A major aim of project-based science (PBS) is to develop students’ thinking and problem-solving skills by allowing them to solve authentic problems. Students can engage in inquiry-based activities that require them to generate questions, design investigations, gather and analyze data, construct explanations and arguments in light of empirical evidence, communicate their findings, and make connections among ideas (NRC 2000; Minstrell and van Zee 2000).

Problem-based learning pedagogy and strategies are used to implement project-based science

One way of implementing PBS is to use problem-based learning (PBL), in which students formulate their own problems. (Editor’s note: See “Project-Based Science: A Primer,” p. 23 in this issue for more on PBL.) These problems are often ill-structured, mirroring complex real-life problems where data are often messy and inconclusive. In this article, we describe how we used PBL in a ninth-grade biology class in Singapore, where the socio-cultural context is different from the United States in some aspects. We discuss the tools, pedagogy, and strat-
egies that we used during a unit on food and nutrition. Students took 16 weeks to complete their projects (while also completing other biology classwork).

**Incorporating PBL into PBS**

The features of PBS include the use of “driving questions” that organize and drive activities, investigations to answer these questions, artifacts that represent students’ ideas and understanding, collaboration to share information, and technological tools that support students in learning tasks (Krajcik, Czerniak, and Berger 2002). Our use of PBS was based on these design principles, as well as the characteristics of PBL (Barrows and Tamblyn 1980; Gallagher et al. 1995), in which a problem acts as the stimulus and focus for student activity and learning.

Features of PBL include students initiating learning with an ill-structured problem, using the problem to structure the learning agenda, using the instructor as a metacognitive coach, and working in collaborative groups. Ill-structured problems are those in which

- the initial situations do not provide all the information necessary to develop a solution;
- there is no single right way to approach the task of problem-solving;
- as new information is gathered, the problem definition changes; and
- students are never completely sure that they have made the best selection among solution options.

Our students wrote their own problems based on what they were interested in investigating (i.e., their driving questions). Each problem was formulated as a multifaceted, broad, overarching problem statement that presented a scenario, and was written by students in the form of a narrative. Students identified the problems themselves, which were inspired by real-life experiences. Students asked questions based on the problem, and identified issues of interest that they wanted to learn more about. These issues were the topics and subtopics found in their problem statement. Sources of inspiration for students’ questions stemmed from cultural beliefs, folklore, advertisements, the media, personal experiences, daily encounters, and the school curriculum (Chin and Chia 2004).

**Stages of implementation**

Our class of 39 students worked in groups of 4 or 5; there were nine groups in total. Students went through five consecutive stages, which are summarized in Figure 1. Students’ project topics included nutrition and hair growth, dentition, eating disorders, slimming centers, betel nuts, ginseng, and nutritional value of insects. While the first four topics involved important universal nutritional

<table>
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<tr>
<th>Stage</th>
<th>What students did</th>
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<td>1: Identifying the problem (1 week)</td>
<td>Read newspaper articles and case studies on nutrition topics</td>
<td>Problem log</td>
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<td>Wrote questions and ideas in problem logs and mind-maps</td>
<td>Mind-map</td>
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<td>Wrote problem statement</td>
<td>Group problem statement</td>
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<td>2: Exploring the problem space (3 weeks)</td>
<td>Organized own questions around three foci: “What do you know?” “What do you need to know?” and “How can you find out what you need to know?”</td>
<td>Need-to-know worksheet</td>
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<td>Identified resources and tasks to undertake to solve their problem</td>
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<td>3: Carrying out scientific inquiry (6 weeks)</td>
<td>Collected data to answer questions</td>
<td>Internet forum page</td>
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<td>Consulted panel of doctor, dentist, nurse, and medical research worker via internet forum page (e-circle) set up by teacher</td>
<td>Lab investigations</td>
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<td>Conducted investigations in science laboratory</td>
<td>Survey protocol</td>
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<td></td>
<td>Conducted field studies, surveys, interviews, library and internet search</td>
<td>Interview schedule</td>
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<td>4: Putting the information together (4 weeks)</td>
<td>Completed learning logs</td>
<td>Learning log</td>
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<td></td>
<td>Recorded what they had learned; reviewed and consolidated information gathered</td>
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<td>5: Presenting findings, teacher evaluation, and self-evaluation (2 weeks)</td>
<td>Gave oral presentation using technology-based multimedia delivery</td>
<td>Group project file</td>
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<td></td>
<td>Completed self-reflection forms</td>
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and health issues, the latter three were of interest to this particular group of students. (Note: Slimming centers in Singapore are commercial enterprises that claim to help their clients lose weight through a variety of mainstream methods, as well as questionable and controversial techniques such as bio bodywraps, aromatic steam treatments, and lymphatic drainage. They differ from health and fitness centers, which are primarily gyms with exercise machines, and weight-reduction clinics, which may involve liposuction practices and other medical programs and counseling sessions run by doctors and nurses.)

Wherever possible, students’ project ideas and findings were integrated into regular lessons, which focused on enzymes, nutrients and classes of food, a balanced diet, nutritional deficiency diseases, and animal nutrition. At different points in the lessons, teams of student “expert researchers” who investigated the different aspects of food and nutrition were asked to share their knowledge of topics and issues that were raised. These topics included food tests, dentition, and the relationship between diet, weight, and health. For example, some students applied what they had learned about food tests to check for the presence of starch, reducing sugar, protein, and fats in betel nuts and ginseng. Others reported on the structure of human teeth, the role of teeth in the mechanical digestion of food, the dietary importance of calcium in the formation of strong bones and teeth, and how poor-eating habits and nutrition can cause dental diseases to develop.

**Teaching and learning tools used**

We used various graphic organizers and guide sheets to help students structure and organize their thinking, prepare action plans, and document their progress. In this section, we provide examples of some of these teaching and learning tools for the group that worked on slimming centers.

**Problem log**

Students brainstormed questions, issues, and ideas that they were interested in and documented these in their logs. Some entries from the group that focused on slimming centers included

- “What are fats?”
- “Does [abdominal or belly fat] contain fats?”
- “Does drinking alcohol contribute to [abdominal or belly fat]?”
- “Does the sauna help a person to slim down?”
- “How do slimming centers function?” and
- “How do fats disappear when one slims down? Where do they go?”

These student-generated questions were inspired by local cultural beliefs; wonderment about information propagated by advertisements and the media; curiosity arising from personal encounters, family members’ concerns, or observations of others; and issues derived from previous lessons in the school curriculum.

Students then did research to answer their own questions. For instance, to discover more about the effect of drinking alcohol, students learned about the relationship between alcohol, calorie intake, and...
the metabolism of fats. (Note: Drinking high-sugar soft drinks could also provide a compelling question.) In their groups, students then collated and discussed their ideas to jointly write driving questions and a problem statement.

**Group problem statement**

The overarching, driving questions of the slimming-center group were “What are the different ways to lose weight if one is overweight?” and “What are the advantages and disadvantages of the different ways of losing weight?” The group’s fictional problem statement read:

*Ms. P was severely overweight. She tried to lose weight by exercising, but it was to no avail. Finally, she decided to seek help at slimming centers 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.*

Since these students were from an all-girls’ school, it was not unusual for them to identify with and use a female character in their problem statement. However, weight management is a compelling issue for many teenagers, male and female alike. In their teenage years, students have a vested interest in investigating and learning about the relationship between exercise, diet, and maintaining a healthy weight.

The driving questions impelled students to learn more about the concepts related to maintaining a healthy body weight and lifestyle through exercise and a calorie-controlled, balanced diet. The slimming pills students referred to in their problem statement were orlistat and sibutramine, which have been medically used for the treatment of obesity. Orlistat blocks the action of lipase, the enzyme that digests fat in the intestines and reduces the amount of fat eaten from being absorbed. Sibutramine increases satiety when someone eats by boosting levels of serotonin, the chemical made naturally in the body that creates the feeling of fullness.

Although these two slimming pills have generally received the support of most health professionals when they are used under supervision, there are also other more questionable slimming pills sold by unlicensed vendors that may contain undeclared substances. Claiming to be fat-blockers, metabolism-boosters,
or pills that prevent hunger and suppress food cravings, such products promise the ultimate quick fix to people seeking weight reduction. Some slimming pills could be harmful if someone has a medical condition, or is on certain medication for an underactive thyroid (and the slimming pill contains a thyroid-stimulating ingredient). The slimming biscuits mentioned in the problem statement are low-calorie, high-fiber cookies that claim to make people feel full when consumed with large amounts of water. Some are fruit-based while others contain unspecified products as ingredients.

**Need-to-know worksheet**
The need-to-know worksheet established a learning agenda for students by organizing their discussion around three focus questions:
- What do you know?
- What do you need to know?
- How can you find out what you need to know?

Examples of students’ entries are provided in Figure 2 (p. 46).

**Project planner form**
On the project planner form, students recorded the individual roles of each group member and also documented the teacher’s comments during conference sessions. The teacher wrote evaluative comments and suggestions pertaining to group dynamics (e.g., teamwork, time management, conflict management, and enthusiasm) and work performance.

**Project tasks allocation form**
The project tasks allocation form helped students to plan ahead for the next step in their inquiry and distribute their workload. Students had to describe their tasks in detail, specify who was in charge of carrying out the assigned tasks, and document the due date.

**Survey questionnaire and interview schedule**
Using an online survey questionnaire, students solicited people’s ideas, experiences, and perceptions about slimming methods and slimming centers. Students prepared for interviewing respondents by planning and writing down the questions they wanted to ask ahead of time.

Students’ interview respondents included people working at slimming centers, volunteer overweight individuals, and a doctor. Some of their interview questions included:
- “Do you use different methods for different people?”
- “How long does the entire [weight loss] treatment last?”
- “Other than using equipment, are there any other ways that can help your clients lose weight?”
- “What do you think of people going to slimming centers?”
- “What do you think of crash diets?”
- “Will exercise help if obesity is due to hereditary factors?” and
- “How are we supposed to know whether we have excess fat inside our body?”

**Learning log**
In their learning logs, students documented what they learned after every group discussion. Specifically, they had to make entries in a four-column table with the following headings:
- What we wanted to find out
- What we have found out
- How we found that out
- Science concepts learned

This helped students to review and consolidate the information they had gathered.

**Self-evaluation form**
The self-evaluation form titled “How Did I Do?” (Figure 3, p. 47) helped students to reflect on their own performance related to knowledge-application skills, communication, and independent learning. Students also reflected on the problems they encountered while working on their group projects. They evaluated themselves on a four-point rating scale: 1 for “not yet,” 2 for “some of the time,” 3 for “most of the time,” and 4 for “all the time.”

**Assessment rubric**
Criteria for assessment were made explicit to students up front. This was a holistic assessment of both the processes and the products of the project work. Performance indicators pertained to the quality of students’ questions, ideas, use of resources, data-collection methods, findings, written reports, and oral presentation.

The group that worked on slimming centers learned about the composition, distribution, and metabolism of fat in the body, as well as the relationship between calorie intake and the expenditure of energy. After comparing the advantages and disadvantages of different weight-reduction methods, they concluded that sensible eating and exercising were still the best methods of losing weight and maintaining a healthy weight level, and that quick-fix remedies and fad diets (e.g., slimming creams, pills, and biscuits) were best avoided.

During their project presentation to the class, the group said, “Although we have seen many effective slimming treatments, we still think that the best way to stay slim is the natural way. The slimming treatments cost too much and also have some side effects.” Students also learned to be skeptical about the advertisements put up by the slimming centers, which appear frequently in local newspapers. More importantly, they learned to compare the pros and cons of the different touted methods of weight loss, evaluate claims made by the
media, question the validity of such claims, and exercise critical-thinking skills.

Findings and challenges faced

Given the ill-structure of their problems, students’ questions played a vital role in steering the direction of their own inquiry and what they subsequently learned. The questions provided focus and spurred them to brainstorm ideas, make comparisons, evaluate evidence, construct arguments, and provide justifications. Students engaged in different modes of inquiry and learned about varied methods of seeking answers to their questions. Students’ experiences with PBL were generally positive because they were personally meaningful. Nevertheless, using PBL in the classroom does not come without pedagogical challenges.

During the problem-identification stage, some students experienced difficulties in generating questions and formulating their own problems since they were used to being provided with well-defined problems. However, allowing students time to think through the week and giving them opportunities outside class to talk with friends and family members helped them to come up with more ideas. Giving students sample articles on issues related to nutrition to read and discuss also helped them develop ideas.

Because of ill-structured problems and the multidisciplinary nature inherent in such an approach, students may stray far from the central objectives of the science lesson and become distracted by topics peripheral to the core content. This problem is particularly pertinent if students’ projects form part of regular curriculum, and are not for enrichment purposes. Teachers have to keep an eye on the progress of students’ learning and remember to help students consolidate the key concepts of a topic.

Also, when different groups investigate selected areas in depth, each group develops specialized knowledge of a certain area, while knowing little about other areas. In such cases, individual groups that work on specialized topics should exchange and share their knowledge with other groups through class presentations or cooperative learning strategies (Aronson et al. 1978).

With internet searches, students may just copy-and-paste information from websites onto their presentation reports without much critical analysis or synthesis of available materials. Also, the large amount of irrelevant information available on the internet 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 available information, 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, and acknowledge and cite references properly.

To help students use different methods of inquiry to seek answers to their questions, teachers also need to teach students skills related to carrying out science investigations (Chin 2003), conducting interviews and surveys, learning basic statistics, as well as using graphs and spreadsheets. The use of various graphic organizers and guide sheets (e.g., “need-to-know” worksheet and self-evaluation form) also helps to provide scaffolding for students.

Conclusion

PBS that is implemented via PBL and driven by students’ questions is based on students’ interests and motivated by the need to answer their own questions. It affords many possibilities for transforming classrooms into active learning environments with a dynamic interplay of questioning, explaining, designing investigations, communicating ideas, collaborating, and reflecting. To be successful, teachers play important roles as metacognitive guides in helping students to formulate a feasible problem, plan a course of action, evaluate evidence, and synthesize the information amassed. By using graphic organizers, guide sheets, and a variety of scaffolding tools, teachers can help to organize students’ thinking as they work toward solving their problems. Because most authentic problems in our lives are ill structured, students are better prepared and equipped to face future real-world challenges when given the experience of working on ill-structured problems in science classes.

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References


