

# Turning Crisis into Opportunity: Nature of Science and Scientific Inquiry as Illustrated in the Scientific Research on Severe Acute Respiratory Syndrome

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**Abstract** Interviews with key scientists who had conducted research on Severe Acute Respiratory Syndrome (SARS), together with analysis of media reports, documentaries and other literature published during and after the SARS epidemic, revealed many interesting aspects of the nature of science (NOS) and scientific inquiry in contemporary scientific research in the rapidly growing field of molecular biology. The story of SARS illustrates vividly some NOS features advocated in the school science curriculum, including the tentative nature of scientific knowledge, theory-laden observation and interpretation, multiplicity of approaches adopted in scientific inquiry, the inter-relationship between science and technology, and the nexus of science, politics, social and cultural practices. The story also provided some insights into a number of NOS features less emphasised in the school curriculum—for example, the need to combine and coordinate expertise in a number of scientific fields, the intense competition between research groups (suspended during the SARS crisis), the significance of affective issues relating to intellectual honesty and the courage to challenge authority, the pressure of funding issues on the conduct of research and the ‘peace of mind’ of researchers. These less emphasised elements provided empirical evidence that NOS knowledge, like scientific knowledge itself, changes over time. They reflected the need for teachers and curriculum planners to revisit and reconsider whether the features of NOS currently included in the school science curriculum are fully reflective of the practice of science in the 21st century. In this paper, we also report on how we made use of extracts from the news reports and documentaries on SARS, together with episodes from the scientists’ interviews, to develop a multimedia instructional package for explicitly teaching the prominent features of NOS and scientific inquiry identified in the SARS research.

**Keywords** Nature of science · Scientific inquiry · Scientists · Development of instructional materials

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## 1 Introduction

Understanding the nature of science (NOS), especially the key features of the scientific endeavour, has long been regarded as a major component of science literacy and an important objective of science curricula in many countries (e.g. American Association for the Advancement of Science 1993; Council of Ministers of Education 1997; Millar and Osborne 1998)<sup>1</sup> However, it has been consistently reported that many students, and even many teachers, do not possess adequate NOS understanding (Lederman 1992; Abd-El-Khalick and Lederman 2000; Moss et al. 2001; Finson 2002). While there have been many attempts to improve teachers' understanding of NOS, Abd-El-Khalick and Lederman (2000) report that little success has been achieved. Their critical review suggests that 'approaches that utilise elements from history and philosophy of science and/or direct instruction on NOS are more effective in achieving that end than approaches that utilise science process-skills instruction or non-reflective inquiry-based activities' (p. 694). The authors also point out that while there might be compelling theoretical arguments to support the effectiveness of history of science and philosophy of science in improving learners' NOS conceptions, further empirical research is essential. Among research efforts in this direction, Irwin (2000) demonstrates encouraging results with a group of 14-year-old students by integrating substantial amounts of historical material into the topic of *Atoms and the Periodic Table*. Lin and Chen (2002) also provide empirical evidence of positive impact on understanding of NOS among a group of prospective chemistry teachers by integrating historical cases into a pre-service teacher education programme.

Bell et al. (2003) and Schwartz et al. (2004) have investigated the effectiveness of promoting NOS understanding among high school students and pre-service teachers by providing the authentic research experience of working with practicing scientists. Results show that better understanding of NOS and the nature of scientific inquiry do not necessarily result from doing science per se (Bell et al. 2003). There also need to be frequent opportunities for reflection on NOS in the context of that authentic scientific research experience through journal writing and seminars (Schwartz et al. 2004). In their recent comparison of the epistemic beliefs of chemistry students and research chemists, Samarapungavan et al. (2006) come to the broadly similar conclusion that apprenticeship experiences are no automatic guarantee of epistemic development in students. They suggest that engaging students and expert researchers in conversation and reflection on epistemic issues related to research work will have a greater chance of success.

While apprenticeship or internship experiences offer enormous potential for enhancing NOS understanding, they create major logistical problems—especially in East Asian classrooms, where class size is routinely about 40, and may be as high as 50 or 60. Our response has been to present students with insight into authentic scientific practice through the development of a case study of contemporary scientific practice. A detailed review of 17 experimental studies of context-based or STS-oriented approaches at secondary school level by Bennett et al. (2007) indicates that such approaches have positive impact on students' understanding of scientific concepts and attitudes to science and school science, especially when attention focuses on recent scientific research and innovations. While none

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<sup>1</sup> In a recent publication, Lederman (2006) sought to restrict use of the term *nature of science* to the characteristics of scientific knowledge (i.e., to epistemological considerations). In common with definitions adopted by Osborne et al. (2003) and Clough (2006), our conception of NOS encompasses the characteristics of scientific inquiry, the role and status of the scientific knowledge it generates, how scientists work as a social group, and how science impacts, and is impacted by, the social context in which it is located.

of these studies focused specifically on NOS understanding, there is good reason to anticipate similarly favourable learning outcomes with respect to learning *about* science and scientific inquiry. Indeed, there are compelling arguments that critical consideration of socioscientific issues provides an ideal forum for students to deploy and develop their NOS understanding (Sadler 2004; Sadler and Zeidler 2005; Zeidler et al. 2005), especially when the issues are controversial (Kolstoe 2000; Oulton et al. 2004) or have strong personal relevance (Ryder 2002). Khishfe and Lederman (2006) remind us that although locating NOS teaching within controversial topics (in their case, discussion of global warming) can be effective, the essential requirement, as in internship and apprenticeship approaches, is that NOS teaching is both explicit and supportive of critical reflection. The case study described here focuses on an episode that was intensely personal for our students and had many controversial aspects. Moreover, the learning materials were designed to draw explicit attention to important NOS items and to encourage reflection.

By situating the learning of NOS and scientific inquiry within a specific episode in the ‘contemporary history of science’ we were able to meet Rudolph’s (2000) call for teachers to acknowledge the context-dependency of scientific knowledge generation. We were also able to address the criticism by Elby and Hammer (2001) that the current consensual list of NOS items (see McComas and Olson 1998) is too general and broad. We concur with the claim of these authors that ‘a sophisticated epistemology does not consist of blanket generalisations that apply to all knowledge in all disciplines and contexts; it incorporates contextual dependencies and judgments’ (p. 565).

## 2 SARS as a Context for Teaching NOS

Encouraged by research findings on the potential of case studies for enhancing NOS understanding, we surmised that the well-publicised ‘history’ of the recent outbreak of the Severe Acute Respiratory Syndrome (SARS) would provide a powerful and familiar context for teaching about scientific inquiry. SARS attracted the attention of the whole world as scientists worked indefatigably to understand the biology of the disease and develop new diagnostic tests and new treatments. Throughout the crisis, extensive daily coverage by the media kept people up-to-date on the rapid development of scientific knowledge about SARS.

We saw the exceptionally rapid development of scientific knowledge about SARS as an opportunity to develop a set of instructional materials for enhancing teachers’ and students’ NOS understanding, particularly their understanding of contemporary scientific practice and its close inter-relationships with technology and society. We approached a number of scientists who had played a major role in the SARS research with a request to talk about their work. Our goal was to incorporate selected excerpts from the interviews into instructional materials to illustrate aspects of NOS and scientific inquiry. Our decision to utilise authentic experiences of practicing scientists working in a field closely related to the everyday lives of citizens was a response to Rudolph’s (2003) assertion that, in any portrayal of science, ‘at least two things should be considered: (1) what it is scientists actually do in the myriad research settings that exists, and (2) some vision of what the appropriate relationship should be between science and the public’ (p. 76). It was our contention that the scientists’ descriptions of how they conducted research during the SARS crisis would provide an authentic portrayal of real world science practice and the ways in which practice is related to societal concerns.

Instead of examining scientists’ espoused views about NOS, as in some early studies by Kimball (1968), Pomeroy (1993) and Southerland et al. (2003), we made use of scientists’

*descriptions* of their work to highlight for the audience of our teaching package how certain aspects of the scientists' work are related to various aspects of NOS and scientific inquiry. We concur with the recommendation by Glasson and Bentley (2000) that communicating descriptions of science and science practice provided by scientists can be an effective means of developing and enriching teachers' NOS understanding.

It is important to note that the scientists involved in the SARS research are working in a field of science that is under rapid development and change. Hence, their descriptions of investigative methods and comments on the ways in which their practices are influenced by society and technology may be surprising to some students and teachers. Indeed, the research has generated a substantial database for comparison with the list of NOS elements currently advocated for inclusion in school science curricula, as summarised by McComas and Olson (1998) from their analysis of a number of international science education standards documents. In particular, their descriptions have given us insight into some aspects of NOS in modern science that are in need of greater attention in the school science curriculum.

In this paper, we describe how we made use of the familiar and well-documented story of SARS and scientists' descriptions of their work and experience during the SARS epidemics to develop an instructional package for explicitly teaching NOS. We report on the prominent features of NOS and scientific inquiry identified in the scientific research on SARS and how these features were explicitly emphasised in our instructional package. The effectiveness of an explicit and reflective instruction using this instructional package in promoting student teachers' understanding of NOS and scientific inquiry is reported in a separate paper (Wong et al., [in press](#)).

### 3 Interviews with Scientists

To ascertain aspects of the nature of science and features of scientific endeavour exemplified in real world scientific research, we approached ten scientists who had played a key role in the advancement of research on SARS with a request to participate in our research and curriculum development project. We explained the purpose of the study, which was to demonstrate NOS aspects and features of scientific inquiry based on their experience during their fight against SARS. We also requested the scientists' permission to include video clips of their interview in our instructional materials. Nine scientists from five different research institutes in Hong Kong, mainland China and Canada kindly agreed to take part. Their specific contributions included identification of coronavirus as the pathogen of SARS, decoding of the genomic sequencing of the SARS-coronavirus, development of new diagnostic tests, and understanding of the transmission modes of SARS. Table 1 summarises each scientist's major contribution to the research on SARS and the geographical location of their research institute.

The nine scientists were sent the interview protocol given in Appendix A and a brief document outlining the ideas about science currently advocated for inclusion in school science curricula in different countries (McComas and Olson 1998; Lederman et al. 2002) upon their acceptance of our invitation, which was several weeks before their interview. This allowed them adequate time for recalling their research and other relevant experience during the SARS crisis. We also reminded the scientists of the targeted audience for the teaching package we would compile from their description of their work and requested them to answer the series of questions listed in Appendix A in 'laymen's terms'. This enabled an easy translation of relevant episodes of the interviews to be incorporated in the

**Table 1** Summary of scientists' major contributions to SARS research

Scientists	Major contribution to the research on SARS	Region of research institute
Dr. FL	Led his research team in decoding the genomic sequence of the SARS coronavirus	Hong Kong
Dr. LP	First scientist to obtain the partial genetic sequence of SARS-coronavirus, a finding that contributed to the identification of coronavirus as the causal agent of SARS	Hong Kong
Prof. DL	Led his research team in decoding the genomic sequence of the SARS-coronavirus; developed a rapid diagnostic test; traced the molecular evolution of the SARS coronavirus	Hong Kong
Dr. AC	Participated in decoding the genomic sequence of the SARS-coronavirus	Hong Kong
Dr. RC	Participated in the development of a rapid diagnostic test	Hong Kong
Dr. KT	Studied the genomic sequence and biology of selected genes of the SARS-coronavirus	Hong Kong
Prof. GZ	Led the consortium which traced the molecular evolution of the SARS-coronavirus during the course of the SARS epidemic in China	Mainland China
Prof. AS	Described the epidemiological and clinical factors and outcomes of a series of SARS cases; and proposed the mechanism for transmission of SARS	Canada
Dr. RS	Led a development program for a SARS vaccine	Canada

instructional materials. The interviews lasted for 30–180 min. All interviews were recorded, translated if required, and transcribed for analysis. Whenever there were uncertainties concerning scientists' remarks, clarification was sought through follow-up phone calls or emails.

#### 4 Data from Reports and Documentaries

Local and international reports and documentaries produced by the media, together with research reports on SARS published in scientific journals, were perused and analyzed alongside the scientists' interview data. We were careful to ensure the reliability of the data obtained and selected from documentaries by using only sources with a sound track record for the quality of news reporting and production of documentaries. The information from each source was further triangulated against each other and against the detailed scientific development provided by scientists.

The documentary analysis and the inside story of the SARS research provided by the scientists gave the essential background details of a series of 'historical' events during the SARS crisis, as given in the second column of Tables 2–5.

#### 5 Identification of Prominent NOS Features in the Story of SARS

Between July 2004 and February 2005 the authors held bi-weekly meetings to identify, discuss and agree on the NOS element(s) embedded in each historical event of the detailed account of the SARS story and associated scientific development. The embedded NOS

**Table 2** Introductory review of the SARS epidemic

Time	Historical development of the SARS epidemic	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
Nov 2002	News that a mysterious respiratory illness, later known as SARS, had occurred in Guangzhou.	Picture of the infected lungs of a SARS patient	
	News from Guangzhou about panic buying of vinegar and banlangen, a type of Chinese medicine believed to cure flu.	Photos and news headlines of people queuing up for vinegar and banlangen	Cultural embeddedness of science: belief in Chinese versus Western medicine
Dec 2002–Feb 2003	Spreading of SARS to many cities in Southern China.	An animated map of Southern China showing the gradual spreading of SARS from Guangzhou to the cities close to the border with Hong Kong.	
Mid-Feb 2003	Dr. Liu, a Guangzhou-based professor who was infected with SARS, visited Hong Kong. He stayed at the Metropole Hotel, from where SARS started to creep into the Hong Kong community. A number of residents living in the hotel became infected.	A 100-s video reconstruction, based on later scientific evidence, of how Dr. Liu could have infected other people living in the same hotel through droplets from coughing leaving viruses on the elevator button.	Science relies on empirical evidence and logical arguments.
	Most of them left Hong Kong by air to other countries, and quickly spread the disease to the rest of the world. At this point, WHO was unaware of what was happening.	The video shows how SARS was spreading to other parts of the world through air traffic, initially without anyone noticing.	
4 Mar 2003	A Hong Kong citizen, who was infected by Dr. Liu at the Metropole Hotel, was admitted to the Prince of Wales Hospital (PWH) of the Chinese University of Hong Kong (CUHK).	Photos and news headlines showing the outbreak of SARS in PWH. Within days, many patients and doctors in the same Ward became infected.	
	He became the index patient of the outbreak in this hospital.		

**Table 2** continued

Time	Historical development of the SARS epidemic	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
15 Mar 2003	<p>Dr David Heymann, Executive Director of Communicable Diseases at WHO announced that the disease was to be named Severe Acute Respiratory Syndrome (SARS).</p>	<p>A 50-s video showing a team of scientists at WHO compiling a list of symptoms to be announced internationally so that everyone would know what to look for. The team compiled guidelines for hospitals, including how to construct isolation units, what protective clothing to wear, and what to do in the event of an outbreak. Once the information was ready, it was disseminated throughout the world via the Internet.</p>	<p>Science has global implications.</p>
18 Mar 2003	<p>CUHK and laboratories in Germany, Canada and Singapore announced that the virus causing SARS might be a paramyxovirus.</p>	<p>Photos and news headlines showing the appearance of the paramyxovirus and a 12-s news excerpt of the announcement made by CUHK.</p>	<p>Science is tentative.</p>
22 Mar 2003	<p>The University of Hong Kong (HKU) successfully isolated the SARS virus, which was later known as coronavirus, and devised a basic diagnostic test for it.</p>	<p>Photos and news headlines showing the appearance of the coronavirus and the team responsible for the breakthrough, followed by a 30-s video of the news announcement made by HKU.</p>	<p>Science is tentative.</p>
Late Mar 2003	<p>Even with the breakthrough in identifying the causative agent of SARS, the number of cases of infection and death due to SARS kept rising.</p>	<p>Photos and news headlines showing the spreading of SARS into the community of Hong Kong and a 20-s video showing SARS spreading in hospitals in Toronto and Taiwan.</p>	<p>Scientific knowledge (about diseases) may impact on society.</p>
27 Mar 2003	<p>WHO requested airlines to screen passengers for SARS on flights leaving Hong Kong, Singapore, Hanoi, Toronto and some parts of China.</p> <p>Hong Kong Government announced a series of emergency measures to reduce the spread of SARS</p>	<p>A photo showing the temperature screening of passengers at an airport.</p> <p>News headlines and photos about the emergency measures in Hong Kong, including the suspension of schools.</p>	<p>Scientific knowledge (about diseases) may impact on society.</p>

**Table 2** continued

Time	Historical development of the SARS epidemic	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
28 Mar–31 Mar 2003	A residential building in Amoy Gardens in Hong Kong was found to have an alarming number of cases of infection.	An animated graph showing the number of infected cases in Amoy Gardens, rising from 7–185 within 4 days.	
31 Mar–1 April 2003	The Hong Kong Department of Health imposed quarantine on Block E of Amoy Gardens. An unprecedented order from the Hong Kong government to move all residents of Block E to isolation camps to allow a thorough investigation of the mysterious severe outbreak.	A 20-s video showing government health workers and residents of Amoy Gardens, all in masks, being sent to isolation camps in a rural area. It also shows the cross-disciplinary investigation team entering the building to find clues to the cause of the outbreak.	Science and political decisions are inter-related.
12 April 2003	The first genomic sequence of SARS-coronavirus was coded by a team of scientists from various laboratories in Canada, including British Columbia Cancer Agency Genome Sciences Centre and British Columbia Centre for Disease Control.	A 40-s video showing genomic sequencers running automatically and pictures of typical genomic sequences. The narrator of the video says: '... Just 20 days after the discovery of the SARS-coronavirus, a team in Canada announced they have cracked the virus's entire genetic code... Never in the history of science had a new disease been sequenced so quickly.'	
16 April 2003	Teams at CUHK and HKU became the third to produce the genomic sequence of the SARS virus, after Canada and US Centers for Disease Control and Prevention.	Photos of the HKU and CUHK sequencing teams.	
23 May 2003	Researchers from HKU and the Centre for Disease Control and Prevention, Shenzhen, successfully isolated the coronavirus causing SARS from civet cats.	Photos of civet cats in cages in restaurants and news headlines of the announcement of findings by scientists in Hong Kong and Mainland China that civet cats were the likely origin of SARS. Unique dietary habits in Guangzhou might have caused the disease.	



**Table 2** continued

Time	Historical development of the SARS epidemic	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
23 June 2003	Hong Kong was removed from the World Health Organisation's list of SARS-infected areas.	<p>News headlines about the removal of Hong Kong from the list, followed by a concluding 20-s video flashing through memorable events around the world during the SARS epidemics. The narrator says: 'All over the world, countries coordinated and fought back against the disease.' Dr Julie Hall, a WHO Medical Officer, says: 'It really is a good news of tingling human story, seeing the world which is often so fragmented pulling together to really try and fight against this common cold.'</p>	Scientists are not limited to Western white males.

**Table 3** Elaborated story of the 'hunting for the cause of SARS'

Time	Historical development of the identification of SARS virus	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
Mar 2003	<p>Dr. Klaus Stohr, a scientist with the World Health Organisation (WHO), initiated the establishment of an international collaborative network among 11 laboratories, located in 10 countries.</p>	<p>An introductory activity asking students to name one piece of scientific knowledge and the scientist or scientists responsible for it.          [It is expected that learners may only be able to name the most famous scientist associated with a particular piece of scientific knowledge.]</p> <p>Learners are reminded that local science education (in common with practice in many countries) focuses more on the products of science than the development of science. Hence most textbooks fail to mention collaboration and competition among scientists, which our informants identified as key features of the knowledge generation process.</p>	<p>Both collaboration and competition are common among scientists.</p> <p>Scientists often built on earlier findings by their predecessors. Collaboration among scientists can also be across time.</p>
		<p>A 60-s video showing Dr. Stohr making several phone calls and inviting different labs to form an international research consortium through telephone conferencing—thus enabling rapid sharing of data and information about SARS. Learners are asked to identify and describe the nature of collaboration shown in the video. They are also asked if they can see beyond collaboration (we are looking for students to identify competition, as reflected in the hidden message of the video narrative).</p>	<p>Technology can change the ways in which science is conducted and the speed with which it is completed. Without recent advances in telecommunications and availability of the Internet, the large-scale collaboration could not have established so rapidly.</p>
		<p>A 40-s video edited from the interviews with Dr. LP and Dr. RC, in which they talked about how the pace of their research was accelerated by 'competing' against time, resources, their own self-esteem and social demands.</p>	<p>Scientists are competitive by nature; they compete with each other, themselves, time, resources, etc.</p> <p>Scientists are not detached from society and they often work strenuously to meet social demands.</p>

**Table 3** continued

Time	Historical development of the identification of SARS virus	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
18 Mar 2003	<p>CUHK first announced they had found evidence that paramyxovirus was the causative agent of SARS.</p> <p>Laboratories in Germany, Canada and Singapore immediately announced that they had also found evidence of paramyxovirus in samples collected from patients.</p>	<p>Learners are shown a photograph of the pattern of iron filings produced by a bar magnet. They are asked to draw what they see.</p> <p>[It is anticipated that those who recognise the pattern of iron filings as a representation of magnetic field lines will draw solid lines, even with arrows showing the direction of magnetic field lines. Other will simply draw broken lines.]</p>	<p>Subjectivity of scientists and theory-laden observation. Scientists' observations are influenced by their knowledge and the theoretical framework they employ—i.e., their observations may be affected by what they expect to see or prepare themselves to observe.</p>
22 Mar 2003	<p>HKU found evidence suggesting that the causative agent was coronavirus. A laboratory in Rotterdam and CDC in Atlanta quickly announced that they had also found evidence in favour of coronavirus.</p>	<p>Learners are shown a picture with an 'embedded view' which is not immediately obvious to most observers.</p>	<p>Tentative nature of scientific knowledge (linked to the skepticism and open-mindedness of scientists)</p>
		<p>Learners are then asked to identify and describe examples of theory-laden observations from an 80-s video showing the progression from the agreement among different laboratories that a paramyxovirus was the causative agent of SARS to the agreement that a coronavirus was the real causative agent of SARS. The video includes excerpts from the press conferences of both announcements and the characteristic appearance of both types of virus.</p> <p>[It is expected that some learners may even be able to identify that the virologists who identified the viruses from their characteristic appearance were basing their views on their own expert knowledge, for a lay person would be unable to recognise the patches on the microscopic slides as viruses.</p>	

**Table 4** Elaborated story of the 'genomic sequencing of the SARS-coronavirus'

Time	Historical development related to genomic sequencing of SARS virus	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
Late March–April 2003	Following the identification of the SARS-coronavirus, laboratories all over the world (using expertise in many different areas of science) were trying to ascertain the entire genomic sequence of the virus.	A 40-s excerpt from an interview with Prof. DL, explaining the different roles within the research team responsible for the sequencing of the SARS-coronavirus.	Collaboration is very common within a research team, particularly for large-scale research in modern science.
April 12–16, 2003	The first genomic sequence of the SARS-coronavirus was coded by a team in Canada, followed by CDC in the United States and teams in Hong Kong.	Prof. DL also explained that no hypothesis was made in the search for the genomic sequence. A 120-s interview excerpt in which Dr. FL recalled the dilemma his research students faced when deciding the head of their SAR-genomic sequence late at night on April 15th and how he made use of that to educate his students about the essential virtues of scientists.	There is no one rigid stepwise procedure for doing science. Every scientist wants to be the first to announce new findings in their research field as the prestige associated with making significant scientific progress has huge implications on future research funding. Thus the competition between different research groups is very common. Scientists should possess essential virtues, including carefulness, honesty and courage to challenge authority.

**Table 5** Elaborated examples of the ‘the interrelationship of science, technology and society (STS)’

Time	Examples of STS during and after SARS	Multimedia items/teaching and learning activities	Embedded elements of NOS and scientific inquiry
April 2003	The availability of genomic sequencers is essential in generating the SARS-coronavirus sequence	A 30-s video of Prof. DL showing the sequencer used by his group to generate the SARS-coronavirus sequence.	Science and technology are interrelated. Often technology comes before science, and makes new science possible.
Since Mar 2003	Findings suggested that SARS is spread through droplets. To avoid infection, people wore masks and washed their hands more frequently. Workers in buildings cleaned the lift buttons more frequently.	Learners are asked to give examples of habits developed during the SARS crisis that are still practiced. Photos showing these habits during and after SARS.	Science influences social and cultural practice.
Since late Mar 2003	In Beijing, Dr. Jiang disclosed the truth to the media and drew international attention to the severe outbreak of SARS in mainland China. He was put under house arrest.	Learners are asked to give examples of similar stories from the history of science—occasions when political or social and cultural factors have affected the progress of science. 60-s interview excerpts of Dr. AC and Prof. GZ expressing their views on the Chinese government’s decision to suppress information about the spread of SARS.	Political, social and cultural factors influence the development of science.
Since May 2003	The sale of civet cats and other exotic animals was banned when evidence identified civet cats as the origin of SARS.	Photos and newspaper headlines about research in Hong Kong and Shenzhen CDC revealing that many civet cats carried a coronavirus that was 99.8% genetically identical to the human coronavirus. Also some animal traders involved in slaughtering the animals had antibodies of the virus carried by civets. These findings indicated that the virus was passing between animals and humans.	Scientific claims are based on logical deduction.
		Researchers commented that civets might have been infected from yet another unknown animal source in the markets, where many different animals are caged in close proximity. Such market practices could provide a venue for the spread of the virus.	The findings of science affect political decisions, which in turn may affect social and cultural practice.

features in each historical event were first identified with reference to the list of advocated NOS features found in curriculum standards documents. Additional NOS elements were established to cover prominent features identified in the scientists' interviews and/or certain historical events of the scientific development of SARS that did not fall under the existing list NOS elements generated from curriculum standards documents (McComas and Olson 1998). Full agreement among authors on the finalised list was achieved.

The story of SARS provided some vivid illustrations of many of the NOS elements advocated for the school science curriculum (McComas and Olson 1998)—such as, the multiplicity of approaches used in scientific investigations, the theory-laden nature of observation and interpretation, the tentative nature of scientific knowledge, the dependence of scientific research on technological innovation, the impact of social and political factors on scientific research and the impact of scientific findings on social and cultural practice.

In addition, our data also revealed some NOS elements and features of real world scientific inquiry *not* commonly included in the school science curriculum. Notably, the need to combine and coordinate expertise in a number of scientific fields, the intense competition between research groups (suspended during the SARS crisis), the significance of affective issues relating to intellectual honesty and the courage to challenge authority, the pressure of funding issues on the conduct of research and the 'peace of mind' of researchers.

## 6 Development of the Multimedia Teaching Package<sup>2</sup>

These prominent features of scientific practice were contextualised within a series of critical 'historical' events during and after the SARS epidemic using video clips from relevant interviews with scientists and excerpts from news reports and documentaries. The video clips were edited and collated with photos, pictures and news headlines into a series of episodes describing the development of the SARS research and its impact on political decision-making, social and cultural practice and technological innovation. The product was a multimedia teaching package designed to explicitly emphasise particular elements of NOS and scientific inquiry through individual tasks, group discussion, and problem solving activities.

The teaching package begins with an introductory review of the history of the SARS epidemic designed to set the scene for a 4-h instructional experience. Table 2 lists the embedded elements of NOS and scientific inquiry and provides a brief description of the multimedia elements associated with each historical event. The introductory review, designed for presentation in a story-telling manner is intended to prompt learners in their attempts to identify aspects of science exemplified in the various episodes of the SARS story. This functions as a warm-up exercise, enabling learners to reflect on their current understanding of NOS.

Following the introductory review, the package elaborates three key components of the SARS story, namely (i) the hunt for the cause of SARS, (ii) the genomic sequencing of the SARS-coronavirus and (iii) the interrelationships among science, technology and society. Each component consists of a rich list of elements about NOS and scientific inquiry. In the following subsections, elements of NOS and scientific inquiry exemplified by episodes of the SARS story in the three key components are described in detail according to the order

<sup>2</sup> An updated set of instructional materials can be accessed through the website <http://learningscience.edu.hku.hk> as training material under "teaching resources".

of their appearance in the package. For each NOS element identified, we also describe learning and teaching activities designed to explicitly emphasise the element.

## 7 NOS Elements as Reflected in the Hunt for the Cause of SARS

Significant episodes in the hunt for the cause of SARS, the relevant features of NOS exemplified, and the elements included in the multimedia package and learning activities, are summarised in Table 3.

### 7.1 Collaboration and Competition among Scientists

The traditional textbook portrayal of scientists as solitary heroes who make great scientific discoveries fails to reflect the collaborative and competitive nature of real-world scientific practice. In this key component, we included a video clip from the program, *SARS: the True Story*, produced by the British Broadcasting Company (Higgins and Learoyd 2003) which describes how Dr. Klaus Stohr, a scientist with the World Health Organisation (WHO), initiated the establishment of an international collaborative network, utilizing telephone conferencing, among 11 laboratories spread across 10 countries. This occurred *immediately* after the WHO became aware of the seriousness of the epidemic.

We knew that it was a race against time, so we had to find very quickly the pathogen, the causative agent for this disease. (Dr. Klaus Stohr)

He contacted the world's top microbiologists, from America to Beijing and asked them, just once to work together... (Jack Fortune—Narrator)

These scientists are competitive by nature but we called up 11 laboratories in 10 countries... (Dr. Klaus Stohr)

24 h later, all the labs had agreed to forgo their rivalries and collaborate. For the first time in history, the full force of the world's scientific might was united. (Jack Fortune—Narrator)

In this episode, we will first draw learners' attention to the fact that collaboration is common in real-world science practice when scientists from different groups see a common interest to be exploited or concern to be addressed. We will also highlight the amazingly short time for the establishment of this large-scale collaboration on SARS—something that was only possible because of modern modes of communication, bringing out the interconnection of scientific and technological advancement. We will then draw teachers' attention to the hidden message in the above narrative. The phrases '...just once to work together' and 'for the first time in history...' reflect the highly competitive stance among different research groups that is characteristic of normal situations. Collaboration among scientists is included in many of the curriculum standards but has only recently been mentioned in (a few) science textbooks. Competition and funding issues in the scientific community is almost entirely absent from both curriculum standards and school science textbooks.

In our interview with the nine scientists, we were told repeatedly that scientists are constantly 'competing' with all manner of constraints, lack of time and limited resources, and with other research groups working on similar projects. In consequence, we included an excerpt of our interview with Dr. LP that emphasises this particular message.

Competition isn't just with other teams but also with time... The fact that science improves so quickly is all because scientists compete with each other, with time... and their own.

We also included an interview with Dr. RC conducted by a local television company during the most serious and critical moment of the SARS crisis, when many doctors in her hospital were being infected. She was almost in tears as she shared her frustration and helplessness.

After the two colleagues passed away, some of our colleagues are in a life-threatening situation. We are now receiving phone calls if our research can give immediate help. We need to work on urgent requests... hoping that we can help stop or reduce the rate of infection... We have become so stressed out... We also wish earnestly that we can lessen the harm and have been asking ourselves "how come our research still can't be any help?"

The feelings expressed by Dr. RC reinforced the need for scientists to compete against time and highlighted the pressure on them to meet social demands. Her distress and expressions of concern demonstrate that scientists are not isolated from the social environment in which they work. Another purpose for including this video clip is the need to address the common stereotypical image that scientists are always men, often weird looking and frequently detached from society (Chambers 1983). Dr. RC's interview, together with several references to other female scientists in our teaching package, help underline the message that women can also be good scientists.

## 7.2 Objectivity of Scientists and Theory-laden Observation

Although it is now over 20 years since Hodson (1986) urged teachers to acknowledge the theory-laden nature of scientific observation, it is still only rarely elaborated in science textbooks, and is often overlooked by both teachers and students.

The elaborated story of the hunt for the causative agent of SARS was infused with several examples of the theory-laden nature of scientific observation. The historical account of the 'hunt' will be used as an exercise to probe the understanding of learners on this aspect of nature of science. We will show a video clip showing that immediately following the announcement on 18 March 2003 by a group of scientists from Hong Kong and Germany that the virus causing SARS was paramyxovirus, other research groups around the world quickly announced that they had also found evidence that paramyxovirus was the causative agent of SARS. However, only a few days later, on 22 March 2003, another group of researchers in Hong Kong announced that further evidence showed that coronavirus, rather than paramyxovirus, is the causative agent of SARS. Immediately after this announcement, several laboratories, including Rotterdam, Frankfurt and the Center for Disease Control and Prevention (CDC) in Atlanta, also confirmed the coronavirus theory. This episode illustrates the theory-laden nature of observation and shows how scientists' expectations or predictions influence what they see and how they interpret the data. Acknowledgement of the biased observation of data is in stark contrast to the usual school science curriculum portrayal of scientists as objective and impartial in interpreting data.

The video clips of news reports about the rapid development of knowledge of the cause of SARS were organised in a sequential manner to explicitly draw teachers' attention to



the agreement of other laboratories directly after a laboratory announced new findings. We also made use of a video clip showing the appearance of the coronavirus as observed by John Nicholls, the pathologist who first recognised that the halo of dots surrounding the virus was strongly suggestive of a coronavirus, as another example of theory-laden observation. We made the point that because they lack the expert knowledge of the appearance of various viruses, lay people would be unable to identify the crown-like coronavirus.

### 7.3 Tentativeness of Scientific Knowledge

We used the search for the identity of the SARS-virus to emphasise the tentativeness of scientific knowledge. All nine scientists considered revision, modification and refutation of existing scientific knowledge to be commonplace in their work. Indeed, their everyday task is not to maintain or safeguard current scientific knowledge but to move science forward by introducing new data and ideas, and providing new frameworks to interpret existing data from different perspectives. The scientists in our study all recognised the theory-laden nature of observation and noted that there can be different interpretations of the same set of data because scientists utilise their favoured theories. Disagreements and arguments among scientists are common and an inevitable stage in the journey towards more established and well-accepted scientific knowledge. The initial acceptance of the paramyxovirus as the causative agent of SARS, and its rapid replacement by the coronavirus as a consequence of new evidence and subsequent empirical tests based on the Koch's postulation, was used to illustrate the tentativeness of science. We also linked tentativeness to some essential characteristics of good scientists—skepticism and open-mindedness.

## 8 NOS Elements as Reflected in the Story of the Genomic Sequencing

Prominent features of NOS identified in the elaborated story of the genomic sequencing of the SARS-coronavirus, and items included in the design of the multimedia component to explicitly highlight these features, are summarised in Table 4.

### 8.1 Large-scale Research and Necessity for Collaboration

Both Dr. FL and Prof. DL led large research teams to sequence the SARS-coronavirus. During his interview, Prof. DL described the different stages involved in the genomic sequencing of the SARS-coronavirus and the need for a range of scientific expertise.

In doing genomic sequencing, our working pattern was like that in a factory. Researchers were assigned different tasks. Some were in charge of data collection, e.g. some studied the anamnesis such as when the patient got infected, when the patient was hospitalised and when the patient got his first fever. Some were responsible for cultivating the virus. Some were responsible for studying the gene of the cultivated virus and extracting the RNA. Another group then turned the RNA to DNA. The next group would then sequence the DNA, whereas another group analysed the sequence.

Research in molecular biology often involves the deployment of skills and expertise in a series of highly focused areas. Dr. KT illustrated it using an analogy with shoe-making. In the old days, the whole shoe was produced by a shoe-maker, but in modern times each stage of production is completed by a group of workers who then pass it on to the next group along the production line. The scale of research in molecular biology has grown so much that it has become almost impossible for a researcher to be skilful in all tasks. Thus collaboration within a research team is essential. To be successful, scientists also need to be aware of work done by other groups and be willing to use it to advance their own thinking.

## 8.2 More than One Scientific Method

One of the most pervasive myths of science is the notion that a common series of steps is adopted by all research scientists in all situations (McComas 1998). This is probably a direct consequence of the ‘scientific method’ occupying such a prominent position in the introductory chapters of science textbooks encountered by students at the very outset of their formal learning in science. Many students and teachers consider that making a hypothesis is an essential component of this stepwise generation of scientific knowledge (Watson et al. 1999). However, the interview with Prof. DL concerning the decoding of the genomic sequence of the SARS-coronavirus provided a clear counter example:

After we knew that coronavirus was the causative agent of SARS, we did the sequencing, and no hypothesis was needed during this process, we just sequenced it... Right, like the human genome project which sequences our three billion base pairs, it's not hypothesis-driven.

This type of knowledge generation without making hypotheses is increasingly common in newer fields of science such as molecular biology. With recent advances in technology, most of the tedious data collection is now done by high-speed computers, and data collection which previously took months to complete now only takes minutes. The much reduced data generation time makes meticulous hypothesizing and theorizing before actual experimenting less important than in the past. Scientific investigations in which data are obtained first and then interesting problems are identified by ‘data mining’ have become much more common in recent years.

## 8.3 Competition and Funding Implications

During the interview with Dr. FL, about a year after the SARS crisis, the tension and excitement generated at the time when his research team was competing to be the first research group to announce the entire sequence of SARS-coronavirus was still very much in evidence. This interview episode reinforces the point that competition among scientists, particularly from different research groups, is a significant aspect of science and should no longer be ignored in the school curriculum. Indeed, many of the scientists we interviewed mentioned that their greatest pressure and concern in their research work comes from the limitations of resources and funding that might compromise their capacity to compete with other research groups. Some Hong Kong scientists expressed frustration about the huge difference in the number of genomic sequencers between their laboratories and the laboratories in Canada that announced the first sequence of SARS-coronavirus.

## 8.4 Honesty and Courage to Challenge Authority

Dr. FL's account of the dilemma faced by his research team before disseminating their findings about the sequence of SARS-coronavirus on the WHO network for public scrutiny reflects an interesting phenomenon: claims made by prestigious research institutions are much more likely to be accepted by other scientists than claims emanating from elsewhere. The crucial point is that the Hong Kong team's data conflicted with the data accumulated by the highly prestigious Center for Disease Control and Prevention (CDC) of United States.

Around 10 p.m., it was the last base pair...my research students didn't know what to do... In the US sequence, the first base pair of the head was an "A", but ours started with a "T". ...my students asked me if we should put an "A" or a "T". When that student asked me, I thought of one thing, this was one of the best chances for me to share with my students one of the important points, that is "data don't lie". I stopped everyone in the team from working and asked them what we should do as the CDC sequence started with an "A" and ours started with a "T". No one answered, as Hong Kong students are usually shy... So I told them to take out all the raw data, and we not only did a duplicate or a triplicate... Over and over again, we found that it was a "T", so I said, "Do we still have any doubt about whether to put an "A" or a "T"?" And one student was really funny, he said, "Fred, CDC could not be wrong." And I said, "Well, I don't care much about whether CDC could be wrong or not, our research confirmed over and over again that we started with a "T" instead of an "A", so we should enter a "T" instead of an "A." At about 11:30 p.m., we uploaded our sequence.

This decision of Dr. FL's group to hold firmly to their own data instead of suppressing them in favour of what the prevailing authority claimed is enormously valuable in emphasizing to learners the importance of scientists being honest and not submitting to authority. Several of the video interviews with scientists included in our instructional package reveal other desirable attributes for scientists, including being meticulous, organised, sensitive to the need to collect and record data accurately, and being aware of the theory-laden nature of observations and interpretation of data.

## 9 Inter-relationships among S–T–S as Reflected in the SARS Story

There are numerous examples of the interrelationships among science, technology and society in the SARS story. The events, the NOS elements exemplified, and the learning and teaching activities included in the multimedia package are summarised in Table 5.

### 9.1 Inter-relationship between Science and Technology

The science curriculum often portrays technology as no more than the application of science, and many teachers and students hold the view that 'science comes first and technology follows'. The following comment by Prof. DL provides an illustration of the dynamic interrelationship of science and technology.

It is scientific knowledge about DNA structure and the DNA sequencing reaction which leads to the production of DNA sequencers... With the DNA sequencers, a DNA sequence can be obtained in a much reduced time... leading to the cracking of the SARS-coronavirus... and recently the entire human genome.

He proceeded to state that contemporary research in molecular biology relies extensively on advanced technology. Sadly, laboratories with inadequate funding for the acquisition of advanced equipment find it difficult to compete at the frontier of scientific research.

Events during the SARS epidemic illustrate the impact of scientific findings on technological development. To prevent the spreading of the SARS disease, WHO identified and disseminated a list of symptoms of SARS in mid-March 2003, and requested stringent screening of passengers' body temperature at airports in the infected places, including Hong Kong, Singapore, Toronto and some cities in Mainland China. These guidelines prompted the development of high-speed body temperature sensors. Hand-held infra-red temperature sensors and sophisticated thermal imagers were installed in these airports by late March 2003, and are still in use today.

## 9.2 Interactive Influence between Science and Political Decisions

There are several episodes in the instructional package that describe the influence of scientific findings about SARS (e.g. the transmission mode through aerosol droplets) on political decisions during and after the epidemic. For example, the unprecedented decision of the Hong Kong government to suspend all schools when many parents sought to prevent their children from being infected by keeping them at home. Another unprecedented government decision was made in response to medical statisticians identifying an alarmingly high infection rate among residents in a particular residential building (Amoy Gardens). The decision was taken to isolate the building and move all residents to a rural camp site to permit a thorough and unimpeded examination of the building. The sale of civet cats was banned after researchers announced evidence which pointed to civet cats as the source of the original SARS cases in Guangdong province. When Dr. RC was talking about the data leading to the ban on eating civet cats, she put particular emphasis on the social impact of research findings.

The data [including early SARS patients were mostly restaurant workers who handle wild animals and serve exotic food like civet cats; civet cats carried a coronavirus almost identical to human coronavirus] directly affected the business of merchants selling exotic animals. These people may not even have learnt science at all in their life but their lives have been heavily affected by science.

Sadly, there were also some occasions when scientific research on SARS was impeded by political decisions. In mainland China, in a misguided effort to prevent widespread panic, strenuous efforts were made to conceal the true extent of the epidemic. When Dr Jiang Yanyong exposed the cover-up in a letter to a Beijing television station and *Time* magazine, he was arrested and detained. Dr. AC commented on this incident as follows:

In Mainland China, when the government said there were no cases of SARS at the beginning of the epidemic... how could the scientists in China do research on samples collected from the SARS patients there if there were no cases?... Certainly scientific research is oftentimes controlled by the will of the government.

Professor GZ, a molecular biologist, said that he could see ‘both sides of the coin’ with regard to the delay in announcing details of the SARS infection in China. In an interview conducted 18 months after the SARS crisis was over, he commented:

We have learnt from SARS that if the government wants to keep this kind of thing secret, it’s not good... The government didn’t want to release information in the early stages because they were afraid that the media was going to make the situation worse...

Now the WHO doesn’t think SARS is a very severe disease. Even if SARS comes back, the WHO will treat it very calmly... Media may sometimes be dangerous in causing over-reaction among the people... and that probably would influence the research and also the medical treatment... It’s really not necessary to panic, but the media didn’t know that...I think we have to educate the government, the media and the people...

Clearly, Professor GZ holds the view that irrational panic can be suppressed by educating the general public and promoting a better understanding of science and the nature of science.

### 9.3 Interactive Influence between Science and Social and Cultural Practice

In Hong Kong, many social practices developed during the crisis in response to scientific findings about the transmission of SARS are still evident. For example, face-masks are worn when people fall ill or when they visit hospitals; lift buttons are cleaned more frequently; two pairs of chopsticks, one for eating and the other for picking up food from shared dishes, are provided by most restaurants. In other words, science is seen to have had a profound influence on day-to-day social and cultural practices.

We have also noted some examples of well-established social and cultural practices influencing people’s responses to the possibility of SARS infection. In western countries or regions with a strong western influence like Hong Kong and Singapore, patients were treated with Western medicine. In contrast, people in Mainland China searched for traditional Chinese medicine and traditional ways of preventing SARS infection. For example, it was widely believed that boiling and vaporizing vinegar into the surroundings may reduce the chance of being infected. In our package, photos showing people queuing up for Chinese medicine and vinegar in Mainland China are compared with photos of people in regions under Western influence being treated by Western medicines such as Ribavirin and steroids. Unfortunately, many SARS patients who were treated by the latter means suffered from long-term side effects.

## 10 Significance of the Study

This investigation on the work of scientists on the SARS research provides empirical evidence of some prominent features of NOS in contemporary scientific fields which have not been adequately emphasised in the school science curriculum. This supports the important message by Rudolph (2000) that educators, curriculum designers and teachers should be open enough to accept that there is no single preferred or informed NOS framework which is static with time. Rather, NOS is as tentative as scientific knowledge itself (Lederman 1995). We suggest that teachers, curriculum planners and science

educators engage in reconsideration of the aspects of NOS included in the school science curriculum in order to reflect more fully the practice of science in the 21st century. In particular, we would like to see much more emphasis on the need to combine and coordinate expertise in diverse scientific fields, the intense competition between research groups, the significance of affective issues and funding constraints on the conduct of research, and the complex interactions within the social, cultural and political milieu in which scientific practice is located.

We hope that our efforts in ‘turning crisis into opportunity’ through identifying prominent NOS aspects in the story of SARS, and designing learning activities to explicitly teach about these aspects, can encourage others to capitalise on examples of contemporary scientific inquiry in real-world practice. Contemporary examples adjusted to fit the level of targeted students possess several instructional advantages. For instance, when scientists who have made a key contribution to the advancement of the field talk about the ‘inside stories’ and narrate first person experiences, there is a much enhanced sense of authenticity and greater interest among students. The rapid and accelerating pace of scientific development ensures that there is no shortage of intriguing stories of authentic scientific inquiry to keep our students captivated for years to come.

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## Appendix A

### Questions of the Semi-structured Interview with the Scientists

1. Could you describe the findings and contributions of you and your research group in the battle against SARS in the past few months?
2. Could you describe the research methods that you have used to achieve the findings and contributions you have just described?
3. What are the main concerns and pressures you faced during SARS research?
4. Could you comment on whether each of these elements has been demonstrated in your research work on SARS? If yes, please give a concrete example. [The scientists were provided with a list of NOS elements compiled with reference to the analysis of school curriculum documents by McComas and Olson (1998) and Lederman et al. (2002)].
5. Are there any other additional elements that you have experienced which are not included in this list?
6. In your opinion, which elements of NOS should be taught to school students?

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