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Problem-Based Learning in Science Education

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ABSTRACT

Problem-based learning (PBL) is an influential way for inquiry-based learning in which students use an authentic problem as the context for an in-depth investigation of what they need and what to know. Problem-based learning differs from didactic teaching in that students, faced with a description of new situation or event, are required to define their learning needs and questions in order to achieve understanding of the situation or event. Problem-based learning is an educational approach that challenges students to work cooperatively in groups to seek solutions to real-world problems and to develop skills to become self-directed learners. Instruction is more student-centred. Learning is active rather than passive. The teacher plays several roles, including lecturer, facilitator and coach. Moreover, this approach lets students improve their critical thinking skills, analyze and solve complex, real-world problems, work cooperatively in groups, and communicate orally and in written form. The aim of this paper is to provide framework for theoretical and practical application of PBL in science education.

Keywords: Problem-Based Learning; Science Education; Inquiry; Instructional Approach.

INTRODUCTION

The roots of problem-based learning can be based on the progressive movement, especially on John Dewey's beliefs that teachers should teach by tempting to students' natural instincts to investigate and create (Delisle, 2002).

Problem-based learning began at the University of New Mexico School of Medicine in the 1960s. PBL in medical schools is supported to a large degree by information-processing theory. The central ideas of this theory are that the learning situation activates prior knowledge, facilitating new learning, parallels ways in which this knowledge will be needed in real world situations, increases the probability that the learner will recall and apply what is stored in memory (White, 1996; Virtanen et al, 1999; Aspegren et al, 1998; & Delisle, 2002).

Social constructivist approaches to learning have been applied through classroom practices such as collaborative learning, problem-based learning, and peer teaching groups (Stage et al, 1998; Shepardson, 1999; Reigeluth & Squire, 1998). PBL is one of the best exemplars of a constructivist-learning environment. PBL is an influential way for inquiry-based learning in which students use an authentic problem as the context for an in-depth investigation of what they need and what to know. This constructivist process is shaped and directed primarily by the student, with the instructor as the "thinking" coach (Savery & Duffy, 1995; Plucker & Nowak, 1999; Levin, 2002; Greenwald, 2000; Sage & Torp, 1997).

Constructivism concentrates on learning how to think and understand. Students also use their knowledge to solve real problems because constructivist learning is transferable. We defined it as a meaningful learning. In constructivist classrooms, students create organizing principles that they can take with them to other learning settings. Third, learning activities are in an authentic, real-world context, therefore constructivism engages students. Students in constructivist classrooms learn to question things and to apply their natural curiosity to the world. Fourth, constructivism promotes social and communication skills by creating a classroom environment that emphasizes collaboration and exchange of ideas with the others. Students must learn how to articulate their ideas clearly as well as to collaborate on tasks effectively by sharing in group activities. Students must exchange their ideas and must learn to discuss with others, moreover, they evaluate their contributions in a socially acceptable manner. This is essential to success in the real world, since they will always be exposed to a variety of experiences in which they will have to cooperate and navigate among the ideas of others.

As a result, constructivism gives students ownership of what they learn, because learning is based on students' questions and explorations. The students are also more likely to retain and transfer the new knowledge to real life (Karagiorgi and Symeou, 2005).

Brooks and Brooks (1993) identified four criteria for a good problem-solving situation as a example of constructivist approaches:

- "Students make a testable prediction.
- Students can use available or easily accessible materials.
- The situation itself is complex enough to support varied approaches and generate multiple solutions.
- The problem-solving process is enhanced, not hindered, by a collaborative approach." (p.35)

There are some recommendations for constructivist model of learning based on the work of Shepardson (1999); Sage and Torp (1997); Domin, (1999); and DeVires and Zan, (1995):

- Promoting learning around larger tasks or problems relevant to students
- Structuring learning around primary concepts
- Supporting the learner working in a complex, authentic environment
- Seeking and valuing students' points of view.
- Assessing learning in the context of teaching and incorporating self-assessment
- Supporting and challenging student thinking through cognitive coaching.
- Encouraging collaborative groups for testing student ideas against alternative views
- Encouraging the use of alternative and primary sources for information
- Adapting curriculum to address student questions and ideas

Children have to learn to share, communicate, and work together. The Vygotskian practice led to social constructivism that incorporates the same ideas as Piaget's individual constructivism and then puts in the interaction of children. Children cooperate and then children create meaning. The teacher's role is to decide the meaning the children have created to explain various concepts, process, or skills (Dickinson et al., 2000).

Problem-based learning has as its organizing centre the ill-structured problem which is messy and complex in nature, requires inquiry, information-gathering, and reflection, is changing and tentative, has no simple, fixed, formulaic, "right" solution. Problem-based learning is focused on minds-on, hands-on learning organized around the investigation and resolution of messy, real-world problems. Problem-based learning includes three main characteristics:

- Engages students as stakeholders in a problem situation.
- Organizes curriculum around this holistic problem, enabling student learning in relevant and connected ways.
- Creates a learning environment in which teachers coach student thinking and guide student inquiry, facilitating deeper levels of understanding.

A PBL provides authentic experiences that promote active learning, support knowledge construction, and naturally integrate school learning and real life, as well as integrating disciplines. Students are engaged problem solvers, identifying the root problem and the conditions needed for a good solution, pursuing meaning and understanding, and becoming self-directed learners. Teachers use real-world problems and role-playing as they coach learning through probing, questioning, and challenging student thinking. Teachers are problem-solving colleagues who model interest and enthusiasm for learning and are also cognitive coaches who foster an environment that support open inquiry. As teachers construct a teaching and learning template, they have clear goals for each event, and the goals support student thinking at different levels. As teachers coach students toward these goals, they anticipate embedding essential instruction and assessment at critical points during problem investigation (Smith, 1999; Delisle, 2002; Levin, 2002; Gallagher et al, 1995; Fenwick & Parsons, 1998).

Students are given an ill structured problematic situation. The situation requires inquiry, information gathering, and reflection. After information gathering and evaluation of data, the root problem may change and let new avenues for the investigation. Students must analyze, synthesize, and evaluate to gain a sense of the whole and formulate a viable solution. Well-structured problems, on the other hand, provide the information, the compass, and a clear destination for the problem solver, tapping only the lower-level thinking skills of knowledge, comprehension, and application. They pursue information by phoning, questioning, and experimenting. They clarify and share what they know. This process helps them access to prior knowledge and begin to make connections. Students can share the problem and their solutions by using concepts maps, charts, graphs, proposals, position papers, memos, maps, models, videos, or home page on the World Wide Web (Delisle, 2002; Ngeow & Kong, 2001; Ram, 1999; Gallagher et al, 1995; Greenwald, 2000; Reigeluth & Squire, 1998).

Studies showed that PBL improves students' academic achievement, as well as allows them to work in groups cooperatively and construct their knowledge through social negotiation compared to traditional teaching methods (Polanco et al., 2004; Sungur et al., 2006; Goodnough, 2003). Even though there are many studies to show effectiveness of PBL, there is not enough study to present curriculum materials for teachers to explain how to implement PBL in the actual classroom. The focus of this paper is to describe PBL and identify factors associated with it and more importantly provides a lesson plan that illustrates theoretical and conceptual link between science and real world problems. So teachers can implement these teaching methods in their classroom to improve their students' academic achievement in science.

1- Curriculum Design

PBL is a curriculum development and instructional approach. The curriculum consists of carefully selected and designed problems that demand from the learner acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies, and team participation skills. The process replicates the commonly used systemic approach to resolving problems or meeting challenges that are encountered in life and career (Sage & Torp, 1997; Domin, 1999; Krynock & Roob, 1996).

PBL application has six important aspects:

1. The role of the problem,
2. The role of the teacher,
3. The role of the students,
4. The role of thinking skills,
5. The role of social interaction,
6. The role of assessment (Plucker & Nowak, 1999; Delisle, 2002; Levin, 2002; Ram, 1999; Greenwald, 2000)

Role of the Problem

Problem-based learning starts from a problem. In other words, it starts with a complex problem that "create a need to know" rather than starting from textbook lesson and then giving problems (Aspegren et al, 1998; Smith, 1999).

PBL begins with the introduction of an ill-structured problem on which all-learning centres. The problem is ill structured and complex, which requires students to search beyond the readily available information to solve the problem. The problem is authentic and engaging; requires active student involvement; based on students working cooperatively in small groups; builds on students' prior knowledge; interdisciplinary; ends in a concluding activity; and incorporates local and state learning goals (Plucker & Nowak, 1999; Bartels, 1998; Sage & Torp, 1997).

Smith (1999) gives some real-world problems as an example. One of them is that "you have a US road atlas. Our teacher will give you other information you need, or help you find the information, but you need to ask for it and explain how it will help you answer the questions" (p.162)

Role of the Teacher

In problem-based learning, the traditional teacher and student roles change. The students assume increasing responsibility for their learning, giving them more motivation and more feelings of accomplishment, setting the pattern for them to become successful life-long learners. The faculty in turn becomes resources, tutors, and evaluators, guiding the students in their problem solving efforts (Delisle, 2002). Teachers assume the role of cognitive and metacognitive coach rather than knowledge-holder.

Teachers design an ill-structured problem based on desired curriculum outcomes, learner characteristics, and compelling, problematic situations from the real world. Teachers develop a sketch or template of teaching and learning events in anticipation of students' learning needs. Teachers investigate the range of resources essential to the problem and arrange for their availability. Teachers model, coach, and fade in supporting and making explicit students' learning processes (Bartels, 1998; Sage & Torp, 1997).

Role of the Students

Students assume the role of active problem-solvers, decision-makers, and meaning-makers rather than passive listeners. As the students are coached in their roles as real-world investigators and active learners, they become self-regulated learners empowered to investigate needed information, pursue logical lines of inquiry, and learn actively. The students develop into self-directed learners and problem solvers (Plucker & Nowak, 1999).

Students construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences. When they learn something new, they have to reconcile it with their previous ideas and experience, maybe changing what they believe, or maybe discarding the new information as irrelevant. In any case, they are active creators of our own knowledge. To do this, they must ask questions, explore, and assess what they know. They are responsible for all of their learning (Goodnough, 2006).

PBL provide students with guided experience in learning through solving complex, real world problems.

It is designed to help students;

•Construct a broad and flexible knowledge base
•Develop effective problem solving skills
•Develop self directed, lifelong learning skills
•Become effective collaborators and
•Become motivated to learn (Chin and Chia, 2004).

Role of Thinking Skills

A PBL activity, when well designed and implemented, should encourage critical thinking. Problems should be without an easily identifiable solution and encourage students to consider alternative perspectives. Teachers should help students develop thinking skills within the context of the problem being solved (Plucker & Nowak, 1999).

Students involved in problem-based learning acquire knowledge and become proficient in problem solving, self-directed learning, and team participation. Studies show that PBL prepares students as well as traditional methods. PBL students do as well as their counterparts from traditional classrooms on national exams, but are in fact better practitioners of their professions (Hmelo-Silver, 2004).

In problem-based learning, students participate in complex, life-like learning situations where they take the lead in gathering information, drawing conclusions, making decisions and simulating the processes of the world beyond their classrooms. Problem-based activities may feature in a particular subject or learning area contexts or for periods of time for specific purposes rather than serves as the central instruction (Chin and Chia, 2005).

Role of Social Interaction

A PBL classroom is organized around collaborative problem-solving activities that provide a context for learning and discovery. Collaboration both within and between groups forces students to reflect on their peers' and their own problem solving. The reason why teachers put students in cooperative learning groups is so all students can achieve higher academic success individually than were they to study alone (Plucker & Nowak, 1999; Stahl, 1994; Ngeow & Kong, 2001; Ram, 1999).

Role of Assessment

Students assess and share with the group their own problem finding, problem solving, knowledge acquisition, and self-directed and collaborative learning skills. Authentic assessment methods for which students develop discussion criteria include journal writing, lab notebooks, self-rating scales, peer interviews, and conferences with teachers. The role of notebook is to record the observations, data, and hypotheses. This kind of journal-type record is known as problem logs. Specific assignments planned for the log-helped teachers keep track of students' thinking. Concept maps developed by the students helped them make the links between pieces of information and find the conceptual whole among disparate perspectives. Maps also helped students understand that science is organized around essential concepts, which are developed through nonlinear associations of information. (Gallagher et al, 1995; Greenwald, 2000; Plucker & Nowak, 1999)

It is important to have predetermined criteria to evaluate the students' performances. Students should not be scored/graded against their peers, but against predefined criteria. Ideally, students should be provided with the criteria before the assessment. Accordingly, the grade book and student feedback reflect levels of competency, rather than comparative scores.

I believe, the assessment should focus on both product and process because both of them are complementary each other. Just looking to product doesn't show that students learn. Students should be able to show how they come out this product, what they learn and how they transfer new knowledge in their project.

2- The Benefits of Problem-Based Learning

PBL promotes metacognition and self-regulated learning as students generate strategies for problem definition, information gathering, data analysis, and hypothesis building and testing. PBL engages students learning in ways that are similar to real world situations and assess learning in ways that demonstrate understanding and not mere replication. Students usually have misconceptions that can interfere with learning; problems can confront those misconceptions and help students look at things in new light. Students become more aware of their own understanding when they have to justify their decisions. The problem and solutions are meaningfully connected, so they are easier to remember (Smith, 1999; Greenwald, 2000; Domin, 1999; Krynock & Roob, 1996).

PBL makes students more engaged in learning because they are hard wired to respond to dissonance and because they feel they are empowered to have an impact on the outcome of the investigation. PBL offers students an obvious answer to the questions, "Why do we need to learn this information?" and "What does what I am doing in school have to do with anything in the real world?" The ill-structured problem scenario calls critical and creative thinking by suspending the guessing game of, "What's the right answer the teacher wants me to find?" PBL promotes metacognition and self-regulated learning by asking students to generate their own strategies for problem definition, information gathering, data-analysis, and hypothesis-building and testing, comparing these strategies against and sharing them with other students' and mentors' strategies. PBL engages students in learning information in ways that are similar to the ways in which it will be recalled and employed in future situations and assesses learning in ways which demonstrate understanding and not mere acquisition (Gick & Holyoak, 1980; Ram, 1999).

PBL is used different subject area such as biology, chemistry, and physics. Teachers can use PBL in many ways. Teachers can give students a scenario that describes one the problem in the environment or issues then they will try to find and answer. For example, in my classroom I came up an idea to use problem based learning model using historical perspective about photosynthesis. In the 1770s Joseph Priestley performed experiments showing that plants release a type of air that allows combustion. He demonstrated this by burning a candle in a closed vessel until the flame went out. He placed a sprig of mint in the chamber and after several days showed that the candle could burn again. Like as his experiment I gave students a story about a scientist.

It states: 200 hundred years ago a scientist did an experiment. First, he put a young mouse with enough water and food under a glass box. He put this box somewhere that can get enough sunlight but nothing else (air, food, etc.) soon after the mouse died but most of the water and the food still was in the box. He did a second experiment. This time besides the young mouse with food and the water he also included a living green plant in a small pot with soil and some water. He again covered them with glass box and put the same place as before. The mouse did not die and lived long enough to grow big as the plant did.

After reading this short story, I divided students into small groups and let them think what made the mouse live long and why. After the discussion in the class students searched the Internet for information to find their solution to situation. This beginning activity let them think and connect with their prior knowledge to come up with an answer.

The other example of PBL can be local problems. Students investigate one of the problems which are related to their personal life and environmental problems or local problem in their area such as air pollution, water pollution, global warming etc. Moreover, disease can be used in PBL. For example, students may investigate some diseases n the world such as cancer and Parkinson.

A sample plan for the teaching and learning events of the PBL experience should be included:

- Prepare students for PBL
- Meet the problem
- KNK (Know, Need to Know)
- Define problem statement
- Gather and share information
- Generate possible solutions
- Evaluate fit solutions
- Performance assessment
- Debrief problem experience

An Example for PBL Lesson Plan
Topic: Germs, Germs, Germs
Level: High school biology
Concepts:

-Students will have an understanding of types of environments where bacteria can be found.

-Students will apply their discoveries about bacteria to problems in their everyday lives, such as good hygiene, disease prevention, and food preparation.

Materials:

Petri dishes	Masking tape
Blood agar or other agar	Permanent markers
Q-tips	Incubator or heat lamp

I. Whole class discussion

1. Brainstorm a list of places where we might find bacteria in this school.
2. What makes you think there would be bacteria in any of these places?

II. Small group and/or whole class discussion

1. If we wanted to find out if there were bacteria in these places, how would we go about doing that?
2. What are some things we would have to think about when planning how to investigate this? (Make a list.)

III. Activities

-Continue having students develop their own methods for collecting and growing bacteria samples. Have students decide what materials and procedures they could use.

-Use a more structured activity:

1. Students collect bacteria on blood agar petri dishes.
2. Incubate the dishes.
3. Students observe and describe dishes, then share with class.

4. Discussion about the areas of the school that produced the most growth, the conditions in these areas that fostered growth, precautions to take to prevent growth, what to do if they wanted to encourage bacterial growth.

Extensions:

1. Students actually investigate how to prevent bacterial growth using the experiments they designed.
2. Students try to grow pure cultures of the different kinds of bacteria they found, and try to identify what kinds of bacteria they have grown.
3. Do an activity with beneficial bacteria such as making cheese or yogurt.

Teacher Hints:

-Make sure the students divide and label the petri dish with a permanent marker.

-Make sure they put their names and where they collected their samples.

-Make sure they leave the fourth quadrant empty as a control.

-Make sure the students don't lift the lid of the dish until they are ready to inoculate it.

-Use tape to collect samples in dry areas, Q-tips in wet areas.

-Incubate the dishes for three days. (Read instructions on incubator, or use heat lamps.)

-If you use heat lamps, make sure to not "fry" the dishes. (Check them often!)

-Introduce the term colony after students have observed them growing.

Questions to ask students:

1. Where have you seen bacteria growing in your everyday life?
2. Speculate: What are some reasons scientists need to study bacteria?
3. What is the purpose of dividing the dish and labelling it?
4. What is the purpose of leaving the fourth quarter empty?
5. Predict: What would happen if you left the lid completely off the dish?
6. What do you think the petri dish will look like after incubation? (You may draw a picture, as well!)

Many students will have misconceptions about bacteria, and the activity and discussions can help address some of them. For example, students have seen mould growing on bread and confuse that with bacteria. Also, microorganisms through getting sick, eating certain foods, carrying out bodily functions, etc, have affected all students' lives. The lesson can be followed with research about bacterial diseases/infections and activities dealing with useful bacteria. That way student knows there are both helpful and harmful bacteria.

3- Implications for Education

Teacher education requires identifying how PBL can be used as a strategy for teaching and learning; how it improves their own learning; and how to use PBL in their own classrooms. In PBL classrooms, if teachers give students a challenging task that engages them, their learning will be deeper and more meaningful and will last longer.

Teachers should use question-and answer dialogue less than they do. They should organize more class time for student questions, student individual and group reports, true dialogue, cross-discussion, and small group work. Teachers should encourage students to talk to one another during class about science topics.

Identify several complex issues, conflicts, puzzles, decisions, or circumstances from their own teaching materials or from real-world experiences, which are attractive on the basis of maximum integrative curricular yield and learner appeal. Map out the conceptual complexities and learning opportunities within these issues, conflicts, puzzles, decisions, or circumstances. Identify those mapped complex issues, conflicts, puzzles, decisions, or circumstances, which are problematic and ill structured in nature. Select the "problematic centre" which is most attractive in terms of maximizing the learners' interest and engagement and yielding curricular benefits. Develop a focus for the chosen problematic centre by experimenting with possible roles and situations, identifying in some way what one needs to know and do in order to bring the problem to an acceptable state of closure, decision, resolution, or understanding.

As a result of PBL, students acquire knowledge and become capable of problem solving, self-directed learning, and team participation. PBL increases higher-level thinking skills by asking students to think about a given problem more critically and to analyze data to derive a solution.

I believe that PBL provides authentic experiences that promote active learning, support knowledge construction, and naturally integrate school learning and real life, as well as integrating disciplines. Students are engaged problem solvers, identifying the root problem and the conditions needed for a good solution, pursuing meaning and understanding, and becoming self-directed learners.

CONCLUSION

Problem Based Learning (PBL) is one of the examples of a constructivist-learning environment. In this paper, I try to provide classroom practices with problem-based learning because students construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences.

A PBL provides meaningful learning opportunity for students who can actively involve in their learning. In problem-based learning, students “construct the understanding through their prior experiences” (Savery & Duffy, 2001, p.2). Students participate in the instruction and determine the direction of the instruction. The goals of the learners are defined by the learners themselves. They are motivated and they need to take initiative in their learning.

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