Problem-Based Learning: Implementing Project Work In Biology Through Ill-Structured Problems

Christine Chin
National Institute of Education, Singapore

Chia Li Gek
Curriculum Planning and Development Division
Ministry of Education, Singapore

Abstract
This case study investigated how secondary 3 students carried out project work in biology via problem-based learning that made use of ill-structured problems. Students first identified their own problems for investigation and then worked in groups to solve the problems. Data sources included observations of students at work, interviews, students' written work, as well as audio- and videotapes of students engaged in group work. Issues and challenges related to the use of ill-structured problems were identified, and implications for the implementation of problem-based learning in project work are discussed. These issues pertained to students identifying a problem for study, students' questions and their learning pathways, and the methods of inquiry that students engaged in.

Introduction
The education system in Singapore is largely examination-oriented. At the opening of the 7th International Conference on Thinking held in Singapore in 1997, the prime minister noted in his speech that other than being motivated by the reward of getting good grades, the "passion [for learning] is generally lacking among our students, including many among our most able" (Goh, 1998). 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 and rote-learners who would not be ready to meet the demands of the knowledge-based economy. Instead, students must be encouraged to go beyond the memorization of facts, to think critically and creatively, and to apply their knowledge in problem-solving in new and unfamiliar contexts.

In response to this concern, the Ministry of Education launched its vision of "Thinking Schools, Learning Nation" in 1998. As part of this vision, the school curricula were revised to encourage more thinking, questioning, and independent learning on the part of students. One initiative implemented to promote active learning and higher-order thinking in our students is collaborative project work. This is consistent with the goal of inquiry-based science instruction to engage students in the investigative nature of science through hands-on activities and problem-solving. To infuse more authentic inquiry in science projects, one can use problem-based learning where students generate their own problems which are often realistic, ill-structured, and precede learning.

In problem-based learning (PBL), problems act as the stimulus and focus for student activity and learning (Boud and Feletti, 1991). Students learn while searching for solutions to problems and in the context in which knowledge is to be used. Unlike traditional teaching approaches which introduce problems only after students have acquired the relevant content knowledge and skills, problems are introduced at the beginning of a unit of instruction. This reverse "problem-first" approach in PBL helps students to understand why they are learning what they are learning (Gallagher, Stepien, Sher, and Workman, 1995).

Characteristics of PBL include using an ill-structured problem to guide the learning agenda, having the teacher act as a metacognitive coach, and students working in collaborative groups. Ill-structured problems are those where (a) the initial situations do not provide all the necessary information to develop a solution, (b) there is no one correct way to solve the problem, (c) the problem definition changes as new information is gathered, and (d) students cannot be completely certain that they have made the correct choice of solution options (Gallagher, Stepien, She, and Workman, 1995).

In PBL, teachers act as facilitators of learning. Students work collaboratively on a problem that is grounded in their experiences. Because the problem is situated in real-life contexts, students are better able to construct links between school science and the science required to solve real-world problems (Yager and McCormack, 1989). Students identify learning issues pertinent to the problems and ask questions related to these issues. They make their own decisions about what directions to take in their investigations, what information to gather, and how to analyze and evaluate this information.

Purpose and Significance of Study

This study employed PBL in project work where students formulated their own problems, identified learning issues based on the problem, and structured their inquiry around self-generated questions. The purpose of the study was to:

a) investigate how students learn via ill-structured problems,
b) identify some issues and challenges related to the use of such problems, and
c) offer some suggestions on the implementation of problem-based project work in science.

The findings of this study would shed light on how ill-structured problems impact on the way students learn. The issues and problems encountered, as illustrated in this study, can also enhance our understanding about how to better design, manage, and implement project work through PBL that uses ill-structured problems. This study is an extension of our previous work on students' inspirations for their self-identified problems in PBL and the kinds of questions asked (Chin and Chia, 2004a), and how students reacted to this PBL approach (Chin and Chia, 2004b).

Design and Methods

The study, which focused on the theme "Food and Nutrition", took place at an all-girls secondary school and lasted 18 weeks. The second author was the science teacher. The class of 39 secondary 3 students worked in nine groups of four to five each. The students were free to form their own groups which were heterogeneously mixed in terms of ability.

Each group worked on a project topic of their choice related to the given theme. One 35-minute period per week was specifically set aside for students to work on the project. During the remaining four periods each week, the teacher integrated students' project work ideas and findings into her lessons which focused on enzymes, nutrients and classes of food, a balanced diet, nutritional deficiency diseases, animal nutrition, and plant nutrition. For example, at different points in the lessons, teams of "expert researchers" who investigated the different aspects of Food and Nutrition, were asked to share their knowledge of the topics and issues that were being raised. These included food tests, dentition, as well as the relationship between diet, weight, and health.

Stages of Implementation

The students went through five consecutive stages adapted from Sharan and Sharan (1989): (1) Identifying the problem to be investigated, (2) Exploring the problem space, (3) Carrying out scientific inquiry, (4) Putting the information together, and (5) Presenting the findings, teacher evaluation and self-reflection.

In stage 1, the students familiarized themselves with some issues related to "Nutrition" by reading and discussing case studies and newspaper articles on related topics. They then identified the problem that they wanted to investigate. They wrote down their ideas and questions individually into problem logs and mindmaps, and even brought them home. They then jointly wrote their problems statements, and took on real-life problem-solving roles.

In stage 2, the students organized their ideas around three focus questions (Gallagher, Stepien, Sher and Workman, 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 recorded their ideas and questions onto this worksheet regularly as a group. They also identified the resources that they needed and the type of tasks they had to undertake, to solve their problem.

In stage 3, the students collected data to answer their own questions. The teacher set up an Internet forum page ("e-circle") for students to consult a panel comprising a doctor, a dentist, a nurse and a medical research worker. Students used this platform to ask questions related to their research. Some of the groups used the science laboratory to carry out their investigations. Others consulted experts, went on field investigations, conducted surveys and interviews, and looked up information from print and electronic resources.

In stage 4, the students reported on what they had done, completed further Need-to-Know worksheets, and planned for further tasks. They documented their questions, filled in learning logs where they recorded what they had learnt at each step of the project, and planned ahead for the next step in their inquiry. This helped them to review and to consolidate the information gathered.

In stage 5, each group gave a 15-minute oral presentation on what they had learned about their project topic, and this was followed by a question-and-answer session. All the presentations were videotaped. The groups used technology-based multimedia modes of delivery and submitted artefacts. The students also submitted a group project file which documented the group's findings and details of the inquiry process.

Data Collection and Analysis

Planning forms and reflection logs were used to facilitate student knowledge construction, 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. Groups were audiotaped and videotaped during interactive discussions and hands-on activities. Students from each group were also interviewed at the end of the study to find out their experiences of working on their projects in a PBL context.

To determine how the ill-structured nature of a problem influenced the way students learned, all relevant data from students' written work, oral presentations, group discourse transcripts, interviews, classroom observations, and field notes were analyzed jointly using an iterative process. Coding categories (Bogdan and Biklen, 1992) that pertained to issues and problems relating to the impact of ill-structured problems on students' learning were then developed to organize the data.

Results

How Students Learnt via Ill-structured Problems

The findings on how students learnt via ill-structured problems are presented as three assertions below.

Assertion 1. When working on ill-structured problems, students initially experienced difficulties in identifying a problem themselves. However, discussion with family members and friends helped them to formulate personally meaningful problems which they found motivational.

During the problem-identification phase, 16 of the 39 students were able to quickly write down several questions pertaining to their problems of interest. The remaining 23 students initially had difficulties in generating questions and formulating their own problems. Some of these students merely stared blankly at their problem logs. Some doodled on the problem logs and seemed to be engaged in unrelated thoughts. Others were uninterested in the task, preferring to talk with their friends about other matters. These students were probably not used to thinking hard and deeply about problematic issues, having been used to working mainly on given and well-defined problems. Some showed resistance to the PBL approach, preferring to have traditional "normal classroom lessons" instead, where the teacher taught the content of the chapter on nutrition first before giving them a well-defined project to do.

However, when the students brought their problem logs home subsequently and used the time during the week to generate questions, they returned with several interesting ideas and longer lists of questions. Interactive discussions with their family members or friends helped students to generate ideas. During this process, the students discovered problems set in real life situations which were embedded in personal contexts.

After some brainstorming and negotiation, the students decided on a group topic to work on. The project topics for the nine groups were: (1) Nutrition and Hair Growh, (2) Eating Disorders, (3) Betel Nut, (4) Nutrition and Color-blindness, (5) The Effects of Viagra on Impotence, (6) Nutritional Value of Insects, (7) Ginseng, (8) Slimming Centers, and (9) Dentition.

Assertion 2: The ill-structured nature of the problem stimulated students to pose questions which charted their subsequent courses of action.

After the students had formulated their problem statement, they began asking questions that directed them in their inquiry. The Need-to-Know guiding worksheet provided a framework for the group discussions. What students learnt and how they learnt this information were very much driven by their questions. Four kinds of questions; namely information-gathering, bridging, extension, and reflective questions (Chin and Chia, 2004a); served to scaffold students' thinking and advance their knowledge in a productive manner.

An example using group 1 is given below. The students worked on "Sweepers No Enough" and took on the roles of managers of a road sweeping company. Their problem read:

> Residents of Maggie District have been dropping off excessive hair all over the place. Therefore, the road sweepers have decided to go on strike as they cannot cope with the workload of having to clean up the hair-polluted area frequently for little pay. As managers of the road-sweeping company, we have been assigned the task of looking into the matter and considering the problems of hair loss. At the same time, we have to provide the residents with useful tips on preventing hair loss.

Basic information-gathering questions arose directly from students' prior knowledge. For example, Group 1 began their research into hair loss by asking some basic information-gathering questions on hair loss such as "How many strands of hair would a normal healthy adult lose in a day?" and "Why do some people lose hair drastically?". In the process of gathering basic information on hair loss, the group began to hypothesise that hair loss could be linked to some possible causes. They asked bridging questions that drove the project direction: "Does dyeing hair cause hair loss?" and "Does polluted air and heat cause hair loss?". Such questions attempted to find connections between two or more concepts.

In response to the questions, the group visited a hair treatment salon and conducted interviews with the doctor via the "e-circle" (an internet-based discussion forum). They interviewed both hairdressers as well as relatives who suffered from hair loss problems of varying degrees of severity. Their interviews with hairdressers and professionals at the hair treatment salons revealed that the problem of hair loss was closely tied to one's diet. The interview with the doctor on the "e-circle" and the information on the Internet provided information that attributed hair loss to other causes such as hereditary, ageing, hormonal changes, illness, extensive treatment of hair, stress, and radiation therapy.

After their knowledge gaps had been filled, students sought to extend the boundary or scope of learning by asking extension questions such as: "What are the useful tips for the people who are suffering from hair loss?", "How do hair tonics help in the growth of hair?". The group also extended their scope of research into the nutritional value of human hair to plants. The extension questions they asked as they looked into this area were: "What is hair made up of?", "With all the hair that we drop everyday, can we put the hair we drop into good use?" and "Can hair be used as fertilizers to promote plant growth?". In responding to these questions, they found out about the nutritional value of human hair to plants by observing a pot of balsam plant over a period of two weeks after they added human hair to the soil, and compared their observations with a control plant. The plant in the experimental set up appeared to be growing more than the control plant. The students concluded that hair, comprising mainly of protein, contributed an added source of nitrogen to the soil for use by the plant for growth.

Halfway into their research, the group came back to the teacher wanting to abort their project because they had thought that they would be going on the wrong track if the problem they had chosen turned out not to be in line with the topic of "Nutrition". The teacher encouraged them to continue with the topic and directed them to focus on the nutritional remedies of hair loss that were available in the market.

Eventually, the group reported on how the food we consume could affect hair texture. They also added that although hair is made up of proteins, consuming extra protein or amino acid preparations will not promote hair growth, and that large doses of Vitamins A and E may contribute to hair loss.

A second example is given using Group 2. The students worked on "Eating Disorders" and took on the roles of nutritional counsellors. Their problem read:

> Olivia was a teenager who loved to read beauty magazines. She longed to be like the models on the magazine covers. One day, she read of a beauty contest and wanted to join it. She went on a diet and started to slim down. She refused to eat and was anorexic. Her parents found out about her condition and forced her to eat. In order to please her parents and yet to continue to slim down, she forced herself to throw up the food that she had eaten. Her parents were so worried that they consulted counsellors for help. As Olivia's counsellors, it is our duty to help the parents solve their problem with Olivia.

Information-gathering questions recorded in the Need-to-Know worksheets like "How, why and when do people get eating disorders?" and " What happens to people suffering from the disorders?", drove the members of Group 2 to speak to nutritionists and people who knew of patients who suffered from eating disorders. In addition, they also consulted the professionals on "e-circle", looked up books and searched the Internet resources. During the class presentation, they showed part of a taped television documentary on eating disorders. As counsellors in the problem, they reported on the causes and effects of anorexia, bulimia and binge eating.

The next category of questions, the bridging questions, saw students seeking to find relationships amongst biological concepts. It is important that the students were able to see biology as a whole body of knowledge with interconnecting concepts rather than each biological concept in isolation with one another. Members of Group 2 asked, "How do anorexic and bulimic people survive without getting gastritis?". In asking this question, they showed that they were looking for the relationship between the concepts of digestion in one's stomach, the effect of gastric juice on an empty stomach, and the physiological effects of these eating disorders on an individual. Other bridging questions such as "At what age are people driven to such unhealthy methods of slimming?" showed the students wondering whether there was any relationship between age and the tendency towards these eating disorders.

When they were satisfied with the information that they have learnt about eating disorders, the group went on to ask extension questions such as "Do doctors use drugs to treat them?", "What kind of nutrition does the patient need during recovery?" and "Who are the survivors?". The questions led them to go beyond the disorders per se, into situations related to the treatment and recovery of people who have suffered the disorders.

Towards the end of the project, transcripts of the audio-recordings of the group discussions captured a series of interesting reflective questions that were asked by members of the group. Some examples of these were: "Is it worth it to have to go through these (eating disorders) just to look thin?" and "Will you sacrifice health for beauty?". During the presentation, Group 2 shared about the concept of a balanced diet which was a learning objective of the Food and Nutrition topic. They also elaborated on the idea of malnutrition and the effects of starvation on the victims.

Assertion 3: Having students think about how they could find out what they wanted to know led them to interesting and creative information-gathering and data-collection procedures and to pursue different types of inquiry.

Instead of the teacher telling students what they should do to find the answers to their questions, the students had to decide for themselves how they could find out what they wanted to know. This gave rise to different modes of inquiry. For example, besides obtaining information from traditional sources such as library books and other printed materials, the students also surfed the internet, conducted both paper and electronic surveys, field studies, interviews, as well as carried out laboratory investigations.

Seven out of nine groups conducted surveys. Most of the groups gave out questionnaires to friends and classmates. Group 3 (Betel Nut) carried out a survey to find out what the public knew about betel nut, and also to gather information from people who chewed it. Group 6 (Nutritional Value of Insects) wanted to collect information on people's opinion of eating insects instead of meat, as a source of protein. They used e-mail and forwarded their questionnaires to friends and strangers. They also used the Internet Relay Chat (IRC) as a platform for their surveys. Group 8 (Slimming Centres) also conducted a survey to find out what the most popular methods of slimming were.

The students also conducted field studies and interviewed relevant people. For example, Group 1 (Nutrition and Hair Growth) sought answers to questions about whether bad diet, polluted air, heat, and dyeing caused hair loss, and what were some possible remedies. They visited hair treatment salons, consulted 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 investigated the topic on eating disorders such as anorexia and bulimia, took on the roles of nutritional counselors and spoke not only to nutritionists, but also to people who knew of patients who suffered from these disorders. 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 where they found out answers to their questions on the causes and processes involved in tooth decay.

Groups 3, 6, 7, and 8 also made study trips and interviewed people to collect data relevant to their topics. The girls in Group 3 visited Geyland Serai and Little India where the components of the betel quid were usually sold and interviewed stall owners who sold the betel nut. Similarly, Group 6 made frequent visits to the shop selling insects products. Members of Group 7 (Ginseng), in the process of their information gathering, visited several Chinese Medicinal Halls. Group 8 (Slimming Centres) visited slimming centres, sauna, gyms, and Chinese medicine Halls to interview the professionals in the field for answers to slimming and weight loss.

Five groups performed laboratory experiments in search of answers to their problems. Students from group 1 investigated the value of human hair to plants by observing the growth of a balsam plant after they added human hair to the soil, and then compared its growth with a control plant. The students from Groups 1, 3, 6, and 7 also applied what they had learned about food tests to test for the presence of starch, reducing sugars, protein, and fats in human hair, betel nut, insects (mealworms), and ginseng. Group 9 (Dentition) students set up an experiment with a control to investigate the effects of fluoride on chicken bones and egg shells as they wanted to test whether fluoride would strengthen them.

Discussion

This section discusses some issues and challenges associated with the use of ill-structured problems, and gives suggestions for the management and implementation of PBL.

The issues and challenges pertained to: (a) identifying a problem for investigation, (b) asking questions to negotiate the learning pathway, (c) deciding what areas to pursue and focus on, given a multitude of possibilities, and (d) figuring out how to extract relevant information from the available mass and synthesize answers to the questions posed.

Issue 1: Identifying a problem for investigation.

Unlike their previous experiences with project work at lower grade levels, the students were confronted with having to identify and define a problem for investigation. Some students initially faced difficulties in formulating a problem and struggled hard to brainstorm ideas. They were not used to thinking hard on their own and were reluctant to try. Some groups also encountered problems in agreeing on what topic and problem discovered information beyond the realms of the regular school science syllabus where scientific knowledge was integrated with knowledge from other disciplines.

The multidisciplinary flavour of such a project allowed students who were disinclined towards science or whose interests lay outside science, to become more motivated as they were able to integrate their other interests with science. However, there is also the danger that students would stray too far away from the central objectives of the science lesson and become distracted by topics peripheral to the core content. Thus, teachers have to keep a watchful eye on the progress of students' learning and help students to consolidate the key concepts of a topic.

Also, when different groups investigate selected areas in depth, this would lead to a situation where each group would have "specialized" knowledge of a certain area, while knowing little about other areas. In such cases, individual groups that work on specialized topics could exchange and share their knowledge with other groups, through class presentations or co-operative learning strategies such as Jigsaw (Aronson, Blaney, Stephan, Sikes, and Snapp, 1978).

Issue 4. Figuring out how to extract relevant information from the available mass and synthesize answers to the questions posed.

With the availability of the World Wide Web on the Internet, students could end up in a wholesale transfer of information from the web site onto their presentation reports (using copy-and-paste strategies) without much critical analysis or synthesis of the available materials. The huge amounts of irrelevant information collected during searches can overwhelm students and occasionally distract them from focusing on the issues directly related to their problems of concern. Teachers need to guide students to think critically about the overwhelming mass of information that confronts them, and to distill those aspects that are relevant to their learning objectives. They need to teach students how to assess the credibility of the source, evaluate the validity and accuracy of the information they obtain from the Internet, discriminate between relevant and irrelevant information, synthesize the information from various sources, as well as acknowledge and cite references properly.

The ill-structured nature of the problem allowed students to utilise different methods of inquiry to seek answers to their variety of questions. This made them aware that beyond science laboratory work, answers to some questions could be obtained via other more appropriate and valid methods such as literature searches, surveys, field studies, and interviews. In view of this, teachers would need to teach their students the rudiments of other common methods of inquiry, data-collection and data analyses, like how to draw an appropriate sample for surveys and interviews, basic statistics, and the use of graphs and spreadsheets.

Conclusion

The use of ill-structured problems in PBL can engage students in ways that elicit the use of desirable process skills such as brainstorming to identify problems, asking questions to direct their own learning, and figuring out how to solve a problem via different types of inquiry. Since most everyday life problems are ill-structured, the use of such problems in PBL can prepare students to face real-world challenges in their future.

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