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ABSTRACT

Research on how the brain works has resulted in wider-scale adoption of the principles of problem-based learning (PBL) in many areas of education, including technology education. The PBL approach is attractive to curriculum developers because it is based on interdisciplinary learning, results in multiple outcomes, is integrated and competency-based, and emphasizes metacognitive or higher-order skills and real-life perspectives. The educational objectives of PBL are as follows: (1) develop a systematic approach to solving real-life problems using higher-order skills; (2) acquire an extensive integrated knowledge base that can be recalled and flexibly applied to other situations; (3) develop effective self-directed learning skills; (4) develop the attitudes and skills necessary for effective teamwork with others on a task or problem; (5) acquire a lifelong habit of approaching problems with initiative and diligence and a drive to acquire the knowledge and skills needed for an effective resolution; and (6) develop habits of self-reflection and self-appraisal. A model of PBL has been proposed that includes a nine-step self-directed procedure for approaching a problem, a resource critique, reassessment of the problem, summary and integration of what has been learned, and evaluation. PBL can be used in areas of technology education such as communication, manufacturing, transportation, and construction. (MN)

# Problem-based Teaching and Learning in Technology Education

A.R Putnam
Department of Workforce Education and Development
Southern Illinois University Carbondale
Carbondale, IL 62901-4605
bputnam@siu.edu

## Introduction

Over the last four decades, as we learn how the brain works to solve problems, store and manipulate data, and use symbols, we have been in transition from the Behaviorists' theory of learning to theories generated by cognitive scientists, particularly Constructivism (Dirkx & Prenger 1997; Sandlin 2000). Current perspectives on cognition and learning include situated cognition, social cognition and distributed cognition (Borko & Putnam 1998; Putnam & Borko 2000). All of these perspectives explain what it means for learning to be contextualized. All propose that the learner actively constructs meaning through mental processes while learning. Instead of focusing on action and reaction as the behaviorists did, cognitive scientists talk about the nature of mental representation. How do we thank, learn, remember, understand and create?

According to Howard Gardner of Harvard University, viewing the brain as solely an information-processing entity, comparable to a computer gives an incomplete picture. He proposes that all humans have eight separate intelligences. These include linguistic, logical-mathematical, spatial, musical, bodily, interpersonal, intrapersonal and naturalistic intelligences. Gardner hypothesizes that the various intelligences can act separately or interdependently (Weiss 2000).

According to cognitive scientists, each of us has a mind that is unique in its construction as well as its content. The human brain has an internal structure that it continuously updates and alters as more information is received, processed and stored. Everyone has a different way to handle the information they receive and process. While there are different explanations as to how this occurs, cognitive scientists agree that people use their individual strengths and weaknesses to create *meaning*. The *meaning* of the information usually depends upon the *context* in which the information will be used.

We now understand that learning occurs as the learner creates meaning from the need to know and that how the information is presented is as critical as what is to be learned. This presents real challenges for the curriculum developer whose job it is to structure learning experiences with maximum effect and retention.

**Contextual teaching and learning**

Contextual teaching and learning is the way we apply these cognitive theories to practice by connecting the information or content of what we want to teach with the context in which the content will likely be used so that the learner will create meaning for the content. Connecting content with the context is an important part of bringing meaning to the learning process. For that connection to take place, a variety of teaching approaches may be used. The literature on teaching and learning reveals Problem-based, Collaborative, Project-based, Service and Work-based learning as teaching approaches which include context as a critical component (U.S Dept. of Educ. 1998). Characteristics of all CTL approaches include interdisciplinary learning based; resulting in multiple outcomes, based on integrated competencies, emphasizes metacognitive (higher order thinking) skills, elevates the level of learning and emphasizes real life perspectives.

**Problem-based learning**

Problem-based learning is the most comprehensive and widely adopted approach, and has been chosen for the curriculum delivery model at many professional schools around the world. It is an instructional approach that uses real world problems as a context for students to learn critical thinking and problem-solving skills, and to acquire knowledge and essential concepts of the course. It uses real world problems, emphasizes problem-solving skills, teaches critical thinking skills and develops self-directed learning skills.

**Characteristics of problem-based learning**

There are several characteristics of the problem-based approach to learning that make it uniquely attractive to curriculum developers. First, it is interdisciplinary learning based. Knowledge and skills needed in the real world are not acquired in a compartmentalized fashion and held intact in order to pass a test. They are dynamic, and interact with other knowledge and skills on a multidisciplinary continuum. Second it results in multiple outcomes. It is rare indeed when any problem encountered in real life has only one right answer and no unintended outcomes. Teaching students to rely upon finding "the only right answer" creates students who are narrow, and easily frustrated when confronted with the complexities of solving real problems in real life. The third characteristic of PBL is that it is integrated competency based. That means that students learn skills in areas that overlap or complement the areas under investigation. For example, students studying combustion engines also writing skills through technical report writing and math skills through output calculation and testing. The fourth characteristic of PBL is that is emphasizes metacognitive, or higher order skills. Rather than simply teaching students to use formulas to solve problems, or operations of a particular machine, the students learn to solve problems, think and evaluate solutions. Another characteristic of PBL is that it elevates the level of learning. A PBL problem forces the student to go beyond the obvious solution and to explore other options and evaluate the resulting solutions. Finally, a characteristic of all PBL problems is that they emphasize real life perspectives. One of the critical elements that make any PBL problem work is that students understand that the PBL problem is one they could meet outside of class, and that they need to know how to solve it. A critical element to this characteristic is that realistic evaluation must be provided. That means that the person evaluating the solution should be someone who would be making the evaluation in real life.

**Dimensions of problem-based learning**

According to Howard Barrows of Southern Illinois University School of Medicine, a pioneer of problem-based learning, PBL operates in six different dimensions, or areas of skill development. It is designed to teach skills or competencies in each of these dimensions. The first dimension is hypothetical-deductive reasoning or 'the scientific method', which becomes the goal for learning. The PBL process is an ordered instructional approach that models the processes to systematically approach real-life problems. Like all real-life problems, PBL problems are messy and ill structured. There is no single right answer. Problem solution comes from hypotheses generation, inquiring for more information and hypotheses refinement, then move toward a resolution.

Development cognitive flexibility is the second dimension of the PBL process. The *need* for knowledge and skills becomes the goal for learning. Knowledge and skills are *developed* not acquired in a compartmentalized fashion and held intact in order to pass a test.

A PBL problem is designed to stimulate the need to know. As students work through the problem guided by the facilitator, they are continuously made aware of the need to know more.

Recognizing what knowledge and skills are needed, knowing what resources should be used, learning how to acquire them in an efficient, effective manner and learning to shape this newly acquired knowledge so that it contributes to the problem solution are all part of the mindset and skills that make up the third dimension of PBL, developing self-directed learning skills. PBL curriculum leads to the development of the capacity and habit of mind that integrates knowledge and seeking, recall and shaping.

The third dimension of the PBL process is self-directed learning. The PBL process focuses students on planning for and critically reviewing sources that will serve as efficient and effective means for acquiring the necessary knowledge and skills. Recognizing what knowledge and skills are needed, knowing what resources should be used, learning how to acquire them in an efficient and effective manner, and learning to shape this newly acquired knowledge so that it contributes to the problem solution; are all part of the skills and mindset, that make for life long learners.

The fourth dimension of the PBL process fosters the development of collaboration skills: working as a team player. Most significant problems in real life can only be resolved satisfactorily through the collaborative efforts of a number of people approaching the problem from multiple perspectives, knowledge, skills and wisdom. The PBL process is designed to encourage development of the skills necessary to work and learn effectively as members of a collaborative team working toward a common goal without sacrificing the development of the individual as a competent, confident, independent contributor to society.

The fifth dimension of the PBL process over-arches all the others. PBL is student centered. Its goal is to produce students who take responsibility for the improvement of themselves and their community. This means that the default for every decision is: "It's the students' responsibility." What needs to be learned? It is the student's responsibility to decide. How do we manage time and resources? Students' participate in the decisions. How do we manage a problem with group dynamics or behavior? The challenge is given to the students. When the problem is being developed, it belongs to the faculty. Once it is given to the students, it is theirs.

The sixth dimension of the PBL process is the development of self-reflection and self-appraisal habits that are necessary for honest self-assessment and setting realistic goals. Throughout the PBL process the facilitator verbalizes models for self-questioning that students can internalize. The facilitator asks "why?" strategically so that students will begin to assess the accuracy and depth of their knowledge. Students are asked to cite evidence for their verbal self-evaluation at the end of each problem so that students will begin to internalize the habit of reviewing and reflecting on their performance. The students are asked to identify goals for the next problem and strategies for reaching them. As a consequence students develop the capacity and mindset that combines self-reflection and appraisal with goal setting and planning. (Barrows and Kelson, undated)

**Educational objectives of problem-based learning**

The shape of the PBL process is determined by its six educational objectives that mirror its six dimensions; the students will:

1. Develop a systematic approach to solving real-life problems, using higher order skills as problem-solving, critical thinking and decision making.
2. Acquire an extensive integrated knowledge base that can be recalled and flexibly applied to other situations.
3. Develop effective self-directed learning skills, identifying what they need to learn, locating and using appropriate resources, applying the information back to the problem, and reflecting on, evaluating, and adjusting their approach for greater efficiency and effectiveness.
4. Develop the attitudes and skills necessary for effective teamwork with others work on a task or problem.
5. Acquire a life long habit of approaching a problem with initiative and diligence and a drive to acquire the knowledge and skills needed for an effective resolution.
6. Develop habits of self-reflection and self-evaluation that allow for honest appraisal of strengths and weaknesses and the setting of realistic goals. (Barrows & Kelson, undated)

**Approach to the problem: the problem-based model**

When the student is given the problem simulation the student should determine the problem. When first approaching a task, situation, or problem the students bring their own knowledge to the problem. They; realize what they actually already know and what they will need to learn. The students will need to gather necessary information or learn new concepts, principles, or skills as they engage in the learning process.

The second step in approaching the problem is that the student should generate hypotheses. Based on the presenting problem the students attempt to generate as many ideas about causes or explanations they can think of on the basis of their past experiences and knowledge. These should be recorded.

The third step in approaching the problem is inquiry. Using the list of ideas (hypotheses) that were generated the students determines the questions that should be asked in an attempt to verify or deny those ideas. These questions will guide searches that may take place on-line, in the library, and in other out-of-class searches.

The fourth step in approaching the problem is data analysis. As the inquiry is undertaken, each item if new information gained about the problem is analyzed against the hypotheses that were generated for its ability to verify or deny any of them or possibly cause new ones to be generated.

The fifth step in approaching the problem is problem syntheses. As the inquiry and analysis proceeds, all new information that is felt to be significant, in the light of the hypothesis being considered, is recorded under facts. Occasionally a student may be asked to summarize the important data to make certain the group is working on the same mental representation of the problem. The summary develops student's ability to present data in an organized manner. After the summary is given the students should review the hypotheses in detail to see if in the light of the synthesis they need to be reorganized in different hierarchies, some eliminated, or new ones added.

The sixth step in approaching the problem is commitment as to the cause for the problem. The hypotheses generation, inquiry, analysis, and synthesis process continues until the student has gone as far as they can go on their present accumulated knowledge in analyzing the problem and possibly suggesting way to treat and manage it. At this point the individual student is asked to make a commitment as to what they; think might be responsible for the problem, even though they might not have as much information as they; would like at this point (this provides a strong motivation to self-directed learning to verify the correctness of their public commitment).

The seventh step in approaching the problem is identifying the learning issues to be studied. After the students have made their commitment as to the causes and possible problem the students review these learning issues and their relevance to the objectives. They then each choose individual learning issues that they will take responsibility for researching. Students should take learning issues in areas that they are unfamiliar with, or have little background in, and to avoid areas in which they do possess experience and knowledge.

The eighth step in approaching the problem is identifying the learning resource to be used. Each student is asked to identify the learning resources they plan to use. Students should use primary resources of information and to use experts in the faculty in consultation (resource faculty). Each student is asked to bring resources they found useful, notes they made, and to copy diagrams or illustrations that could be helpful resources for the group.

The ninth step in approaching the problem is self-directed learning. This is the period when students' access knowledge and skills they have decided they must have, using whatever resources are available. Students are encouraged to range widely and select carefully. The goal is to give free reign to need to know, capitalizing on the energy and direction that the problem generates.

After self-directed learning the next step is resource critique. Each student is asked to describe the learning resources they actually ended up using in their self-study, not what they learned, but what they used to get the needed information. The students are asked to critique these resources in terms of accuracy and value on the information found.

The second step after self-directed learning is reassessment of the problem: application of the new knowledge to the problem and the critique of prior thinking and knowledge. At this point the students are considered experts and should start with the problem over again to critique their prior thinking and knowledge used in the first session. They are asked to consider in the light of their new learning, with their hypotheses should have been what questions should have been asked, and how the problem should have been analyzed and understood.

The third step after self-directed learning is summary and integration of what has been learned. Once the students feel they have finished their work with the problem and their learning related to the problem, they are asked to describe what they have learned in words, discussions, diagrams, and definitions. They compare this problem with similar problems in the past and how their learning with this problem should prepare them for similar problems in the future.

The fourth step after self-directed learning is evaluation. Each student is asked to evaluate his or her own performance in three areas: problem solving, self-directed learning, and support of the group with its tasks. The group is then asked to comment on that self-evaluation adding constructive comments from their own perception of the student's performance. Self-evaluation is an essential component of effective self-directed education. (Barrows, 1997)

**Problem development**

Developing the problem is the most critical step in the entire problem-based teaching process. When selecting or developing a problem the following criteria should be carefully considered. First, it should be authentic. Is it significant from both the students' perspective and from that of the real world? Is it engaging? Does the problem approximate how it would actually be encountered in the real world? Is it contemporary? Is the final assessment to be done by a person or people who would normally make those decisions in the real world?

Second, the problem should be interdisciplinary. How well does the problem address the defined knowledge and skill areas for which it was designed? Is the knowledge base to be probed multidisciplinary? Do a number of hypotheses immediately spring to mind as soon as the problem is posed? While there may be one best solution, the problem should allow for logical entertainment of several solutions which, at the outset, sound reasonable.

Third, and related to the first criteria, is that the problem should be ill structured and complex. Real world problems never present themselves as simple, well-defined efforts which lend themselves to easy solutions. Is the problem presented to the student with information that one would initially have encountered in the real world. Are all the inquiry sources needed available to them?

**Examples of PBL problems in technology education**

Problems for a problem-based learning unit can come from any source or location. Some of the best sources are activities and events in which the students are interested or involved. The more emotional involvement the students develop in the problem setting, the more effective the problem will be. Following are examples of PBL problems in the clusters of Communication, Manufacturing, Transportation and construction. In all cases, the problem should be carefully developed, and encountered by the student in a manner in which the problem would be encountered in real life. After the students have worked through the problem the final assessment should be also be realistic.

Communication

Ask the students to assume the responsibility of a multi media publicity campaign for an upcoming campus event which is important to them, such as a sporting event, dramatic production, or concert. Have the problem presented to the students by a media professional from an advertising agency, television station print media, or other outlet. Different student groups will produce different media, but must collaborate to present a consistent message with proper timing. Final efforts will be assessed by the professional who first presented the problem. Results can also be evaluated.

Manufacturing

Students form a corporation to produce a product to fill an identified need to be marked through the school store or other school outlet. If more than one school is involved, it will be more realistic. It is important to have school administration involved at this point. The product solution should be presented and marketed to the school administration and sales outlets at the prototype stage. Business management of the corporation is by the students, but must operate ethically and within school policy. Students should be elected by their peers to assume the different jobs within the corporation after interviews and presentations by the students applying.

Students should first encounter the problem as a need to be filled and an opportunity. The corporation then becomes a way of enabling and managing the opportunity. Team meetings of the various functions should be frequent, and concepts such as "just in time" are important to the overall learning experience. Complexity is controlled through time limits caused by the school calendar. Production must be finished and the corporation dissolved by the end of a set term. Final assessment should be done after the final audit, and by a knowledgeable business professional or manufacturer.

Transportation

Students develop an emergency management plan for the school. The plan should provide for all necessary services for the school as well as evacuation and access of emergency services at the same time. Different continuances should be provided for in the plan.

The students should first encounter the plan through the charge of a school or community official. Final assessment should be done by an appropriate official, probably the one originally making the charge.

Construction

Students plan and design a local or regional "rails-to-trails" section. The plan should be complete and include drawings and cost estimates. The problem is best encountered through the presentation by a recreation or park official. A similar exercise is to plan and design a local recreational area. Final assessment should include review by a civil engineer.

**The teachers' role**

The teachers' role is always to guide students through the problem-based learning process. Curriculum planning is done while planning the problem. After the student encounters the problem, it belongs to the student. The teacher becomes a tutor who helps the students establish objectives, establish structure while encountering the problem and reason through the problem. When reasoning through the problem, students should be guided through developing hypotheses, gaining information, determining learning issues and developing action plans. The teacher should always communicate at the metacognitive level. Do not provide information. Do not evaluate responses. Probe knowledge and reasoning. Always challenge terms, opinions and facts; always ask "why".

When monitoring or managing the problem-based dynamics, five simple rules for a tutor will serve you well. First, involve all students in the process. Work hard to keep all students involved. If a student is sitting quietly and not responding, say things like: "What do you think, Mary?"

Second, avoid overwhelming students. If you frustrate them, you can set up failure. Be aware of when a challenge is becoming too great.

Third, encourage group responsibility. Group and teamwork are objectives of problem-based learning. Do not hesitate to engage in team building exercises when necessary. Remember that the students own the problem; encourage them to take responsibility for all its parts.

Fourth, Make educational diagnoses. Use your knowledge of your students to determine pace and depth in the search for a solution to the problem. Decide when they should dig deeper, or struggle with an issue. Determine when an individual needs prodding, extra help, or group intervention.

Fifth and final rule: Model, support, then fade from the process. Remember, when in doubt, opt for student-centered action. Hold back and let the process work. Ask the students for problem synthesis. And always remember, always ask: "why"?

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