Nature of Science Approach to Science Teaching and Learning

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Redirection for Science Education

Much has been said in the local media about making a living in the new economy. It has been perceived that one way of keeping a competitive edge in the emerging knowledge-based global economy would be in the development of human potential — effected in the local educational system by the Thinking Programme. This is not a new challenge for Singapore as its leaders have long tried to promote entrepreneurship and develop human talent to offset a lack of land, a skilled workforce and financial capital (in the initial years of nationhood at least). With the onset of the third millennium however, the stakes are even higher and more challenging. Hence the consistent emphasis on the need to develop the human potential in Singapore.

The Thinking Programme (TP) that has been introduced in the schools by the Ministry of Education aims to foster critical and creative thinking; to acknowledge and give due recognition that having the 'facts' alone is insufficient, and that being able to evaluate the evidence is crucial as well. It is an explicit aim of the curriculum now in place in Singapore schools to devote more time to appreciating contextual issues in the subject matter. Pupils are encouraged to delve deeper, probe and ask hard questions in contrast to a previous situation whereby the completion of the prescribed syllabus was paramount and thus left little time for such matters. Such teaching and learning environments can do nothing but assist the growth of general literacy and democratic living in a technologically-oriented society.

Our policy makers have recognized that science plays, and will continue to play a critical role in the development of the economy of Singapore. The challenge is how best to develop the ability to bridge what students learn in school science with the needs of the market place for the products of science (without neglecting the spirit and process of science). To do so, both teachers and students must acquire and develop a clear conception of what is science and its implications for science teaching and learning.
Figure 1. A model of Science and Scientific literacy based on Maienschein (1998).

Figure 1 clarifies the active interplay between Science Literacy and Scientific Literacy. Clearly, there is a ‘knowing’ component (the facts, concepts, principles and structure) which is the predominant mode of science content knowledge encountered in schools and a ‘knowing about’ science which is often only implicit in the intended curriculum. We feel that the TP is thus a timely correction towards the nurturing of scientific literacy or ‘knowing about science’, though at no time does the curriculum neglect teaching and learning for science literacy or ‘knowing science’ (see Maienschein, 1998). However, in the pursuit of scientific literacy, critical thinking is a necessary but not sufficient condition, for its development. We maintain that what is advocated and taught in the local TP is both timely and desirable, particularly when students learn to develop the logical, intellectual processing skills in critical and creative thinking. Yet, these by themselves do not necessarily focus on the process of knowledge construction or generation that is linked to the processes of concept learning and conceptual change (Yeoh, Lim & Jackson, 1998).
Boulton and Panizzon (1998) have claimed that there are two knowledge explosions in science education; one of facts (theoretical knowledge) and the other of the practical processes of how science works, and to be effective teachers need the ability to deal with both of them. Many science educators now recognize that pupils should not only learn science (science literacy) but even more importantly, about science [scientific literacy] (Matthews, 1998a). This body of knowledge has been commonly described as the Nature of Science or NOS.

Every discipline has its own ways of knowing and constructing reality, its syntactic structures, its philosophies and methods of inquiry. Even the process skills in Science (supposedly value free) are associated with a body of content knowledge, which is ultimately time and context dependant. Lederman (1995) rightly reminds educators that there is not a single conception of NOS but many, depending on the context of that particular community and what they value.

The NOS refers to the ‘epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge’ (Lederman, 1997: 1). This is the scientific enterprise which is at the heart of the NOS. It is an extremely complicated field as scientific knowledge arises from social, natural, political, cultural, historical and economic contingencies. A detailed analysis of seven international science standards documents showed that it revolved mainly round the philosophy, history, sociology and psychology of science (McComas & Olson, 1998) which is graphically portrayed in Figure 2. For science educators the phrase ‘nature of science’ is used to describe the intersection of issues addressed by the philosophy, history, sociology and psychology of science as they apply to and potentially impact science teaching and learning. As such, this is a sound basis for guiding teachers to accurately portray science and its enterprise to the students.

Importance of NOS

We neglect the explicit teaching (Lederman, 1998) of the NOS in our science curricula at our peril. To do so would be to devalue or undermine the rich and multi-textured understanding of science, in particular how science functions in practice. Generally, a sound appreciation and working knowledge of NOS serves to enhance the learning of science content, understanding of science, interest in science and informs the process of decision making. Tweney (1998: 153) believes
that scientific cognition is special as it is the 'premier domain in which culture, history, and the social milieu intersect and lead us toward new knowledge'. The pedagogical and theoretical basis of many programmes in the United States that attempt to enhance thinking in schools adopt a cognitive-psychological approach which ignores the contributions of philosophy, affective and social psychology. For these reasons, Paul (1993) dismisses the credibility of such programmes to produce critical and rational thought in students. However, a science curriculum that incorporates the NOS (in conjunction with the TP) will be able to rectify these deficiencies and produce students who are scientifically literate. The challenge therefore, is for the science teachers to translate their understanding of the process of knowledge construction into meaningful and appropriate classroom discourse.

**NOS and the Science Teacher**

There have been numerous debates (see Eflin, Glennan & Reisch, 1999) as to what level of understanding should a teacher possess with regard to NOS. A pragmatic proposal has been suggested by Smith and Scharmann (1999) to concentrate on judging whether questions or fields of study are more or less scientific than others. In contrast, Matthews (1998b) advocates modest understandings of terms like law, theory, explanation, causes, hypothesis and observation in concurrence with Gibbs and Lawson (1992). However, nearly all agree that a philosopher's understanding of NOS is not necessary for students, teachers and even scientists.
Lederman (1998) proposed that the following understandings of NOS are elemental for our local high school science teachers. They ought to comprehend that scientific knowledge:

1. is tentative and is subject to change;
2. is empirically based on and/or derived from observations of the natural world;
3. is subjective and thus theory-laden;
4. necessarily involves human inference, imagination, and creativity that lead to the invention of explanations;
5. is socially and culturally embedded; and
6. recognize the distinction between observations and inferences; and
7. recognize the functions of, and relationships between scientific theories and laws.

BIOLOGICAL EVOLUTION: A CASE STUDY IN THE NOS

Biological evolution is often a difficult and controversial topic to teach in the high school syllabus. School children (e.g. Demastes, Good & Peebles, 1995), not to mention teachers (Lee, 1998) and the general public (The Straits Times, 11 December 1997), have been shown to be unclear about many of the issues surrounding the theory of biological evolution. It would be simplistic to suggest that improvements in their understanding and acceptance of evolution could be resolved so readily by just better teaching/learning (Smith, Siegal & McInerney, 1995) — in other words, better science literacy (knowing science). The profound biological ideas associated with evolution are many including genetics, ecology and physiology which by themselves are not only conceptually difficult but also often inter-linked. In view of the high level of cognitive difficulty in the study of evolution, we wish to use this as a case study to illustrate some of the obstacles that exist in the teaching and learning of evolution. We suggest that many of the difficulties surrounding a scientific conception of biological evolution lie in the pedagogic neglect of scientific literacy because few educators appreciate the meaningful insights that emerge from ‘knowing about’ evolution. These can be summed up as the two main obstacles in teaching and learning of evolution.

Firstly, there is a near universally poor understanding of the NOS. Many researchers have pointed out that a poor understanding of the NOS in both teachers and pupils have lead to difficulties in understanding biological evolution. One common problem is the inability to appreciate the differences between inference, fact, theories, laws and hypotheses. Only when science teachers have a working
knowledge of the NOS and the methods of science enquiry can educators in turn help learners separate half truths, emotional reactions, and dogmatic assertions from the century-old scientific endeavour in explaining the theory of biological evolution. It is our view that much effort still remains in educating the biology educators in Singapore with regard to the NOS.

A second impediment to the meaningful understanding of evolution is due largely to conflicts with religious beliefs. In the past two decades, the relationship between biology and religion has been overshadowed by the creationist-evolution controversy, especially in the United States. Much of the antagonism between the hard-core evolutionists and creationists (Fysh & Lucas, 1998) have shown a clear lack of appreciation of scientific facts and equally important, the NOS. It was also reported that in Malaysian schools, the teaching of science has downplayed biological evolution, and is in essence a creationist science (Loo, 1999).

The phenomenon whereby a belief in the veracity of evolution is divorced from an ability to reason and argue scientifically in this topic has been documented by previous researchers working with pupils (Demastes, Settlage & Good, 1995), teachers (Lee, 1998; Lee & Yeoh, 1998), university undergraduates and with academicians (Dagher & BouJaoude, 1997; Jackson, Doster, Meadows & Wood, 1995). Researchers are in agreement that understanding and acceptance in a potentially controversial area like evolution depends more often on social, religious and metaphysical factors rather than on conviction in the explanatory powers of science. Indeed, the issue is complex. For example, Jackson et al. (1995) have demonstrated that personal beliefs, especially amongst strongly religious people were resistant to change despite increase in knowledge of biological evolution. Of concern to science educators, Roth and Alexander (1997) have reported that religious commitments may interfere with the learning of science especially in controversial areas such as abortion, euthanasia and about human origins.

THE NOS APPROACH

In order to surmount the inherent obstacles for the effective teaching of scientific literacy, we propose two NOS strategies for science teaching and learning. One, there is the need to nurture among teachers the acceptance of the metaphysical and sociological processes underlying the scientific enterprise.

No longer is the 'cold, hard and rational' conceptual change model seen as adequate as a model of instruction in science, especially in an
area with a strong affective component such as biological evolution. Rudolph and Stewart (1998) have presented evidence that the neglect of metaphysical issues in science education have led to difficulties in understanding science. In particular, they have suggested that egocentrism and anthropomorphism (attribution of human traits to non-human beings) as historically persistent traits that should be considered as part of the sense making processes that occur in classrooms. These researchers have also argued that Lamarckian thinking, teleology and essentialism are rather 'natural' ways of explaining problems in evolutionary biology by pupils in schools and also by the scientists of the past. However, Zohar and Ginossar (1998) advocate what they teasingly call a 'heretical suggestion'. They recommend that the taboo of teleology (advantageous outcomes are considered to explain natural phenomenon) and anthropomorphism as a means of explaining in biology should be removed as these are unresolved issues for educators.

Cunningham (1998: 484) has added that 'by describing the human relationships, beliefs and values that pervade science, sociological insights challenge stereotypes' and thus sociology gives a realistic picture of how science is practiced and constructed by society. We are mindful that the development of the theory of evolution is often persuaded by the personal biases or prejudices of many scientists. Even now one reads of academic feuds between two giants in evolutionary biology — Stephen Gould and Richard Dawkins. Nonetheless, it must be emphasized that nearly all members of the scientific community are in agreement on the veracity of evolution. It is widely acknowledged as the means for explaining both the diversity and unity of life since the beginning of time.

Under these circumstances, there is the urgency to engage in the process of values clarification whereby one reveals these 'hidden' metaphysical issues during sensitive and informed teaching. All viewpoints would have an equal chance of being heard and differences can thus be discussed fruitfully, though not always resolved fully. There is a great urgency in having to listen to what learners bring to the evolution class, especially when faced with issues of creationism in the biology lesson. For example, Dagher & BouJaoude, (1997) in Lebanon and Fysh & Lucas (1998) in Queensland have tried to tackle these issues in their classroom with participants who hold strong religious faiths. The science teacher who understands the sociological underpinnings in the science classroom can similarly offer a more authentic and inclusive education. Science, after all, is still a human enterprise. While we recognize that societal attitudes and beliefs can affect the corpus of science and its practices, at no time do we advocate any form of
relativism (Smith & Scharman, 1999; Sokal & Bricmont, 1998). Certain 'truths', are just that; not some form of negotiated meanings among scientists with deep vested interests to advance themselves.

The second NOS strategy is to promote and to nurture the new image of the NOS in biology. For a start, our new understandings of the NOS in the latter half of this century have firmly demolished the idea that scientific knowledge is always constructed in a rational, logical and even monolithic method. Science, as most philosophers of science now understand it to be, consists of multiple methods; some even seemingly illogical and counter-intuitive in extreme cases. In other words, scientific progress which does not borrow from or is influenced by external societal factors is just a myth. Ignorance of this dialectical relationship of science and society is unfortunately still held by many educators and scientists alike.

Consequently, most understandings of the NOS by educators and scientists alike are premised on the physics model which places heavy emphasis on experimental laws, equations and models (Rudolph & Stewart, 1998). It was felt that this had placed biology under unnecessary demands to be equally rigorous in finding clear-cut, empirical evidence. Biology instead, often relies on a probabilistic modus operandi, with extremely complex systems not easily amenable to physics-like experimentation. This is even more so with regard to biological evolution which is considered to be in the domain of the historical sciences together with paleontology and bio-geography (Sober, 1993). For example, Darwin had amassed a huge amount of observational data to support his case for evolution although he did not present any experimental results.

RELATING SCIENCE AND RELIGION

Recently, the National Association of Biology Teachers in the United States issued a statement on the teaching of evolution which highlighted that teachers may hold deep religious faith while still accepting evolution as a valid scientific theory (McInerey, 1997). Besides such assurances from secular organizations, many theologians of different faiths (e.g. Barbour, 1997; Haught, 1995) have proposed some extremely thoughtful models for the reconciliation between science and religion. They have basically sought dialogue and explored the higher realities that exist between the two commonest means of Man's search for understanding — Religion and Science. From the inquiry perspective, these are different realms of reality.
Operating within a strongly Islamic position, Haidar (1999) has advocated constructivism as being most compatible with religious beliefs and current understanding of NOS. Loo (1996: 285) asserts that Islamic science in contrast to Western science, has much to offer by having a 'more holistic human-centered approach that is grounded in values that promote social justice, public welfare and responsibility towards the environment'.

A strong confrontational stance between religion and evolution is not fruitful to either side and detrimental to progress in understanding. Even a live-and-let-live attitude characteristic of an 'independent' approach between the two sides was viewed as less satisfactory against adopting an 'integration' or 'dialogue' approach. While discoveries in astrophysics and quantum mechanics have engendered much dialogue and integration between physicists and theologians, biologists generally have instead subscribed to the position of conflict or independence between religion and science. Exciting and novel ways of trying to relate science and religion by showing their methodological parallels have also been advanced by the British physicist turned clergyman John Polkinghorne and many others (e.g. Richardson & Wildman, 1996; Peacocke, 1993).

Unless a dogmatic view of truth in religion is adopted, these new models of interaction between science and religion might help reconcile and challenge many of the difficulties people have with evolution. It will be a sad day indeed if every lesson in evolution for a teacher seems to repeat the legendary confrontation between Thomas Huxley (Darwin's 'Bulldog') and Bishop Wilberforce. And Barlow (1999) has aptly commented that 'religions that do not embrace and give flesh to the story told by science are missing a tremendous opportunity for renewal and relevance'.

Some Proposals for Science Teachers and Teaching

Teachers need to be taught about the NOS during teacher education. We fear that if the Thinking Programme is incorporated, out of context with the NOS in science education, it would be teaching to know science better, not to know better about science. The local data about teachers understandings of NOS (e.g. Lee, 1998) have shown that they have inadequate knowledge about NOS. We therefore propose that the NOS be emphasized increasingly in the science teacher education courses of study during the period of the Pre-and Inservice teacher training and training. This is already being done in the different pedagogical modules in the National Institute of Education. However, more needs
to be done in this area. A course in the university about the NOS might not be entirely adequate or appropriate because the content level may not match the K-12 education system.

In order to succeed as intended, we propose to incorporate aspects of the NOS in the formal school science curriculum. According to the Cambridge GCE 'O' level Biology (5090) syllabus, some of the NOS aims of syllabus are difficult to be translated into testable objectives (University of Cambridge Local Examinations Syndicate, 1998). The newly revised Biology (5093) syllabus should be able to address these issues. While not all NOS objectives can, or should be assessed, we agree with Lederman (1998) that this, in effect leaves acquiring NOS knowledge as an afterthought, as belonging in the realm of affective development. There needs to be explicit teaching of some aspects of the NOS into the curriculum in order to develop and improve scientific literacy.

We propose that the local Thinking Programme should be symbiotically taught (carefully infused with and integrated) with the NOS objectives in mind in the science curriculum. Critical and creative thinking are certainly needed in appreciating NOS — while the history of science provides numerous case studies whereby thinking skills are essential. We have provided a case study involving biological evolution to illustrate some of the possibilities of incorporating NOS into a notoriously difficult topic in science education to enhance its learning and acceptance. Our local curricula have also been sheltered from the extremes of faddish (or what some would call 'fashionable nonsense' [Sokal and Bricmont, 1998]) assaults on traditional conceptions of science by Post-modernists, sociologists, Feminists, Marxists and other critical theorists. How long this situation would remain under control is uncertain. Be that as it may, shouldn’t we aim for a public capable of discerning for themselves, the convoluted and multi-disciplinary issues that living in an increasingly technological society brings? Thus, it is of vital importance to start producing today, scientifically literate pupils, armed with the facts of science, and with the wisdom to use it wisely.

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