IMPLEMENTING PROBLEM-BASED LEARNING IN BIOLOGY

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This paper reports on how problem-based learning was incorporated into the biology curriculum in a secondary three class. The focus of the paper is on how the students generated ideas for their problems, the types of questions that they asked, and how the teacher mediated these investigative activities. As part of their project work on the topic "Nutrition", students generated problems that they were interested in investigating. These problems then became the focus of subsequent inquiry and the students worked in collaborative groups to solve them, with the teacher acting as a facilitator. Data sources included observation and field notes, students' written documents, audiotapes and videotapes of students engaged in group planning and investigations, and student interviews. The results suggest that the students were able to take ownership of their problems, and that students' inspirations for their problems were mainly derived from events in their own daily life experiences. The findings are potentially useful in the implementation of problem-based project work in Singaporean classrooms. Implications of the findings for instructional practice are discussed.

INTRODUCTION

In 1995, a survey conducted by the Ministry of Education (MOE) in Singapore found that local employers perceived our graduates to be competent, hardworking and cooperative, but not strong in creative and innovative thinking, and in dealing with problems that were not well defined (Goh, 1996). These weaknesses were attributed to the way students had been learning in classrooms, which were largely teacher-centred. In response to these concerns, it was recognized that changes had to be made in the education system to reverse the trend of producing students who were concerned only with getting good grades for their examinations, and who were passive learners, unprepared to meet the demands of today's changing society. Instead, students must be encouraged to go beyond the memorization of facts, and to move towards learning how to apply their knowledge in problem-solving.

One of the new initiatives which have been identified to promote active learning and higher order thinking in our students is the implementation of collaborative project work in the classrooms. The rationale for this is that project work offers “possibilities to develop qualities like curiosity, creativity and resourcefulness amongst our young. Projects also nurture critical process skills for the information age. Where projects are conducted in groups, they forge teamwork and interpersonal skills” (Ministry of Education, 1999). The practice of implementing collaborative project work is not a new feature in local classrooms. However, in the past, the nature of project work tended to be highly structured. Studies conducted on highly structured activities, where procedures were specified and results were known, found that students were often not able to relate the activities to everyday experiences (Marx, Blumenfeld, Krajcik & Soloway, 1997, p. 342). The students “often did not discover the intended ideas and relationships or accommodate their understandings in light of experimental results”. Also, the students became so caught up in carrying out prescribed procedures that they failed to think deeply about the underlying science concepts. Hence, such activities promoted hands-on but not necessarily a minds-on approach to learning (Tobin, Tippins & Gallard, 1994). The key weakness of highly structured tasks is that not much thinking is generated.

One way to address this concern is to model the projects after real life problems. Such problems are ill-structured and provide a deep and meaningful stage at which students can apply skills of thinking in the course of scientific problem solving. The search for solutions begins with “a search of the problem space” which is an “initial phase of problem solving involving the construction of an internal, mental representation of the problem using existing schemata perceived as relevant by the problem solver” (Appleton, 1995, p. 383). During the process of exploring the problem space, students engage in many search strategies which involve thinking. The thrust of such learning is Problem-Based Learning (PBL) where students generate their own problems which are often realistic, ill-structured and precede learning. The learning order is reversed from traditional learning methods which introduce problems only *after* students have learnt the necessary body of knowledge. The “problem-first” approach in PBL ensures that students know *why* they’re learning. Three features of problem-based learning include initiating learning with an ill-structured problem, using the problem to structure the learning agenda, and using the instructor as a metacognitive coach. Ill-structured problems are those where (a) the initial situations lack all the information necessary to develop a solution, (b) there is no single right way to approach the task of problem solving, (c) as new information is gathered, the problem definition changes, and (d) students will never be 100% sure that they have made the correct selection of solution options (Gallagher, Stepien, Sher & Workman, 1995). In PBL, students also experience “doing science” where there is the “pursuit of meaningful questions through the use of procedures that are thoughtfully generated and evaluated by those who are asking questions”, and this is part and parcel of scientific inquiry (Palincsar, Anderson & David, 1993). Students' questions play a crucial role in the learning process, and a range of questions must be addressed in order to find a solution (Gallagher, Stephien, Sher & Workman, 1995).

As an instructional model, PBL has great potential in promoting inquiry in science classrooms. However, the use of this approach is relatively new in schools and not much research has been done in this area. Our understanding of how students respond when asked to formulate their problems, pose their own questions and design investigations to answer them is still relatively primitive. Hence, it is of interest to study how PBL can be implemented in a secondary science class. The purpose of the study was to investigate students’ thinking and collaborative knowledge construction in problem-based project work in a biology class. The focus was on students' inspirations for their problems and the types of questions asked. The specific research questions were:

- What are the students' inspirations for their problems?
- What kinds of questions do students ask, individually and collaboratively?
- How do these questions guide students in knowledge construction in the problem-based learning process?

The results of this study would shed light on how students could be motivated to learn in collaborative problem-based learning contexts. As Singapore begins to implement project work in her schools, it is important to understand how students conceptualise their problems and how teachers can guide their students in this process. Although teachers are now encouraged to implement project work in schools, the intended changes "will not take root and innovation will not be sustained if one just adopts the traditional top-down models of dissemination that rely on single workshops, distribution of curriculum materials to be used exactly prepared, and lists of prescribed practices" (Marx et al., 1997, p. 349). As teachers are still largely inexperienced in this area, the findings from this study would provide useful information relating to the issues in the implementation of problem-based learning.

METHODS

The 18-week study, which focused on the topic "Nutrition", took place in a secondary 3 biology class at an all-girls secondary school. The class consisted of 39 girls (15-year-olds), and there were nine groups of 4-5 members each. The students were free to group themselves according to their own preferences, and the groups were heterogeneously mixed in terms of ability. Other than the group's election of their leader, no other group roles were formally assigned. The students were briefed on proper group behaviour during the course of the project work. This included the importance of teamwork, listening to one another, taking turns to speak, respecting each other's right to voice their views, proper time management, and some tips on conflict management (Cohen, 1994). Some parts of this project work were carried out during curriculum time, with one 35-minute period per week specifically set aside for students to work on the project, prepare drafts, and give oral presentations. Besides carrying out their project work investigations, the students were also taught regular lessons on enzymes, nutrients and classes of food, animal nutrition, and plant nutrition.

The teacher attempted to integrate students' project work ideas and findings into her lessons. For example, at different points in the lessons, teams of "expert researchers" were asked to share their "expert" knowledge of the issues that were being raised. These "expert researchers" were the students who investigated the different aspects of "Nutrition". The rest of the students were encouraged to raise related questions. The teacher facilitated the discussions and corrected students' misconceptions when they arose. When the groups were unable to answer the questions, they were asked to investigate further and were responsible for providing the results of their investigations in the next lesson.

Stages Of Implementation

The students went through five consecutive stages adapted from Sharan and Sharan (1989).

Stage 1: Identifying the problem to be investigated (Weeks 1 to 3)
Stage 2: Exploring the problem space (Weeks 4 to 6)

Stage 3: Carrying out scientific inquiry (Weeks 7 to 12)
Stage 4: Putting the information together (Weeks 7 to 16 including the school holidays)
Stage 5: Presenting the findings, Teacher Evaluation and Self-Reflection (Weeks 17 to 18)

In stage 1, the class read nine case studies and newspaper articles related to topics such as people's diets, weight loss, health issues, dietary and herbal supplements. Each group was given 10 minutes to read one article and to discuss their views on the articles, before sharing them with the class. This activity served to give the students an idea of some issues related to "Nutrition". Students were then given a problem log each and told to do a mind map on some issues that were of interest to them. They brought their problem logs home and were encouraged to write down their ideas through the week. During the next project work period, the members of the group came together and decided on a group research topic. The teacher showed the class some ways to frame topics into ill-structured problems by using some examples to model the framing procedure. The groups spent time discussing ways to formulate their problem as an ill-structured one and to generate a problem statement in their problem logs.

In stage 2, the students crafted their own project tasks once the problem was identified. The teacher helped the students to establish a learning agenda by organizing the discussion around three focus questions (Gallagher et al., 1995) using a "Need-to-Know" worksheet. The questions were: (a) What do you know? (b) What do you need to know? (c) How can you find out what you need to know? The students also identified the resources that they had to use and the type of tasks they had to engage in, to solve their problem. These included library research, using the internet, conducting surveys and interviews, and hands-on laboratory experiments.

In stage 3, the students constantly redefined the problem as they explored further and gathered more information. Upon seeing that many groups relied heavily on the Internet for information, the teacher pointed out to the class that they had to test the validity of the information available and that all information gathered must be acknowledged to avoid plagiarizing original work. In groups where students planned to conduct interviews as part of gathering information, the students had to plan and write their questions first. The teacher also set up an Internet forum page ("e-circle") for students to gain easy access to professionals in the field of medicine. The "consultants" consisted of a doctor, a dentist, a nurse and a medical research worker. Students used this platform to ask questions related to their research.

In stage 4, members of the group reported on what they had done, completed further "Need-to-Know" worksheets at each meeting, and planned for further tasks. Some of the groups used the science laboratories for their investigations. Others went on field investigations, made field notes, and conducted interviews where possible. Most of the groups worked independently in the execution of their plans, while the teacher was kept informed of what they planned to do. The students wrote notes into their learning journals. At the end of each meeting/investigation, the groups filled in "Learning Log and Project Tasks Allocation" forms where they recorded what they had found out and the science concepts learnt. This helped them to review and to consolidate the information gathered.

In stage 5, each group gave a 15-minute oral presentation in which every single member took part. Several used IT-based multimedia modes of delivery and artefacts. The students also submitted a group project file which documented the group's findings, as well as details of the inquiry process. After the presentation, all the members of the group were involved in a 5-minute question-and-answer session with the audience (the rest of the class and the teacher). All the presentations were videotaped. The teacher evaluated the groups based on criteria related to both the processes and the products of the project work, including the oral presentation. Each student also completed a self-evaluation worksheet "How Did I Do?".

Data Collection And Analyses

Guide sheets in the form of learning/reflection logs and planning forms were widely utilized, not only to facilitate students' knowledge construction, but also to capture students' thinking processes and to record their progress. Together with students' project files, these documents also served as data sources for subsequent analysis. The students were observed during project work sessions and field notes were taken. The teacher identified four groups which showed more enthusiasm in their work. Group interactions were selected for videotaping, and some students from each group were interviewed to find out what were the sources of inspirations for their problems and what they had learnt. The interviews were audio taped and transcribed.

FINDINGS

Initially, the students had difficulties in generating questions and formulating their own problems. However, there were also some who were able to write down several questions. The latter were the same students who frequently asked questions during lessons. However, when students brought their problem logs home and used time within the week to generate questions, they returned with more interesting ideas. For example, when an initially unsuccessful student was questioned about the long list of interesting questions that she later showed the teacher, she revealed that she became more aware of the nutritional issues related to her daily life during the course of the week. She even questioned her family members for interests they might have. This saw the transformation of an uninterested student into one who was motivated to continue to search for answers.

Inspirations For Students' Questions And Problems

Sources of inspiration for students' questions and problems came from three main areas: (a) cultural beliefs and old wives' tales, (b) wonderment about information propagated by advertisements and the media, and (c) curiosity arising from personal encounters or family members' concerns. Several of the questions and proposed topics were influenced by ideas that were socially transmitted by word-of-mouth. Some had elements of truth while others were more of traditional myths. For example, one student was interested in the "funny stuff" that her grandmother brewed for her aunt when she was pregnant and after she had given birth. Other students were curious about the use of Chinese herbs for body nourishment, or how some people end up having "worms" in their stomachs after eating certain foods and who would then not be able to grow fat. Yet others related to the following beliefs: monosodium glutamate (MSG) in foods causes hair loss, jumping around after a heavy meal causes appendicitis, and consumption of black soya sauce during pregnancy would produce a dark-skinned baby. Other concerns arose from the usual teenage issues of growing up, especially in the areas of diet and physical appearances. Some students wanted to validate information that they had read from newspaper articles or in advertisements. For example, a slightly overweight girl was intrigued by perfectly shaped bodies in weight-loss advertisements and wanted to do a project on “Slimming Centers”. The students were also motivated by a sense of curiosity related to their daily personal experiences. For example, one student had a father who was deeply concerned about his hair loss problem and wanted to do a project on “Hair Loss”. Another student who had been drinking ginseng tea, made by her mother who believed that it had “cooling effects” on her, suggested a project on “Ginseng”.

Students' Questions And Problems

The theme “Nutrition” raised a wide variety of questions, perhaps because it was multifaceted and also, many students could relate to it in their daily lives. Questions that the students raised individually were broad and unfocussed. Some of the questions revealed the students' concerns, interests, and unorthodox understanding of science. Most of the students' individual questions could be grouped under the four broad categories (Table 1).

Table 1
Types of Student-generated Questions

Type of Question	Examples
Misconceptions	• Is it true that if you perspire a lot, you are fat? • Does doing hula hoop make your waist smaller?
Basic information	• What kind of sugar do some sweets labeled “sugar-free” use? • What is cholesterol? • What diet do sumo wrestlers keep?
Direct personal experiences	• What causes indigestion? • Why do our stomachs growl when we are hungry? • Why does sweet food spoil our teeth? • Why are most nutritious food not delicious and why do people have a craving for non-healthy food like sweets / chocolates?
Observations of other people	• Why do some people gain/lose weight so easily? • Why is it that most beer consumers have pot bellies?

Those that revolved around misconceptions typically arose from social discourse with friends and family members, and asked for some validation. Questions that demanded basic information only required simple information gathering. Questions that stemmed from direct personal experiences with one's own body and observed trends in other people tended to target at cause-effect relationships and related more to human physiology. Several questions were influenced by the media such as newspaper reports and advertisements, as well as health education brochures. For example, the newspapers often carried advertisements by slimming centres, pharmacies, and hair treatment salons. These elicited questions such as “What is present in slimming pills that can cause people to slim down?” and “Can herbs cure hair loss?”. There were also frequent reports in the newspapers on drug abuse and health issues. These gave rise to questions such as “How does taking too many ecstasy pills cause harm to the body?”, “What happens to a body which experiences long-term starvation?”, “How does the food we eat lead to cancer?”, and “Why does too much MSG affect our health?”. Increased awareness of nutritional issues due to the wide variety of grocery items available in supermarkets and food labels on packaging probably led to questions such as “How do we measure the nutritional content of food?" and "Vegetarians do not consume meat, do they have a balanced diet?".

After brainstorming individual questions and then negotiating among themselves, the students finally decided on a group topic in which to frame their problems, one that most of them could identify with. The questions raised in the groups were more topic-specific. The project topics are given below:

Group 1: Nutrition and Hair Growth	Group 6: Nutritional Value of Insects
Group 2: Eating Disorders	Group 7: Ginseng
Group 3: Betel Nut	Group 8: Slimming Centres
Group 4: Nutrition and Colour-blindness	Group 9: Dentition
Group 5: The Effects of Viagra on Impotence	

The students in Group 4 thought that colour-blindness was a nutritional deficiency disease, although it is generally known to be a sex-linked genetic disease. Group 5 students thought that impotence was linked to different types of food intake, although there are many other factors contributing to this condition. Nevertheless, the teacher allowed them to research on the topic to see whether their conceptions would change in the process of their inquiry. The groups were very motivated in the pursuit of answers to their topics of interest. It was evident that the students owned the problems and went to great lengths to find answers to their questions. The students put themselves in real life problem-solving roles. Some examples of their problems are given below.

Students of Group 7 worked on "Ginseng" and took on the roles of nutritionists. Their problem read:

> Jiahe's grandmother has been taking ginseng regularly and insists that the family follow the good habit. Jiahe is curious about the effectiveness of ginseng. His mother decides to employ us, nutritionists, to research on ginseng.

The students wanted to find out more about the ginseng plant, different types of ginseng, what were the contents of ginseng that made it so nutritious, what side effects there were, and how it affected the body systems. They visited Chinese medicinal halls, spoke to Chinese physicians and family members of the older generation who were more knowledgeable about these traditional herbs, did food tests on ginseng, interviewed those who took ginseng regularly, and conducted a survey on how ginseng was consumed by people. They found out that ginseng was consumed most frequently by senior citizens for health reasons, by working adults to relieve stress, and by students during examination periods.

Group 8's problem on "Slimming" read:

> Miss Piggy was severely overweight. She tried to lose weight by exercising, but it was to no avail. Finally, she decided to seek help at slimming centres and try other means such as taking slimming pills or slimming biscuits. As her good friends, we decided to show her our support and find out more about this slimming method.

The students assumed the roles of school friends of Miss Piggy. They wanted to compare the advantages and disadvantages of different ways of slimming such as treatments at slimming centres, exercising, dieting, and taking slimming pills. They also wanted to find out what kind of equipment slimming centres use. They visited slimming centres, saunas and gyms, spoke to the professionals, and conducted surveys.

Group 1 worked on the problem of hair loss. They worked on finding out if polluted air, heat, and dyeing cause hair loss, how hair tonics help in the growth of hair, why some people lose hair drastically, and what are useful tips for people suffering from hair loss. They also visited a hair treatment salon, had interviews with the doctor via "e-circle", and interviewed both hairdressers as well as people who suffered from severe hair loss problems. In the process, they learnt about the factors that caused hair loss, and the various hair treatments available at treatment salons. Group 2, which worked on "Eating Disorders", took on the roles of nutritional counsellors and studied about anorexia and bulimia. They spoke to nutritionists and people who knew of patients who had these disorders, consulted the professionals on "e-circle", looked up books and searched the Internet. Group 3 was interested in learning more about the betel nut. They wondered if it was addictive, why some people enjoyed chewing it, why it caused teeth to stain, and what effects it had on the mouth and the body. Group 6, which worked on "Insects", took on the roles of salespersons interested in promoting the sale of edible insects. They wanted to find out why some people ate insects, what were the different methods of cooking insects, and the nutritional and medicinal value of insects. They visited a shop that sold insects, tried tasting the insects, and conducted surveys. Their findings included recipes for mealworm cookies, chocolate crickets, and ant lemonade. Group 9 which did their project on "Dentition" took on the role of dental health personnel who wanted to educate people about dental diseases. Their investigations led them to visit a dental fair, and also to find out more about the causes and processes involved in tooth decay.

The data collection procedures used by the students were interesting. Besides obtaining information from traditional sources such as library books, all the students also conducted Internet searches. Five groups performed laboratory experiments in search of answers to their problems. Students from Group 1 found out about the nutritional value of human hair to plants by observing a pot of plant over a period of two weeks after they added human hair to the soil, and compared their observations with a control plant. The students from Groups 1, 3, 6, and 7 also applied what they had learnt about food tests to test for the presence of starch, reducing sugars, protein and fats in human hair, betel nut, ginseng, and insects (mealworms). Group 9 students set up an experiment with a control to investigate the effects of fluoride on chicken bones and egg shells.

Seven out of nine groups conducted surveys. Most of the groups gave out questionnaires to friends and classmates. When data across age groups were required, they approached relatives and family members. One group used the e-mail and forwarded their questionnaires to strangers and friends. They also used the Internet Relay Chat (IRC) as a platform for their surveys. The students also conducted "field studies" and interviewed relevant people. Wherever possible, the teacher integrated students' ideas and project findings into her lessons. For example, when teaching about food tests, Groups 1, 3, 6, and 7 carried out these tests (as described above) and reported their findings to the class.

DISCUSSION AND CONCLUSIONS

Although the students had difficulties in formulating their own problems initially, and their thoughts tended to be diffused and unfocussed at first, allowing them time to think through the week helped them in the problem-finding process. The students included friends and family members in their search. This made learning more fun. Also, when learning was related to real life situations, motivation for learning increased. The students who experienced difficulties generating questions were the usual ones who hardly asked questions in class, and who were not used to relating to their prior knowledge. This suggests that teachers should encourage students to raise their own questions more frequently during lessons.

The use of guide sheets such as the problem logs, "Need-to-know" worksheets, and the "Learning Log and Project Tasks Allocation" forms helped students to structure and organise their thinking. A facilitating teacher can promote thinking during the problem-finding and problem-solving processes by providing students with such organisers. When students work at filling up their guide sheets with their questions and ideas, the sheets provide a visual focus and allow thoughts to be captured. Some of the weaker students need a "seed" idea. This can be a past experience or a discrepant event which primes a series of questions related to the theme of interest. This later grows into a good list of questions at the end of the problem-finding process. The teacher can help these students by asking appropriate guiding questions which serve to plant these "seed" ideas. Students are motivated and intrigued by real life issues, especially those that have a direct impact on their personal lives. An important implication for educational practice is that students learn well when syllabus content is related to real life issues. The teacher can make teaching more effective by couching syllabus objectives in real life contexts, especially in daily life examples that the students can relate to. When this happens, students are more motivated to learn.

Several misconceptions that students had about nutrition-related issues surfaced during the learning process. This suggests that teachers can use such opportunities to elicit students' ideas and deal with them accordingly. A wide range of related topics of personal relevance were generated by the students. These had science-technology-society connections and impinged on issues which teachers may not normally discuss in regular lessons, especially if they focus mainly or only on the prescribed science content of the syllabus which aim to develop specific science concepts. Teachers can spice up their lessons by infusing these students' ideas (that deal with folklore or teenage concerns) into their lessons and addressing them in appropriate ways. The nature of students' problems gave rise to different modes of inquiry that went beyond the traditional experimental paradigm that is common in school science. For example, students conducted interviews and field studies. This broadened their knowledge of the different possible methods that researchers use in scientific inquiry. Because the students' work took them beyond the usual concepts taught in science, there was also an inter-disciplinary element (incorporating geography, social studies, art and design) to it. For example, the students learnt that some people in other countries ate termites, worms, and caterpillars as delicacies or staple foods. Also, they learnt that people from certain cultural groups liked eating betel nuts and ginseng because of traditional reasons. Furthermore, they had to design creative products for their multi-media presentations.

Problem-based learning, which involves students' own problems, is an effective way of promoting student-centred learning in the classroom. This is because learning is based on what the students are interested in. The students learn new knowledge through the process of problem solving and seek to apply these in their search for answers to their problems. Motivation for learning is high as the students take ownership of the problems and as they diligently pursue answers which they find meaningful. The implementation of PBL in the classroom must be purposeful and must be supported by appropriate data-collection tools. The aims and objectives of each stage of implementation must be clearly stated. Students must also be clear of how each task can help them in their information-gathering process. Also, time must be allowed for students to search as many information sources as possible in the process of problem solving. The teacher also needs to keep a constant check on student learning as the amount of information available can overwhelm students and may not necessarily be very relevant to the students' projects.

REFERENCES

Appleton, K. (1995). Problem solving in science lessons: How students explore the problem space. *Research in Science Education*, *25* (4), 383-393.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research*, *64* (1), 1-35.

Gallagher, S. A., Stepien, W. J., Sher, B. T., & Workman, D. (1995). Implementing problem-based learning in science classroom. *School Science and Mathematics, 95* (3), 136-146.

Goh, C. T. (1996). *Prepare Our Children for the New Century: Teach them well*. Speech at the Teachers' Day Rally, 8 September 1996, Harbour Pavilion, World Trade Centre. Press release [On-line]. Available: http://www.moe.edu.sg/abtmoe/pa/contract/rally/speech.html.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., & Soloway, E. (1997). Enacting project-based science. *The Elementary School Journal, 97* (4), 341-358.

Ministry of Education. (1999). *Project Work: Information for Parents* (brochure).

Palinscar, A. S., Anderson, C., & David, Y. M. (1993). Pursuing scientific literacy in the middle grades through collaborative problem solving. *The Elementary School Journal*, *93,* 643-658.

Sharan, Y., & Sharan, S. (1989). Group investigation expands cooperative learning. *Educational Leadership*, *47* (4), 17-21.

Tobin, K., Tippins, D. J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 45-93). New York: Macmillian.