6. ENHANCING STUDENTS’ UNDERSTANDING OF THE NATURE OF SCIENCE AND THE INTERCONNECTION BETWEEN SCIENCE, TECHNOLOGY AND SOCIETY THROUGH INNOVATIVE TEACHING AND LEARNING ACTIVITIES

INTRODUCTION

International and Local Trends

Understanding the nature of science (NOS) and the interconnection between science, technology and society (STS) has been a prominent objective of science curricula worldwide (e.g. American Association for the Advancement of Science, 1993; Council of Ministers of Education, 1997; Millar & Osborne, 1998). Research confirms the contention that sound knowledge of the NOS and STS will enhance students’ learning of science content, interest in science, and ability to make informed decisions based on evidence (Driver, Leach, Miller, & Scott, 1996; McComas, Clough, & Almazroa, 1998; Aikenhead, 1994).

In Hong Kong, the Junior Science Curriculum implemented since 2000, and the S4-5 Physics, Chemistry and Biology curricula implemented since September 2003, have followed the world trend and placed explicit emphasis on the understanding of NOS and STS in their objectives and content. Stated in newly reformed Physics, Chemistry, Biology and Senior Science Curricula (CDC-HKEAA, 2007), which has just been implemented in 2009, the overarching aim is to provide science-related learning experiences for students to develop scientific literacy and become life-long learners in science and technology. Among the broad aims under this overarching aim, understanding NOS and STS continue to be spelt out explicitly, namely,

- Students should be able to
  - appreciate and understand the nature of science in science-related contexts
  - make informed decisions and judgments on science-related issues
  - be aware of the social, ethical, economic, environmental and technological implications of science, and develop an attitude of responsible citizenship

These new emphases are particularly important when more and more social issues in our daily lives demand a populace which is scientifically literate in following new developments in science and scientific debates.
Urgent Need in Teacher Training and Provision of Curriculum Resources

Research conducted in different countries has consistently come up with the disappointing result that science teachers themselves do not have an adequate understanding of NOS (Lederman, 1992) and the interrelationship of STS (Rubba & Harkness, 1993). Furthermore, various studies, including a study in Taiwan where rapid reform in science education is also taking place, report that the implementation of teaching of NOS and STS is impeded by the limited availability of relevant curriculum resources, particularly those in local contexts and language (Tsai, 2001). Similar limitations have also been found among the Hong Kong science teachers, in a recent study on teachers’ understanding of STS and beliefs about its implementation (Wong, 2004). The main concerns of teachers in this study include limited curriculum time, inadequate supporting resources and lack of necessary pedagogical skills.

The above findings and the fact that Hong Kong teachers have not themselves experienced this kind of learning, underscore the urgent need of enhancing both their understanding in NOS and STS and the pedagogical knowledge and skills that are necessary for this kind of teaching.

Timely Response to Education Reform

In response to the science education reform which demands new goals and new types of teaching approaches, and the concerns and difficulties expressed by Hong Kong science teachers, the authors of this paper have launched a curriculum innovation project supported by the Quality Education Fund¹ (QEF) of Hong Kong. Through the development of a series of innovative teaching and learning activities, the project team aims to help teachers to foster students’ understanding of NOS and the interconnection of STS. In addition, the wide range of activities developed in this project also aim to develop the various generic and transferable skills including, problem-solving, creativity, critical thinking, numeracy, communication as well as collaborative skills. These knowledge and skills are essential for students to develop into sensible and responsible citizens who participate actively in a dynamically changing society, and contribute towards a scientific and technological world.

In this paper, we first give a brief summary of the two-year QEF project plan to achieve the above goals. We then focus on reporting the curriculum materials we developed in this project. Findings about teachers’ experience in classroom implementation of the materials will be reported in an independent article.

THE QEF PROJECT

Project Plan

High quality curriculum or teaching materials do not naturally result in student learning. Such materials have to be mediated by teachers with necessary content knowledge, beliefs and intention (Schwartz & Lederman, 2002; Lumpe,
Haney, & Czerniak, 1998). Thus we attempted to achieve the above goals and objectives through two phases:

First phase – production of curriculum materials and teacher training

(i) Designed and developed 12 sets of curriculum materials of a range of innovative activities related to the teaching and learning of NOS and STS in the form of practical work, scientific investigation, case studies, model-making, critical analysis of news/scientific articles, explanatory stories of science, etc. Each activity would be furnished with comprehensive teacher’s guides.

(ii) Ran training workshops for about 70 participating teachers from about 40 schools, who are enthusiastic about learning and practising the pedagogical skills required for implementing the innovative activities.

(iii) Obtained comments and feedback from the participating teachers to further refine the quality of the teaching materials.

(iv) Recorded classroom implementation of the innovative activities. The video recordings would help participating teachers to reflect on the lessons through self and peer evaluations.

Second phase – wider dissemination of curriculum materials and exemplary implementation

(i) Produced CD-ROMs consisting of all sets of teaching materials and videos of exemplary lessons in which participating teachers implement the innovative activities in their own classrooms.

(ii) Disseminated the above output to all science teachers in Hong Kong and encourage them to implement the innovative activities in their own classroom teaching for effective learning of NOS and STS.

The lesson videos which document the implementation of the innovative activities aimed to serve as an invaluable tool for in-service teacher professional development, pre-service teacher training and school staff development, through interactive collaboration in one of the following ways (Black & Atkin, 1996):

– Exposure to other ideas broadens teachers’ awareness of possibilities for change and fosters a sense that alternatives are available.

– Existence of proof of new methods under normal classroom conditions gives moral support to teachers and challenges them.

– Demonstration of actions, reflecting the new ideas, in a real context deepens teachers’ understanding. Also, such modeling strengthens the proof of existence.

Exemplary case teaching has been found particularly appropriate in preparing teachers for reform-based teaching (Putnam & Borko, 1997) because the opportunity for teachers to experience workable alternatives to conventional practice in actual classroom settings is often quite limited.

Unlike live observations, videos allow for multiple and repeated opportunities to replay, analyze and re-analyze. It also provides the opportunity to study the fast-paced, complicated world of classroom teaching and to reflect on it. Thus in addition to the
infusion of the non-traditional teaching approaches to the community of teachers, we also hoped to promote the habit of reflection which is an essential element for the teaching profession.

Curriculum Materials

In this section we elaborate on three sets of teaching packages showing how we integrate content knowledge with innovative activities in promoting NOS and STS. We give a description of the rationale, highlights of each set of materials and the expected student learning outcomes of each sample activity. Greater details are given in the first set of teaching resources to provide a more complete picture of the formats and style of the teaching packages we developed.

(I) Understanding LASIK

**Rationale.** Traditionally the science curricula have focused more on science content (e.g. refer to the curriculum documents of Physics, Chemistry, Biology and Integrated Science in Hong Kong before or in the 90s). Its application and implication to society are often provided as add-on information. Even practical work or demonstrations are mostly “cookbook” type experiments and are designed to demonstrate scientific principles rather than relating science to the technological applications, as reported in Angell, Guttersrud, Henriksen, and Isnes (2004). The decrease in students’ interest in science is often due to the lack of appreciation of the relevance of science principles to daily life (Reid & Skryabina, 2002).

LASIK which stands for ‘Laser in situ keratomileusis’, is an example of modern technology where a laser beam is used to correct vision by reshaping the cornea of the eye. As short-sightedness is very common among Chinese populations and the demand for LASIK surgery is increasing, this is a highly relevant topic in combining science, technology and their effects on society for students. LASIK involves fundamental scientific principles in Optics which is a topic in the Physics curriculum of the proposed new senior secondary level. It also fits in with one of the Electives, Medical Physics. Additionally, it relates to the topic Organisms and Environment in the Biology curriculum and highlights the interdisciplinary nature of modern science and technology.

In this teaching package (Figure 1–8), we introduce the medical operation as a practical task for students to perform like eye surgeons. This practical work can be integrated with the physics principles of the correction of short- and long-sightedness by the use of concave and convex lenses. Unlike conventional practical work, students will not follow a traditional “cookbook” protocol closely so as to obtain well-established results.

We then make use of the history of the scientific development of LASIK to raise some elements of the nature of science. Lastly LASIK is a typical STS topic. Societal issues including the pros and cons of a surgical procedure, the associated risks, and the issue of informed consent can be discussed in the classroom.
Extracts of the curriculum package

Below we present two key activities in this curriculum package.

Let’s do “eye surgery” in the laboratory!

LASIK operation – a form of eye surgery in which the cornea of a patient is reshaped so that the image formed is adjusted back onto the retina. Now you are going to simulate this eye surgery.

List of equipment and materials you will find useful for your ‘surgery’

| Equipment and Materials | Description |
|-------------------------|-------------|
| Lamp housing            | with a letter F as an illuminated object |
| Convex lens             | covered with a black plastic sheet with a centre opening to simulate our eye lens |
| “Cornea”                | made from gelatin |
| Clamps and a stand      | to fix the position of the lamp house and the ‘eye’ |
| Lens holder             | to fix the position of the ‘lens’ and the ‘eye’ |
| Movable stand           | with a piece of paper attached to its top surface to act as a screen to simulate the retina |
| Lighter or Hot water    | to heat up tools for reshaping the cornea |
| Any tools that can reshape the ‘cornea’, e.g. spatula, deflagrating spoon, combustion spoon, scalpel, stirrer with ring handle, a ring made from metal wire, etc | to reshape the cornea |

You could ask for other tools you think are necessary for your “surgery”!

Figure 1. Activity: Modelling LASIK.

Investigation Setup

– The cornea is placed over the eye lens.
– A lamp house with an illuminated letter “F” acts as the object in front of the eye.
– A movable stand with a screen on it is used to capture the image.
Simulation of correcting short-sightedness

1. In the case of short-sightedness, we simulate it by forming the image of an object in front of the retina. For correction of short-sightedness, you have to reshape the cornea and move the image backward onto the retina (downward in the simulation set-up).

Procedure:
Locate the image (illuminated letter “F”) on the movable stand sharply, this is the image formed by the short-sighted eye.

(a) Think about how to reshape the cornea to correct the short sightedness - Describe with the aid of a simple diagram how you can do so. Now try out your idea.
ENHANCING STUDENTS’ UNDERSTANDING OF THE NATURE

Teacher’s notes:
- Use the lighter to heat up the spatula.
- As shown in the picture, use the heated spatula to flatten the cornea to refocus the image back to the retina surface. (The cornea becomes more concave.)

Remark for 1(a) & 1(b): Teachers should not tell the answers to students directly. Guiding questions like “What kind of tool do you need to reshape the cornea?”, “Will you need to increase or decrease the converging power of the lens?”, “What shape will you make for the correction?” should be asked.

Figure 4. Procedure of correcting short-sightedness.

(b) Are your ideas successful? Please illustrate how, with the aid of a diagram.

Teacher’s notes:
After the flattening of the cornea, it is found that the new position of the image is below the original one. As the lens is made more concave, the image is shifted backward to the retina. (As shown by the red arrow)

Figure 5. Explanation of correcting short-sightedness.

Simulation of correcting long-sightedness
2. In the case of long-sightedness, we simulate it by forming the image of an object behind the retina. For correction of long-sightedness, you have to reshape the cornea and move the image forward onto the retina (upward in the simulation set-up).
Procedure:
Locate the image (illuminated letter “F”) on the movable stand sharply, it is the image formed by the long-sighted eye.

(a) Think about how to reshape the cornea to correct the long sight - Describe with the aid of a simple diagram how you think you can do so. Now try out your idea.

Teacher’s notes:
- Reshape the cornea with heated metal ring.
- The donut shape on the topmost of the cornea effectively increases the curvature of the cornea and increases the converging power of the eye (Please see the remark in 1(a))

(b) Are your ideas successful? Please illustrate how, with the aid of a diagram.

Teacher’s notes:
After the reshaping of the cornea, it is found that the new position of the image is above the original one. It is shown that the lens becomes more convex and the image is shifted towards the retina. (As shown by the red arrow)
3. Doctors suggest that the thickness of the patient’s cornea is an important factor for whether a patient is suitable for doing LASIK. Can you suggest a reason?

**Teacher’s notes:**
*The correction requires removal of corneal tissues. For serious short-sightedness or long-sightedness, many tissues have to be removed. Possible rupture of the cornea may result if it is too thin.*

After the investigation, you should have learnt that the lens is not the only part that refracts light in our eyes.

**Common Misconception**
Many students have a wrong concept that only the lens refracts the light in our eyes. Apart from the lens, the cornea, aqueous humour and vitreous humour also play a role in refracting the light in our eyes.

**Activity: Learning about the Nature of Science through the History of Development of Refractive Surgery**

*The long pursuit of correction of eye defects.* The quest for the correction of eye defects could be dated back to early Chinese civilization. Folklore states that people with short-sightedness put sandbags on their eyes at night. The pressure effect of the sandbags on the cornea changed the curvature, which focused the eyes for a short period the next morning.

**Technology can come before the understanding of the related science.**

(Q.1)

Q1. Suggest possible reason(s) why the sandbags help to correct short-sightedness.

**Teacher’s notes:**
*The pressure effect of the sandbags may cause two changes to the eyes: 1) Shorten the eye ball 2) Cornea may become less convex*

*(Do you think those ancient people understood the scientific principle behind their practice?)*

**Technology is driven by societal demand and human’s need.**

(Q.2 & Q.3)
Q2. Before the invention of LASIK, we already had contact lenses and spectacle lenses. What encouraged scientists and technologists to invent LASIK?

**Teacher's notes:**
Our need for good vision, society's demands and health issues all encourage scientists to use theory to invent better ways to correct vision, since the existing technology (spectacles and contact lenses) could not satisfy our needs. E.g. It wastes time to clean up contact lenses. The pressure that the spectacles exert on nose makes people feel not comfortable.

**Teacher can bring out the point that human's pursuit of better life and being unsatisfied with the existing situation are always one of the drives for new invention and applications of scientific knowledge.**

Q3. Can you list some occupations in which the use of spectacles/contact lenses is potentially?

**Teacher's notes:**
Fireman: The intense heat can deform the contact lenses. Professional drivers: Crushing may damage the spectacle lenses. (Any other reasonable answers are accepted) Remarks: In fact this is another example of societal demand which drives the development of technology.

**STSE**
Development in science can advance technology.
Likewise progress in technology can advance science. (Q. 4)

How were the ideas of refractive surgery developed 55 years ago?
In 1960, a Russian scientist, Dr. Fyodorov, gave birth to the idea of refractive surgery. One day he was treating a young boy who had fallen, and his glasses had broken and cut into his cornea. The damage simply shaved a layer off of the outer surface of the eye. The boy, previously having serious short-sight, now had improved vision in that eye! Dr. Fyodorov was surprised and studied the matter. He published his discoveries, but it was not until later that American doctors, who read about it, had enough funding to begin serious research.

How did the application of refractive surgery start in the U.S.?
Dr. Leo Bores brought the procedure to the United States. Americans also thought of using a laser. In 1978 an ophthalmologist successfully incorporated a high intensity laser which allowed extremely high precision in cutting the cornea during refractive surgery. Since then “laser assisted refractive surgery” has become popular and over 10 million people have benefited from the surgery.
Q4. What critical technology enabled extreme high precision in refractive surgery? Comment on the influence of technology on science?

**Teacher's notes:**

*The Laser is the critical technology that enabled extremely accurate cutting of the cornea in refractive surgery.*

*Notes: Teachers help the students to build up the concept that sometimes science leads technology, but also technology may lead science. E.g. the invention of the electron microscope enabled biologists to study biological tissues deeply which led to the advancement of biology and medical science.*

Q5. A Russian scientist first discovered the potential of curing eye defects by refractive surgery, but American scientists made it popular. Why? What other factors were also critical for this scientific development?

**Teacher's notes:**

*The American scientists, not the Russians, had enough funds to do serious research on refractive surgery.*

*(Teachers help the students to build up the concept that government policy and availability of research funds are also critical for development of scientific knowledge. Brilliant or inventive ideas often require manpower and resources to support the subsequent scientific research investigation).*

(2) Infectious Disease

**Rationale.** This teaching package aims to help students to learn about the general structure of a virus, the lytic cycle for virus reproduction, and basic concepts of virus and flu. Severe Acute Respiratory Syndrome (SARS) and bird flu are used as the contexts to interweave the subject knowledge with several key concepts of the nature of science. Instructional materials including an exercise in making informed decisions, an investigation game and in particular videos of interviews with local scientists who fought against the SARS diseases are included to illustrate some aspects of nature of science as demonstrated in the authentic scientific research.

**Extracts of the Curriculum Package**

Below we present one of the activities (Figure 9–11) in this curriculum package:
Activity – What does the search for the virus causing SARS tell us about science?

In this activity, the episode of how the SARS scientists searched for the causative agent of SARS is used to highlight some important key elements of NOS which most teachers and students may not be aware of.

The two slide^2 above act as a set to bring up one of the key elements of the nature of science – theory laden observation, i.e. what one observes is affected by one’s background knowledge and what one wants to see. In the above picture, people tend to observe very different things, for example, rock with a lake, a crocodile, lava after volcanic explosion, etc. However, when the title is given, most people will start seeing a mother with her son lying horizontally across the page.

The pair of slides on the next page illustrates how the theory laden observation can also occur in authentic scientific research. The upper one shows that on March 18, 2003, scientists in the Chinese University of Hong Kong (CUHK) and Germany announced that the virus was a member of the paramyxovirus family, a human meta-pneumovirus. Shortly after their announcement, scientists from Singapore and Canada also announced they had found evidence of paramyxovirus.

The lower slide shows that only four days after the CUHK announcement, on March 21st, 2003, the scientists of the University of Hong Kong announced that they had found new evidence that identified coronavirus as the pathogen causing SARS. After they made the announcement on the World Health Organization (WHO) network, scientists from Rotterdam, Frankfurt, and Centers for Disease Control and Prevention (CDC) in Atlanta also reported finding evidence of coronavirus.

The two slides are used to invite students to identify and describe the theory-laden observation as evident in the search for the virus causing SARS.

Additionally, the above episode, showing the rapid shift from the acceptance of paramyxovirus to the coronavirus as the casual agent of SARS, also demonstrated that scientific knowledge is not static but tentative – another nature which is not immediately apparent to students as they are used to taking scientific knowledge as established facts.
(3) Bleaching shark fin with hydrogen peroxide

**Rationale.** ‘Reading to learn’ has been advocated for quite a long time (Davies & Greene, 1984; Wellington & Osborne 2001). Reading forms a significant part of our learning. Scientists devote much of their time to scrutinizing research papers. For the general public, they receive much information through newspapers, magazines, pamphlets and the Internet. Hence, training our students to read carefully and critically, as part of the communicative skill, becomes essential – no matter whether we want our students to be scientists or citizens who can make informed judgments based on written sources of information.
However, it has been found that teachers in general only allocate a small part of their teaching sessions for students’ reading. Also, teaching resources on reading, particularly those that have local relevance, are scarce. In the light of this, the materials suggested here aim at illustrating an example of how teachers can make use of newspaper clippings to enlighten students about how to become critical readers of science-related information in the context of a social issue.

In order to make the reading more active, critical and effective, Davies and Greene (1984) proposed that in a reading activity students need (i) a purpose, (ii) coach and (iii) collaboration. The three criteria have been taken into the planning of the activity.

There was an incident at the end of 2003 in which officials in mainland China discovered the use of industrial hydrogen peroxide for bleaching shark fins in a factory. Concerns have been raised over the territory (see a report in the box below). Almost all of the newspaper reports widely discussed the harmful effects of hydrogen peroxide, yet some reports diverted the focus away from the crux of the issue – it is the use of industrial hydrogen peroxide which contains some toxic impurities that matters, not hydrogen peroxide per se. While individual reports mentioned the toxic impurities, much of the attention has been on hydrogen peroxide.

It is believed that this is an opportunity in which we can help students to see the relationship between science, technology and society (STS) and how the science knowledge that they have learnt in their lessons can help them to make sense of news reporting. With some purposeful guidance, students will be able to evaluate the validity of science-related newspaper reports.

**Extracts of the Curriculum Package**

Below we present one of the activities (Figure 12) in this curriculum package:

**Activity – Critical review and analysis of newspaper articles with follow up investigation in verifying their claim**

At the end of the lesson, students should be able to,

1. critically review newspaper reports based on their science knowledge,
2. practice verbal communicative skills with their fellow classmates
3. understand that news reporters can misrepresent a socio-scientific issue,
4. appreciate the interconnection between science, technology and society

In this activity, students will be asked to read a newspaper report individually (see one of the examples in the box below) on the issue and to identify the problem associated with the bleached shark fin. This sets the ‘purpose’ for the reading. As most of the students can easily be misguided by the newspaper report – this was confirmed in our pilot study – the teacher will then provide some guidelines for them to rethink and discuss the issue (coaching) in groups (collaboration). The guiding questions include what the differences between the properties of hydrogen peroxide and industrial hydrogen peroxide are, and how these two substances can affect the body. Also, students will be asked to think about the usual way in which
shark fin is cooked. It is hoped that these guiding questions can help students to relate the effect of washing and prolonged cooking on shark fin and its residual hydrogen peroxide, and hence reach the conclusion that, in contrast to some of the newspaper reports, using hydrogen peroxide itself does no harm to the body. Rather, it is the impurities in industrial hydrogen peroxide that can cause harm. To further verify the stability of hydrogen peroxide (decomposes to water and oxygen gas), students can be asked to plan a scientific investigation to determine its decomposition rate.

Over-consumption can cause cancer and deform foetuses
Sing Tao Daily 2003-12-05

Guangdong government officials have discovered a factory using industrial grade hydrogen peroxide to treat sharks' fins. It might upset people to know that this delicacy is potentially carcinogenic. A pharmacist and a doctor pointed out that industrial grade hydrogen peroxide is very concentrated. Also, it is manufactured carelessly and may be mixed with quite large amounts of heavy metals and other toxins. They may cause gastrointestinal ulcers if consumed. Medical literature has also pointed out that hydrogen peroxide may cause cancer. If a pregnant woman takes the substance, she might give birth to a deformed fetus.

The colourless liquid may lead to stomach ulcers

Like water, hydrogen peroxide is a colourless liquid. It is used as a bleach, oxidizer or germicide in industry. Industrial grade hydrogen peroxide has a high oxygen content. However, our body will accumulate toxic substances from the industrial product after excessive use, which changes body cells and may even cause cancer.
A doctor stated that if our body absorbs too much oxygen, it can damage cell membranes and speed up aging. Hence, it is generally not recommended. But it is used by some naturopathic medicine specialists for treating diseases.

Still toxic after boiling

Professor Lee Kwing-chin of The School of Pharmacy, CUHK indicated that diluted hydrogen peroxide bleach is not very harmful to humans. However the concentration of industrial grade hydrogen peroxide is so high that it may damage the digestive system. Also, prolonged absorption or massive absorption could cause ulcer. He said that medical literature has indicated an association between hydrogen peroxide and cancer.
Legislator Lo Wing-lok, who represents the medical constituency, said boiled bleaching solution would do no serious harm to the human body, but industrial grade hydrogen peroxide would affect our health.
Dr Lo explained that industrial grade peroxide demands a low purity and may be mixed with other substances like organic and inorganic toxins, heavy metals like lead and biotoxins like arsenic. If they were absorbed into the shark’s fin, they could cause various problems.

Figure 12. Newspaper report.
CONCLUDING REMARKS

Throughout the development of the teaching resources, we sought comments and feedback from teachers who participated in our training workshops and in particular teachers who tried out the activities in their own classrooms. The final form of each activity has been revised many times based on the exchange with these enthusiastic teachers who are keen to contribute towards the development of the teaching resources for students to learn about NOS and STS. We concur with the view of Derek Hodson (Hodson, 2006) that “curriculum materials need to have a ‘street credibility’ that can only be gained when they are developed by teachers for teachers.” (p. 305). The instructional packages and the classroom practices have been disseminated to all secondary schools in Hong Kong in the form of CD-ROMs. The instructional packages are also available in the website http://learningscience.edu.hku.hk/. We believe that we have demonstrated in the teaching packages, the principles of how NOS and STSE could be integrated smoothly into the teaching of subject content knowledge. The classroom implementations of these teaching resources have demonstrated that students have the ability to learn the concepts of NOS and STSE and that they have enjoyed the various non-traditional classroom activities. We have found no evidence that the learning of the subject knowledge intended in the packages has been compromised. We hope that teachers will be encouraged by these findings and position themselves to take on the new initiatives in teaching about NOS and STSE.

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NOTES

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2 The slides are modified from the picture http://timepass1.wordpress.com/2009/01/21/lake-in-burma-praying-mountain-another-hoax

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