Facilitating active learning through a thematic science curriculum

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Abstract

This article analyzes students' learning of science in a context of a thematic science unit entitled "Clean Water" of the Hong Kong Junior Secondary Science Curriculum (JSSC). Through lesson observations, three curriculum features, namely, "relevancy to learners' life", "problem-solving and thinking skills", and the "science, technology and society

(STS) approach" were identified in the classes of the "Clean Water" unit of the JSSC. The findings also revealed that these three curriculum features could effectively facilitate active learning atmosphere in the classroom. This article further drew implications for classroom practices in the implementation of science curricula for students living in the 21st century.

Introduction

Since the 1990s, school science curricula in most developed countries have been renewed (Bentley, 1995) because preparing students for continued studies in science disciplines was no longer the exclusive aim of science education. Scientific literacy for all students then came more to the foreground (Fensham, 1985). Science education reform efforts worldwide share a common feature of the 'science for all' approach which caters for the needs of all citizens rather than future scientists or engineers. The impacts of western science curriculum reforms in the 1990s took place in Hong Kong about a decade later. For example, a group of science teachers and educators conducted a SMILE project developing science curriculum materials "to make school science a motivating and invigorating learning experience for students" (Law, Wong, Lo & Yung, 1996, p.1) between 1994 and 1995. This project was an effort of school-based curriculum development to enhance the quality of science education in Hong Kong. For the part of centralized science curriculum, a new Hong Kong Junior Secondary Science Curriculum (JSSC) (CDC, 1998) has been implemented since 2000, echoing the aims of science education for the 21st century proposed by the Curriculum Development Council (CDC, 2000). The main aim of the JSSC is to help Hong Kong students to "develop the necessary scientific and technological knowledge and skills to live and work in the 21st century" (CDC, 1998, p.2). This study examined the official curriculum documents of the JSSC (e.g. CDC, 1986; CDC, 1998; CDC, 2000) in order to identify the purposes and strengths claimed by the centralized science curriculum in Hong Kong. All the curriculum features from the official documents were then compared with the literature. It was found that the JSSC included three major features for the learning and teaching of science:

1. Relevancy to learners' life

The JSSC emphasized the linkage between science and the daily-life experiences of students. Literature (e.g. Jacobs, 1989; Shoemarker, 1989) argued that pupils would find their learning meaningful and be motivated if the subject content was linked with their daily-life experiences. The content of science curricula should hence be more relevant to pupils' daily lives. This assertion was consistent with Carin's (1993) findings in a study about the curricula developed in the 1990s when elite education came to its end in most education systems around the world. The introduction of the compulsory education not only made the school rolls expand rapidly but also make many teachers struggle for methods to motivate those academically less able students in the classrooms. The JSSC (CDC, 1998) therefore aimed at providing students with more stimulating learning experiences by infusing more content that was relevant to students' daily lives.

2. Development of problem-solving and thinking skills

Another perspective supporting recent science curriculum reforms is about the development of learners' ability to think independently and to solve problems. One of the main emphases of science education is "placed on enhancing students' scientific thinking and strengthening their science process skills" (CDC, 2000, p.7). The JSSC actually promotes an investigative approach (CDC, 1998, p.2) for developing students' thinking and problem-solving skills and focuses on the quality of activities that can provide "minds-on" and "hands-on" learning processes for students.

3. Adopting the Science-technology-society (STS) approach

STS education began in North America early in the 1980s. There are four major strands made up the argument for the STS approach to science:

- The capacity of science to provide wealth and health for society.
- The will to bring craftsmen, and then the general public, towards an understanding of science.
- The shock of science in warfare, and later in the environment, and so the need for values and responsibility within science.
- A re-evaluation of neutrality of scientific evidence and knowledge making (scientific epistemology).

(Solomon, 1993, p.15)

National Science Teachers Association (NSTA) of the USA defined STS education as "the teaching and learning of science and technology in the context of human experience" (NSTA, 1990, p.47). The appeal to adopt the STS approach in science teaching aims at preparing children for the challenge of the fast-changing world in terms of technological and economical advancements. Harms (1977) identified four goal clusters for the teaching of science in schools, viz., science for meeting personal needs, science for resolving current societal issues, science for assisting career choices, and science for preparing for further study. According to Solomon (1993), the STS approach should focus on students' understanding of the environmental threats to the quality of life as well as of the fallible nature of science. It should also focus on the economic and industrial aspects of technology. While students' are challenged with their personal opinions, values and attitudes towards democratic actions, multi-cultural perspectives will also be induced to deal with current societal issues. Therefore, STS education really meets the goals of science teaching identified by Harms. Reviewing the curriculum documents (CDC, 1998; CDC, 2000), it was found that the JSSC also aimed at facilitating STS education to a certain extent. Such objectives are clearly stated in the curriculum document:

1) Students should acquire the basic scientific knowledge and concepts for living in and contributing to a scientific and technological world.

2) Students should recognize the usefulness and limitations of science and the interactions between science, technology and society.
3) Students should develop an attitude of responsible citizenship, including respect for the environment and commitment to the wise use of resources.

(CDC, 1998, p.3)

Between 1998 and 2000, a project was carried out to develop teaching strategies and resources for which were tried out in real classroom situations before the official implementation of the JSSC in 2000. One of the teaching packages developed was for teaching the unit of "The wonderful solvent-water". As the project members thought that the title of this unit did not sound closely to student's daily experience, the science concepts in this unit were organized into a coherent theme entitled "Clean Water". To cater the diverse learning abilities of students attending the 9-year compulsory education, the teaching package extensively adopted student-centred learning activities which intended to help students to overcome short attention span by constantly injecting different stimuli to keep up with their motivation. A variety of learning activities were developed to facilitate students to discover, investigate, and explore science about this theme in order to make the lessons more appealing to students.

Method

According to Cohen and Manion (1994), the use of case studies could provide useful information on the interpretive and subjective dimensions of educational phenomena. Therefore, data in this project were collected from lesson observations, student interviews, teachers interviews, and a survey on students' learning outcomes and feeling about the lessons. Four teachers and 197 students from six classes participated in this study. Each class spent from fourteen to seventeen 40-minute lessons for the whole theme. The lessons and interviews were videotaped and transcribed. The four teachers teaching these six classes were invited to view their own lessons on which they made reflections during the interviews. To ensure the reliability of the data, the field notes, lesson tapes and interviews were coded by the two authors separately. The first part of the questionnaire survey was set out to assess students' understanding of scientific concepts learnt in the lessons. In the second part of the survey, students were asked to evaluate the effectiveness and their feeling of the learning experiences provided by teaching designs of this project.

Results

This section would identify the extent the three main features, namely, relevancy to learners' real-life, problem-solving and thinking skills, and the science-technology-society approach, being adopted in the lessons of the "Clean Water" theme. How students learned science through this thematic unit was also reported.

Relevancy to learners' daily-life

"Relevancy to students' daily lives" was one of the features identified in the lessons of the JSSC. The title of the theme, "Clean Water", was established because of the consideration of the relevancy between water and students' daily experiences. In addition to teaching students how to produce clean water, this science unit included the content and examples closely relevant to students' daily life experiences, such as the water cycle in nature. In one of the lessons, teachers arranged some experiments that helped students discover where fog, dew and frost came from. The discovery of the formation of frost brought surprise and joy to students in most classes observed. Nelson (pseudonym) was the first student who discovered frost formed outside a breaker containing ice and salts. He shouted excitedly to notice his teacher. Then all students stopped their work and tried to touch frost from their beakers. Students said that they found ice and the teacher related their findings to the natural phenomenon of frost. Nelson was interviewed after the lesson. The following was the translation of the dialogue:

Interviewer: What did you feel when you found out that frost formed on the outside of the beaker?

Nelson: I was very surprised in the first place so I called loudly Mr. Young (The teacher's pseudonym) and my classmates to see this thing.

Interviewer: Have you seen frost before? What made you so happy in the class?

Nelson: Yes, my father brought me to Tai Mo Shan (the highest mountain in Hong Kong) to see frost one night last winter. That night was cold but it was fun. I've never thought that we could see frost in the laboratory. But it was really frost even though we could only get very little of it.

Interviewer: It was not very cold in your classroom. Do you know how frost is formed?

Nelson: Yes, just like what Mr. Young said, frost will be formed when vapour is cooled down rapidly. Salt will make the ice inside the breaker very cold, below zero degree. So when vapour hits on the cold beaker, it will become frost.

Interviewer: Do you like to learn more about frost, fog or dew ?

Nelson: Yes.

Interviewer: Why?

Nelson: Because we often hear or see these things. We should know what they are made of and where they come from.

There was another scenario relating to students' daily lives. Students watched a video about water pollution in Hong Kong. The teachers took the video themselves in the districts close to the school. Students were impressed by the familiar places and people and showed great interest in further investigating the problem of water pollution. Furthermore, students were asked to retrieve the information of treatment of domestic water by the Water Works Department from the internet. They displayed good motivation to devise methods of purifying water and performed the experiments, such as filtration, making filter columns, and decontamination (observe the effect of chlorinated water on micro-organisms). The learning atmosphere was very active as evaluated by the authors, the teachers and students themselves.

Problem-solving and thinking skills

The lessons in this study also provided many opportunities for students to develop their problem-solving and thinking skills. Kirkwood (2000) asserted that "problem solving is a goal-oriented process which requires the integrated use of a range of higher-order thinking skills" (p.511). He further elaborated that these thinking skills included generating ideas, making interpretations and judgments, and using strategies to mange the complexity of situations. The "Clean Water" theme in this study was designed to develop students' thinking and problem-solving skills. Students were intentionally not given with detailed descriptions of experiment set-ups and procedures during practical activities. They frequently needed to make their own decisions in choosing appropriate apparatus from a equipment list provided in the laboratory. Then teachers would encourage and challenge their students to design experimental methods and solve problems on their own.

In the lessons about filtration, teachers introduced different types commercial household filters to the students. Students were challenged if they could make their own filter columns, which worked as well as commercial ones, by using common materials readily available at home or in shops. It was found that most teams could make their own designs with careful considerations and sound reasons. They understood the relationships among the sizes of materials used, the outcome of the purity of filtered water and the speed of filtration. Students usually had their own theoretical and empirical reasons for the choices of materials or setting up the sequences and thickness of layers. Most reasons given were quite logical in terms of scientific and technological principles. Two examples of students' designs were shown below.

Figure 1

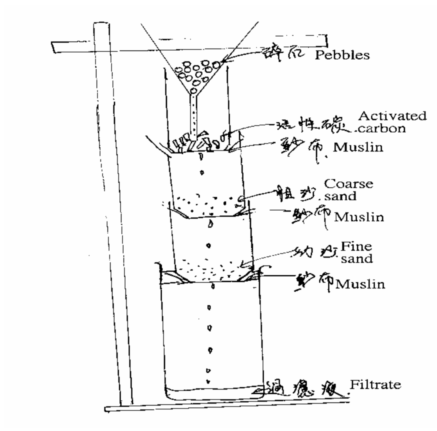
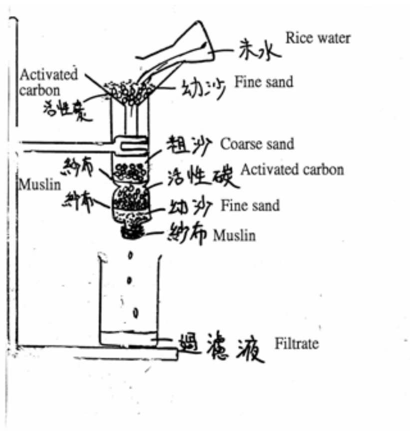


Figure 2



The team designing the filter in Figure 1 reported that activated carbon should not be placed at the highest layer and also lowest layer of the column. The explanation given was that activated carbon would come out with water when it was placed at the lowest layer because the size of its particles was very small. Moreover, the impulse produced by falling water would make activated carbon, if placed at the top of the column, diffuse into other layers. The other team claimed that the thicker the layers, the purer water would be filtered. But this team still limited the thickness of each layer to 5 cm in regard to the size of a home-use filter (Figure 2). By comparing their own filter columns with commercial ones, students could comment on the quality, technical aspects and prices of different bands of commercial filters. This activity really engaged students in solving a practical problem by giving them flexibilities in setting up the equipment. In fact, students were provided with opportunities to think and solve the problem during such an open-ended practical work. Students reported that they were very proud of the filtering effect of some of their hand-made filters which were quite satisfactory comparing to some commercial filters.

A very distinguished outcome was also observed in the lessons about distillation. Students were asked to design their own setup to collect a few drops of water from the steam generated from boiling water. Varying in time spent, most groups finally succeeded in collecting a few drops of water on a watch glass by using a piece of glass slice. Then, a competition was held - to collect as greatest amount (more than 20 ml) of condensed water as possible within a specific time interval. Without showing students the standard condenser in the laboratory, this activity intended to facilitate students to think how to solve the technical problems of collecting distilled water. Discussing, trying out, modifying and re-trying, most teams in the classes observed could finally collect significant amount of distilled water. Figure 3, Figure 4 and Figure 5 shown below were the methods devised by a team in the class of Ms. Ting (pseudonym).

Figure 3

Figure 4

Figure 5

It would be very amazing that students could figure out their own methods to solve the problems of cooling down hot stream effectively and collecting significant amount of distilled water, say 10 to 20 ml. This team initially used some test tubes to collect condensed water. As shown in Figure 3, students put test tubes alternatively over boiling water to collect steam and a crucible to collect condenser water from the test tubes. They explained that several test tubes were used because they intended to increase the area for condensing water. They later replaced the crucible by a watch glass as they found that the crucible was not clean enough. This team soon discovered it was inconvenient to move test tubes around. They thought that there should be some more convenient ways that condensed water would pour down automatically. One of the team members put the test tube the other way around and found that condensed water flowed down automatically. The problem was not yet solved as students soon found that the speed of condensation reduced when the test tubes became warm due to hot steam. To solve this problem, one of the students put some tap water into the test tube for cooling as shown in Figure 4. This team still found that water in the test tubes would get warm after a while. They then decided to put ice into the test tubes (Figure 5). This team managed to collect about 30 ml of condensed water.

During the post-experiment discussion, students of this team reported that some of the distilled water they collected might not come from the water they boiled. Students found that the test tubes containing ice water would collect vapour even when they were not placed on the top of the boiling water. "In your opinion, where does the water come from?" the teacher asked. "Maybe vapour in the laboratory", they answered. The whole class concluded that the set-up in Figure 4 was better than that in Figure 5 when the teacher asked them to choose the best method adopted by all teams. The teacher further asked the class if there any methods could solve the problem of preventing the test tubes containing tap water from getting warm. One student proposed that water inside the test tubes would be changed for every 10 minutes. Grasping this golden opportunity, the teacher said that it would be more convenient if they could make water keep on running in and out the test tubes continuously. Then a student suggested to connect tap water to one end of a tube and make water flow out at the other end. In the closure of this lesson, the teacher demonstrated the standard condenser in the laboratory.

Students were proud of their designs some of which were close to what scientists did in the lessons about filtration and distillation. As a matter of fact, students' learning and achievements in these lessons were so superb that they achieved to solve the problem well and designed setups which were comparable to standard condensers in the laboratory and commercial filters. In Hong Kong, each school is usually equipped with one condenser. Traditional class practice of teaching distillation is to demonstrate the use of the standard condenser to obtain distilled water by the teacher. Students seldom have the opportunity to do the experiment of distillation on their own. The concept of filtration was traditionally taught by performing an experiment of filtering water by using a funnel and some pieces of filter paper. The teaching focus sometimes shifted to teach students how to fold filter papers onto a funnel. The teaching strategy adopted in the unit "Clean Water" of the JSSC was able to engage students in some hands-on and minds-on activities. In the cases of teaching filtration and distillation, students had good opportunities to think and work out their ways in solving problems during the experiments.

The Science-technology-society (STS) approach

According to Solomon (1993), STS education emphasizes students' understanding of the environmental threats to the quality of life and the economic and industrial aspects of technology. Such a STS approach was identified in the teaching of the "Clean Water" theme. Students were required to conduct a group project about the problem of water pollution in the areas around their homes or the school. The first-hand experience of exploring the polluted sites helped students cultivate positive attitudes towards the issue of environmental protection. During the presentation of students' projects, most students reported that they had a better understanding about the urgency of the pollution problem in Hong Kong. Some students expressed their shock about the severity of problems on the sites they visited even though they had already had some ideas about the pollution problem in Hong Kong. They said that the impressions gained from field visits were far more striking than they imagined. Besides, the project provided good opportunities for students to work in groups. The teachers interviewed expressed that the team spirit, communication skills, organization skills and leaderships were generally improved among most of the students in the class.

Role-play is a popular teaching mode suggested for STS education. In the episode of the lessons about the phase changes of water taking place in our natural environment, students in groups acted as water molecules under some situations such as, what happened to water vapour when it came into a freezer, what happened to the water in a kettle being heated on fire, etc. In addition to acting water particles under a variety of temperature situations, students also described and explained the processes and directions of heat energy transferred between water and its surroundings during phase transitions.

Teachers reported that this role-play activity could help students to develop their understanding of phase transitions of matters and their generic skills, such as, communication skills, collaboration skills, and creativity.

Evaluation

At the end of the whole unit, a questionnaire survey was conducted to evaluate the effectiveness of the teaching package. 197 students participated in the questionnaire survey. Firstly, concept matching questions were set out to probe students' understanding of scientific concepts learnt throughout the whole unit. On average, students scored 78% correct in this concept-matching test. The result was very encouraging since the test was done without prior notice and revision. In the second part of the questionnaire, students were asked to evaluate the effectiveness of the teaching package. The results were summarized in Table 1.

TABLE 1. Summary of students' responses

Number of respondents = 197	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
The package can arouse your interest in science	31%	62 %	6 %	1 %
The package can help you understand science concepts	17 %	72 %	10 %	1 %
After studying the package, you want to learn more about water	22 %	66%	9 %	3 %

The overall responses from 197 students were very positive. The majority of students (more than 80%) reported that the learning activities were effective in helping them to learn science concepts and arouse their interests in learning science.

Students were also asked to write a short paragraph about their feeling on their learning of this theme. The translation of three students' responses were shown below to illustrate the general opinions collected in the survey.

Student A:
In our experiments, everything (procedures and setups) was designed by students. It didn't just widen our thoughts but made us feel free and interested in studying. It also enhanced the friendship among classmates. We find that it is easier for us to understand what is in the books (after this unit). Actually, we don't even need the book (textbook) when we've understood it!
....I've also learned a lot in presentation, which develops my confidence, helps to train my skills to present information and ideas. It's more effective than just doing revision (exercises) as I can use what I've learned. Therefore, presentation

can assist our learning.

Student B:
Science lessons were not just 'doing' experiments but we had many chances to 'design' experiments. I believe this is the best way to use our minds. This kind of interactive science lessons is the best way to gain experiences and satisfaction. Of course, there were difficulties in the process of designing experiments. But we could gain more experiences from trying so that we can make it better after each trial. The process really made me grow up a lot and I truly gained benefits from the lesson. These could not be available in traditional lessons before.
I think I've really grown up since then. I also learned more and had more insights about science. It is obviously more helpful than just reading from books.

Student C:
Once, we'd to make a device to filter dirty water, to turn it into clean water. You (Teacher) didn't tell us directly how to make it but guided us to find out the characteristics of each material and let us design the filter independently. At the beginning we had no confidence that we could make it because no instructions were given in the work sheets and workbooks. Fortunately, you encouraged us to think and to do it on our own. After doing many experiments, we were not afraid or worried anymore. We've learned to be more active and careful in designing experiments. Sometimes I really feel that I'm just like a little scientist.
Throughout IS (Integrated Science) lessons this year, I learned not only knowledge from the textbook but also to be a active learner and to look for the truth. Through various experiments, I found out that I can do many things, which I thought I couldn't do at the first time, if I put efforts in them and so I built up my confidence.

Students' responses generally indicated that the teaching strategies and activities adopted in this thematic unit could effectively develop their experimental, problem-solving and thinking skills. Furthermore, students felt that they had a greater confidence in solving open-ended problems than before. They were satisfied with their performance in various activities and were well motivated by challenging questions/activities and rewarding outcomes. More importantly, students were highly involved in all sorts of laboratory activities because they enjoyed the freedom and ownership devolved from their teachers during the whole learning process of this theme.

Conclusions and Implications

The evaluation of the thematic unit of "Clean Water" confirmed that students participated in their learning actively. Three curriculum features accounting for promoting active leaning atmosphere in the lessons were identified, namely, "relevancy to learners' daily lives", "developments of problem-solving and thinking skills, and the "STS approach" in teaching science. This study also draws implications to science education and science teacher education.

First, developing students' skills and cultivating positive attitudes are far more difficult than teaching content knowledge. Traditional science lessons would hinder students' thinking and skill development by inducing recipe-type experiments and transmitting authoritative scientific knowledge to learners. Results of this study revealed that the strategies and activities adopted in this thematic unit could effectively facilitate active learning in the laboratory, particularly in the domains of skill development and attitude cultivation. The message was that students should be the decision maker or the owner of their learning. The role of teachers should be changed from a knowledge transmitter to a learning facilitator. The findings provided evidence that most students had good potential in scientific investigations and solving problems when they were provided with the ownership of learning, the freedom of experimental designs, and adequate time and equipment. The demand for apparatus and equipment was not at all problematic because it was found in this study that most students could get good experimental results in their own designs by using typical laboratory equipment and some simple domestic tools. Shortage of time was the real problem. Time taken for allowing students to design and perform undirected investigations was far more than that required by recipe-type experiments. It seems very efficient to cover the topic of distillation by just demonstrating the setup and the experiment of a condenser. Such an experiment usually takes about 10 to 15 minutes. In the lessons observed in this study, the practical time for students to design setups, try out experiments and modify the methods to collect condensed water was about one hour. Teachers interviewed also expressed that the time constraint was a major obstacle to the implementation of student-centered modes of learning. This problem falls back to the "content and process" debate of science education emerged in the 1980s. The assertion is that students will learn more skills and knowledge through student-centred activities even though less content is taught. The conception of "learning how to learn" is to develop students' interests and skills to acquire knowledge on their own. In the era of knowledge explosion, school curricula can no longer cover sufficient knowledge for students to live in the years after formal education. Allowing more time for engaging students in open-ended investigations would help them to develop skills, attitudes and interests to learn independently in the future. Layton (1992) advocated science knowledge to be learned through practical actions. It follows that the time constraint will not be a great barrier if shifting the emphasis of learning from the content to the process. Thematic science curricula are ideal contexts for actions that "may be attempts to teach or to learn the knowledge, applications of the knowledge in practical or technological situations, or explorations at a deeper level of the knowledge itself" (Fensham, Gunstone & White, 1994, p.4). Similarly, science education reforms in US schools since the 1990s also adopt a 'less is more' notion. According to Bentley (1995), many science programs in the USA "organise content around conceptual themes, with fewer topics treated in greater depth" (p.24).

Another implication of this study was that science lessons should take more forms of open-ended investigations on real-world problems. Typical textbook patterns rarely give rooms for students to think and to make decisions on what procedure they should proceed. Cookbook-recipe type learning activities are built on the traditional paradigm assuming that students can come up with valid scientific laws and conclusions through straightforward induction procedure (Garrison & Bentley, 1990). Following this line of thinking, the teacher-control mode of learning has long been dominating classroom activities in the school. From the results of this study, deep learning, especially thinking and creativity developments, can effectively be achieved by adopting more student-centred activities like peer group discussions, debates, negotiations and open-ended investigations. Then, the role of teachers should change from a knowledge transmitter to a learning facilitator. As a result, adequate teacher preparation is crucial in the implementation of such thematic science curricula. Teachers must accept the paradigm change of their teaching profession. Decision-making authority on the subject content should be devolved to student level to a certain extent. But the importance of teachers should not be de-emphasized. Taking the distillation scenario of this study for example, students would never discover the running water method of standard condenser themselves if the teacher had not followed up the problem of warming water in test tubes encountered by students (Figure 4). Teachers' capability of providing prompt reaction is very important in follow-up discussions. To be competent to cater for the needs of different students, teachers should be equipped with good communication skills for leading discussions and debates, adequate curriculum knowledge for integrating science across themes and disciplines, subject knowledge and skills for inclusion of values and social connections of science, etc. All these are great challenges to most teachers nowadays. In addition to the reform efforts on science education, science teacher education should also be restructured to equip teachers with adequate knowledge and skills to cope with the new challenges of the teaching profession.

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