task in the intended way. Reports on classroom events and learners' products provide information on whether the assistance was adequate.

Teachers reported some language problems, but though some children found it difficult to write a story about the Creature in English, others were reported to have enjoyed the writing. The stories (e.g. Figure 3) suggest that learners may have experienced grammatical problems but were not hampered in expressing their ideas and inferences. The learners' submitted work and the teachers' journals suggested that classes generally stayed close to the lesson plans and design intentions, and that group-work and other suggestions were followed.

Teachers and students responded well to the open nature of the inquiry, as is evidenced in the products. Though the absence of a correct answer received some critical remarks it is a crucial design feature – teachers and students generally lost interest in their own creations once a 'correct' answer was made available.

Design criteria 1 (a), (b), (d), (f) ought to optimize learners' inquiry efforts. Their effectiveness can be assessed based of learners' products: the skeletons, stories, and drawings.



In the task, learners organized data, used existing knowledge to analyze and interpret new data, developed alternative interpretations, established rules for data manipulation, inferred claims from data based on reasoning and debate, etc. Learners' work shows that they used their imagination and creativity to synthesize coherent wholes. In their stories and drawings learners inferred claims about the animal's appearance, movement, diet, etc. All produced a drawing of an animal, including some of the habitat, food, other animals or humans (see Figure 4). Most groups wrote an imaginative essay, of which six were labeled as 'brief', seven as 'rich' (see Figure 3). Skeleton, story and drawing complemented each other in the process.

Design criteria 1 (c), (g) and (h) support learners in reflecting on their findings, and in drawing inferences about 'real' scientific investigations. Data derive from worksheet answers and questionnaire results.

Groups unanimously interpreted the reconstruction as a scientific investigation, but saw scientists as better informed, more imaginative. Learners thought scientists, too, would make

Figure 3 A rich story about the Creature by a Grade 7 group (verbatim)

*The animal was laying very big eggs and we think Its eggs were stronger than other animal's eggs. Because if you can see Its skeleton you can see that the animal was bigger and It is meant that Its eggs were big as we have said. Up to so far we that the animal was the largest animal in the World which was laying eggs. According to our group we think that Its eggs can be 50 cm high. That animal was living on the land and we think It was living next to the water. Because most animal that It is big like our Creature like to live where there is water. The animal like to live where the land is full of trees so that It can take the oxygen from the tree. Up to so far we think that animal was living far away from people so we think that is why there is no person who know or who have seen this animal. According to our group we think that when It was hangry It was eating 2 animals like lion and tiger. So we think this animal was eating meat only. We think this animal is no longer existing. Because we think God made it not to exist.*

different reconstructions due to differences in ideas, imagination, and experience. About half the groups agreed that this was not an experiment and yet yielded scientific knowledge but the

other half were unclear about the word ‘experiment’. Learners were meant to see that they had gained knowledge, but that some of it was less secure, and none of it absolutely certain. At a concrete level this intention was met, e.g. most groups noted that their Creatures had some common features, with more agreement on the function of some of the bones than on others.

After the lessons learners were substantially better able to express views on NOS. Based on pre-post questionnaire comparison (see Dekkers, 2006), as a result of the lessons, learners:

- (1) more readily accepted alternatives to experiments to obtain scientific information,
- (2) but maintained that only experiments provide secure knowledge.
- (3) more readily accepted the role of imagination in science in a wider sense.
- (4) less frequently thought that each scientific question has a single correct answer.



### Conclusion and implications

Science arguably represents the most reliable, most tested, and most consensually agreed knowledge, and yet contains no absolute truth. Accepted science is reliable and trustworthy, and yet its theories may be replaced. There is no single scientific method, but a methodical and systematic approach is key to science. Science depends on the imagination and creativity of scientists, a universal and objective science cannot exist – but no other knowledge matches science’s level of universality and objectivity. Relevance in science depends on one’s socio-cultural setting, and yet the same laws of nature apply to us all. Science depends on empirical facts, but facts are partly mental constructs, not entirely externally given. This science is all about *finding and justifying the best possible answers*. Each aspect of this picture may be debatable, but surely it is a richer picture than the one painted in the first paragraph of this paper, encouraging a more inspiring educational practice.

In the activities studied here this richer picture emerged as a direct result of using the design criteria of Table 1. The activities further exhibited teacher clarity on educational objectives, independence from mastery of subject matter, serious work in answer to an attainable challenge, absence of an urge to find the correct answer, and free use of means of expression other than English. Support for teachers on management tasks and provision of ample resources also contributed to success. It will be worthwhile to elaborate the criteria in developing a more complete approach to teaching NOS.

### Acknowledgements

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- For information on (NOS activities with) Scaphognathus Crassirostris, see these websites (Figure 2 was taken from sites with \* on 3-11-2005): \*[www.teacherlink.org](http://www.teacherlink.org); [dino.lm.com](http://dino.lm.com); [www.dinodata.net](http://www.dinodata.net); \*[www.freewebs.com](http://www.freewebs.com); \*[www.bowdoin.edu](http://www.bowdoin.edu); [www.enchantedlearning.com](http://www.enchantedlearning.com); [www.pterosaur.co.uk](http://www.pterosaur.co.uk).