Problem-based learning pedagogies: Psychological processes and enhancement of intelligences

TAN, Oon-Seng
National Institute of Education, Nanyang Technological University, Singapore

Introduction: Some Reflections on "Problems"

Since ancient times whether it be Greek civilisation during the time of Aristotle (1926), Roman civilization during the time of Cicero (1942) or Chinese civilization in the period of the 100 schools (Loewe & Shaughnessy, 1999), there was recognition of some sort that good teaching and helping people to learn involves the employment of a spectrum of rhetoric and pictorial representation of scenarios. Art, music, role play, parables, real and fictitious stories and the use of problem scenarios were often employed.

Fast forward to today. We see problems as really problematic today. Some things are implicit when we talk about a problem: (1) we recognize that there is a problem, (2) we do not know how to resolve the problem, (3) we want to resolve it, and (4) we perceive that we are able to find a solution. Examples of the types of problem triggers and stimuli include the following (Tan, 2003): (i) failure to perform, (ii) situations in need of immediate attention or improvement, (iii) finding better and new ways to do things, (iv) unexplained phenomena or observations (v) gaps in information and knowledge, (v) decision-making problems, (vi) need for new designs or inventions. The 21st century calls for the increasing ability to cope with change and to adapt. The problems confronting the world and individuals will come with increasing rapidity, complexity and diversity. Corollaries include (i) problems of increasing quantity and difficulty, (ii) newer problems and shorter time frame for solutions, (iii) more global (larger-scale) problems requiring integrated solutions.

The development of computer technology is a good illustration of the pace and complexity of change and its impact. Some 50 years ago Bell laboratory announced the invention of the "transistor". At that time the transistor was a great invention to physicists and engineers as it solved two major problems. Firstly, it replaces the problematic and inefficient triode tube that used lots of power and produced too much heat just for the process of amplifying an electrical signal. Secondly, the operation of the transistor allows for the mechanical switching and relay systems with its wear and tear to be done away with. It was not unusual even up till the mid 1960s for people in Singapore to use vacuum tube radio sets. The transistor radio was some kind of luxury then. Even in the late 70s and early 80s textbooks in science and engineering were still devoted to chapters on how vacuum tubes and transistors work!

The greatest revolution probably came with the invention of chip technology. Jack Kilby and Robert Noyce independently invented the IC (integrated circuit) chip in 1959. Jack Kilby who has over 60 patented inventions is well known as the inventor of the portable calculator. Robert Noyce, with sixteen patents to his name, founded Intel, the company that invented the microprocessor in 1968. The 4004 microprocessor launched in 1971 paved the way for embedding intelligence in an inanimate object for the first time. The power of the microprocessor became even more evident with its evolution into the Intel Pentium which could effectively process data in the form of video, audio and graphics. Today the Intel Centrino mobile technology has tremendous computing power coupled with built-in wireless capability and mobile performance. The size of the original IC (which comprised only one transistor, three resistors and one capacitor) was the size of a human finger. Today each transistor is less than 15 nanometers long (15 billionths of a meter). This means we need about 1000 of these side by side to match just the width of a human hair. A typical PC today uses over 250 million transistors. Technology with new mindsets will inevitably bring changes in the way we deal with information and learning.

Apart from rapid changes in technology and a new knowledge-based economy we have more complex problems today. The uncertainty of a flu pandemic, unprecedented scale of environmental disasters, terrorism and complex political and social-economic problems all point to the need for education to prepare our students for a rapidly changing and sophisticated world. The ability to learn when plunged into an unfamiliar situation and to adapt positively to rapidly changing demands is a reality for every worker today. Our students not only need to learn to confront problems as a matter of necessity but they also need to develop a positive mindset of observation and taking on “problems” as a matter of inquisitiveness to improve and invent processes and products. Problem-solving acumen is developed through experience, immersion and intelligent observation to see possibilities and opportunities. Problem solving in real-world contexts involves multiple perspectives and multiple ways of knowing and multi-disciplinary learning (Tan, 2003). Knowledge in this new economy is increasingly characterized by the creative integration of information and learning from diverse disciplines. In recent years psychologists, sociologists, anthropologists, scientists, entrepreneurs and researchers from various fields have shed considerable light on the nature of creativity, innovation and enterprise. Education needs to address the challenge of preparing the young to function in changing and new environments. It is often too easy to get locked into paradigms and perspectives. I think one of the most important things today is the ability to gain different perspectives, develop multi-viewpoints, be aware of different worldviews and paradigms and different ways of reasoning and thinking so that we can be highly flexible in our thinking in new environments.

Learning, Thinking and Problems

Education is about equipping people with the cognitive and socio-emotional skills to be highly adaptable in fast-changing environments. In science and technology it is now well recognized that multi-disciplinary pursuits are essential for the advancement of knowledge and application. Examples can be seen in areas such as biotechnology, telecommunications, material science, nanotechnology, and supercomputers. In industries and businesses, innovative advances are made often without the benefit of traditional paradigms of learning. The real world thrives on both evolutionary and revolutionary innovations.What is often lacking in education today is the effective use of inquiry and problem-based learning approaches. We also need to draw from the best of theories of the psychology of learning and to apply them to education today. All theories are man-made models and iterations of research-theory-application simply hope to approximate reality as much as possible. Hence we need to benefit from traditions of behaviourism, social learning, humanistic as well as cognitive psychology and understand the multiple-perspective of learning rather than look for a one-size-fits-all model. Our understanding of human learning has in many ways undergone dramatic changes as a result of the past four decades of research into the multiple disciplines such as psychology, neuroscience, cognitive science and education (Bransford and his colleagues, 1999). Research on memory and knowledge, for example, points to the importance of memory not only as associations but more importantly as connections and meaningful coherent structures suggesting that learning is not just about being systematic and breaking things into small parts but also seeing the big picture. That the whole is more than the sum of its parts is not new but learning to get an overview first and learning to get into important details more selectively as and when we need was not the common approach in the curriculum. We now know more about “novice” learners and “expert” learners. We can develop better learning in individuals by providing opportunities for acquisition of procedures and skills through dealing with information in a problem space and learning of general strategies of problem solving. We need to talk aloud thinking processes and strategies and not just content and factual knowledge. Instead of traditional schooling, we may need to look at new ways of engaging the individual, taking into account “plasticity of development” as well as cultural, community and social environmental contexts. Apart from emphasizing behaviours and performance there is a need to realize that individuals can be taught metacognitive processes and self-regulatory thinking. The traditional systematic and linear approach in instructional design may have outlived its usefulness in many instances given our new understanding of human learning and the technological, philosophical and psychological configurations in today’s cyberworld.

Many educators struggle with issues of not wanting to throw out what is working for them. Essentially we need to understand that there are two important axes of the human mind - the axis of “habit” and the axis of “novelty”. The axis of habit is about learning through structured routines, memory and modelling. The brain and mind are wired in such a way that we learn well through pattern recognition, observation and imitation. The mind, however, can also be highly stimulated through novelty – dealing with situations of newness. In this axis the mind seeks for change and new environments and scenarios of challenges. This often calls for a different way of thinking and perspective which would require a more holistic and integrative approach. Many education and training systems tend to emphasize learning by habit and imitation. This sort of instructional approach which is primarily linear and systematic with stimulus-response feedback loop is prevalent not only in schools but also in the design of current e-learning. This is not surprising as we do need to learn through imitation, modelling and memory. Learning by memorization begins in preschool and continues all the way to college education with a prevalence of information accumulation and knowledge recall. The predominance of paper-and-pencil testing and examinations has also contributed to this mode of learning. In many ways the kinds of so-called “problems” that students solve in many of our classes are actually exercises rather than problems. Teachers typically present in class a large number of examples accompanied by comprehensive guidelines and step-by-step solutions. Students are then given similar exercises of a variety of challenges. Often there is very little element of novelty, although these “problems” may call for synthesis and application of the knowledge learnt.

I must reiterate that there is nothing wrong with such an approach as we need such a structured and organized approach for acquiring fundamental knowledge and foundations. These are important in establishing basic axioms, definitions and principles, particularly in disciplines like mathematics, language or basic sciences. There is, however, an overdependence on learning through worked examples and routine exercises. As a result, there is very limited use of the power of problems. For simplicity, we may classify the types of problems along a continuum of routine-artificial at one end and novel real-world at the other end. Routine–artificial problems are your homework exercises and examination-type questions.

According to Shulman (1991): "Education is a process of helping people develop capacities to learn how to connect their troubles with useful puzzles to form problems. Educators fail most miserably when they fail to see that the only justification for learning to do puzzles is when they relate to troubles." What Weldon, Bruner and Shulman alluded to as troubles are what we refer to as real-world problems. Problem-based learning (PBL) is about learning to solve problems in novel real-world contexts.

Pedagogy, Intelligences and Use of Problems

Once upon a time, good pedagogy was about making content knowledge "visible" to students. Behavioristic psychology, as the science of learning, provided the basis for effective teaching and learning in the first half of the last century. The behavioristic establishment led by Skinner continued its influence and contributions through the 1960s and 1970s (Skinner, 1953, 1987, 1989a, b). Making content knowledge visible to the learner was probably underpinned by behavioral science where specific behavioral objectives followed by the management and reinforcement of learning led to the attainment of the desired knowledge and skills. Teaching involved providing clear explanations to students in disseminating knowledge and solving problems. In the industrial age, this sufficed for the classroom.

In the 1960s, recognition of Piaget's work gained momentum (although Piaget began his work in the 1920s). Piaget addressed the internal world of the individual in relation to intelligence and questions pertaining to the structure of the mind (Piaget, 1956, 1959; Piaget & Inhelder, 1969). His work was based on three interrelated conceptions: (1) the relation between action and thought, (2) the construction of the cognitive structure, and (3) the role of self-regulation. According to Piaget, logical thinking and reasoning about complex situations represents the highest form of cognitive development.

Sternberg (1990) noted that Piaget dealt primarily with the relationship of intelligence to the internal world of the individual and that Piaget believed intelligence essentially matures from the inside and directs itself outward. In the 1970s, cognitive psychology gained new ground as interest in "mentalism" grew (Bourne, Dominowski, & Loftus, 1979). Vygotsky (1978), in contrast to Piaget, believed that intelligence begins in the social environment and directs itself inward and that all psychological processes are in genesis essentially social processes, initially shared among people. Vygotsky (1978, 1962) posited that higher mental processes are functions of mediated activity. He contributed significantly to the understanding of intelligence in the theory of internalization, the theory of the convergence of speech and practical activity, and the zone of proximal development (Vygotsky, 1978). In the classroom, an expert teacher may model many approaches of a problem-solving process for the students. The students will need to internalize these processes as their own problem-solving activities if they are to develop effective self-regulation and metacognitive abilities. The cognitive revolution rooted in major works such as those of Piaget and Vygotsky provided much impetus for the psychology of thinking. Although the general goal of thoughtfulness as a hallmark of liberal education has often been articulated, the 1980s saw emphasis on the "teaching of thinking" as a relatively new concept (Resnick, 1987; Costa & Lowery, 1989). Staff development in teaching thinking was stressed, and making teachers' thinking visible was in many ways the next wave of good pedagogy. Hence, toward the last decade of the 20th century, effective teaching was characterized by modeling the process of learning so that students could observe and learn process skills, problem-solving skills, and thinking skills while acquiring content knowledge.

Feuerstein contributed to our further understanding of cognition and mediation. Feuerstein began his work in the 1950s, but his contributions gained recognition only in the 1990s. He had an interesting way of thinking beyond the traditions of his time. Instead of being concerned about what students failed to learn, he turned his focus to what they could learn. When assessment was static and summative, he made it dynamic and truly formative (i.e., developmental). When others were modifying teaching materials for children with learning disabilities, he chose to invest his energies in modifying these learners directly. When behaviorists were looking at stimuli and output behaviors, Feuerstein chose to focus on not only the organism but also the inner structure of cognition. While intervention programs were often concerned with content, he was more concerned with cognitive processes pertaining to learning to learn and thinking about thinking. While psychoanalysts were concerned with emotions and antecedents, he preferred to search for a more proximal and optimistic determinant of cognitive development. Helping learners discover their learning potentials and gain awareness of their thinking and thinking about thinking calls for an important factor: the presence of a competent mediator. Building on the insights of cognitive psychologists Piaget and Rey from the Genevan school, Feuerstein developed a theory of mediated learning experience, which provides the psychological basis for pedagogy that helps make students' thinking visible (Tan, 2006a). The use of challenging learning environments, as in problem-based learning activities, encourages questioning and overcomes the fear of making mistakes. Borkowski, Chan, and Muthukrishna (2000) argued that students should be given opportunities to take initiative in solving tasks, independently and collaboratively. Pintrich (2000) described self-regulated learning as a process by which students engage in different strategies to regulate their cognition, motivation, and behavior, as well as the context. Problem-based learning processes call for strategies that are goal-directed and self-directed, although they are influenced by the context of the problem. Facilitating the acquisition of self-regulated learning strategies is an important aspect of metacognition.

In the 21st century, the knowledge-based economy—fueled by information explosion and accessibility, rapid proliferation of technology, globalization, and demands for new competencies—calls for a different paradigm in pedagogy. Educators have to unlearn the old ways and confront new ways of looking at knowledge and at participation in the learning process. Pedagogy in the 21st century has to go beyond making content and teachers' thinking visible; good pedagogy today is about making students' thinking visible. The challenge of education is to design learning environments and processes where students' ways of thinking and knowing are manifested in active, collaborative, self-regulated, and self-directed learning. The role of the teacher is to enable students to recognize the state, repertoire, and depth of various dimensions of their thinking and to sharpen their abilities to deal with real-world problems. The "visibility" of students' cognition is a prerequisite for effective mediation and facilitation.

The progressive challenges of pedagogy can be summed up as follows:

- Making content knowledge visible to learners
- Making teachers' thinking visible to learners

- Making learners' thinking visible to themselves, their peers, and the teacher

Side-Track: An Observation about Educational Research

Educational research should in many ways be problem-based, not just laboratory-based or school-based. In the western world it can be said that educational research had its genesis in the attempts to apply general psychology to education. Examples of pioneers in the 19th century include William James, his student Stanley Hall, and Hall's student, John Dewey. It is interesting to note that as early as 1892 when William James delivered his talks to teachers on psychology, he held the view that laboratory studies of psychology were not too useful for teachers as they did not treat the individual holistically in real contexts. If William James were alive today, he probably would be in the same school of thinking as Howard Gardner and Robert Sternberg, supporting the use of real-world cases in learning, project work processes and use of portfolio assessments.

When it came to the generation of Stanley Hall (1844-1924) who contributed significantly to the understanding of child psychology, classroom research was de-emphasized in favour of laboratory research. Hall founded a research laboratory at John Hopkins that promoted a scientific study to education. The narrow approach of laboratory study contradicted in many ways James'holistic approaches. Fortunately, Hall had a student named John Dewey who became one of greatest philosophers and psychologists of education. Dewey was a high school teacher before he went on to obtain his doctorate from John Hopkins. He then joined the University of Chicago (a new university then). Dewey, unlike Hall, saw the school as a laboratory. Dewey was against the imparting of mere knowledge, believing that such information was would soon be outdated. He was against rote learning and drill and practice approaches. He was for what we would call today the development of thinking and problem solving skills and against the attainment of decontextualized knowledge. He felt that the individual's intemal mental processes must be understood (Dewey, 1910). Dewey saw the central place of problem-based learning approaches and the importance of the design of the learning environment for more holistic education. He also recognized the uniqueness of the teacher's role as a fellow human being in a community of learners. In fact, he pointed out the danger of not involving the teacher in research on educational psychology. He saw laboratory psychology as limited and all psychological findings as tentative, as working hypotheses for teachers to test.

Educational psychology as a major discipline in the university, however, probably gained the greatest momentum through Edward Lee Thorndike (1874-1947). After graduating from Wesleyan, Thorndike went to Harvard for two years (1895-1897), where he came under the influence of William James. Thorndike then moved to Columbia University where he studied under James McKeen Cattell. Thorndike became a professor of pedagogy and director of the practice school at Western Reserve University and produced the first book on *Educational Psychology* in 1903. David Berliner (1993) observed that Thorndike was a product of his time when people had an unbounded faith in what science could accomplish. He described educational psychology as the application of the science of psychology to the art of education. He saw the study of psychology and research as useful to education in three ways: (i) providing the underpinnings for beliefs about instruction, (ii) prohibiting teachers from making certain egregious errors, and (iii) providing intellectual support to teachers for some of their pedagogical decisions. Unfortunately, for Thorndike there was again a lack of connection to school practices

This resulted in an arrogance and close-mindedness on the part of educational researchers; and a lack of awareness of the multi challenges faced by the teacher as well as the power of social and political influences on the school. The good news for education research is that in more recent decades researchers like Lee J. Cronbach have acknowledged the importance of understanding individuals in their context and the need for educational researchers to show real interest in education and appreciate the challenges of educational practitioners such as instructional, political and social problems in the school context.

Today, educational research employs cognitive, naturalistic and contextual studies; instructional psychology and learning science; the psychology of cognition and development from perspectives of the intelligence such as those of Jean Piaget; the psychology of school subjects such as the conceptions advanced by Lee Shulman; cognition and social mediation as advanced by Vygotsky and Feuerstein and many more.

The work of educators rather than the discipline of researchers should become the basis of our inquiry. Educational psychologists need to be engaged with the school today in practical ways (Lee, Ee & Tan, 2006). Practitioners also need to be helped to employ the science and art of our field. In my book *Educational Psychology: A Practitioner–Researcher Approach* (an Asian Edition) which I co-authored with Professors Richard Parsons, Stephanie Hinson and Deborah Sardo-Brown we argued that the teacher today should be a practitioner-researcher whom we described as one who makes decisions based on “knowledge, experience and constructive reflection” (p.18). In fact we strongly advocate the idea of the *reflective teacher* and *action researcher.* Every chapter begins with a real-word problem in the classroom and we encourage a problem-based approach to learning about educational psychology.

Problem-based Learning

Problem-based learning (PBL) focuses on the challenge of making students’ thinking visible. The PBL process embraces the use of metacognition and self-regulation. PBL is recognized as a progressive active-learning and learner-centered approach where unstructured problems (real-world or simulated complex problems) are used as the starting point and anchor for the learning process.

PBL is not just about problem-solving processes; it is a pedagogy based on constructivism in which realistic problems are used in conjunction with the design of a learning environment where inquiry activities, self-directed learning, information mining, dialogue, and collaborative problem-solving are incorporated (Tan, 2004a). In recent years, PBL has gained new momentum as a result of several developments such as (i) increasing demand for bridging the gap between theory and practice, (ii) information accessibility and knowledge explosion, (iii) new possibilities in the use of multidisciplinary problems, (iv) emphasis on real-world competencies, and (v) developments in learning, psychology, and pedagogy (Tan, 2005a).

PBL approaches in a curriculum usually include the following characteristics (Tan, 2003, 2005):

(i) Use of a *real-world* problem as the *starting point* of learning.The problem calls for *multiple perspectives*.

(ii) The problem challenges students’ current knowledge, attitudes and competencies, thus calling

for identification of learning needs and *new areas of learning*.
(iii) *Self-directed learning* is primary. Thus, students assume major responsibility for the acquisition of information and knowledge.*Harnessing of a variety of knowledge sources* and the use and evaluation of information resources are essential PBL processes.
(iv) Learning is *collaborative, communicative and cooperative*. Students work in small groups with a high level of interaction for peer learning, peer teaching and group presentations.
(v) Development of *inquiry and problem-solving skills* is as important as content knowledge acquisition for the solution of the problem. The PBL tutor thus facilitates and coaches through questioning and cognitive coaching.
(vi) Closure in the PBL process includes *synthesis and integration* of learning. PBL also concludes with an *evaluation and review* of the learner's experience and the learning processes.

PBL typically involves four clusters of stages, namely, (i) The Problem (meeting the problem, problem enquiry, identification and definition), (ii) Learning Goals (activation of prior knowledge, generation of issues and learning objectives), (iii) Discovery, Analysis and Solution Development (information and fact-finding, research and problem-solving processes), (iv) Solution and Evaluation (production, synthesis, presentation, reflection, further iteration and review).

Figure 1 illustrates the key components in PBL approaches.

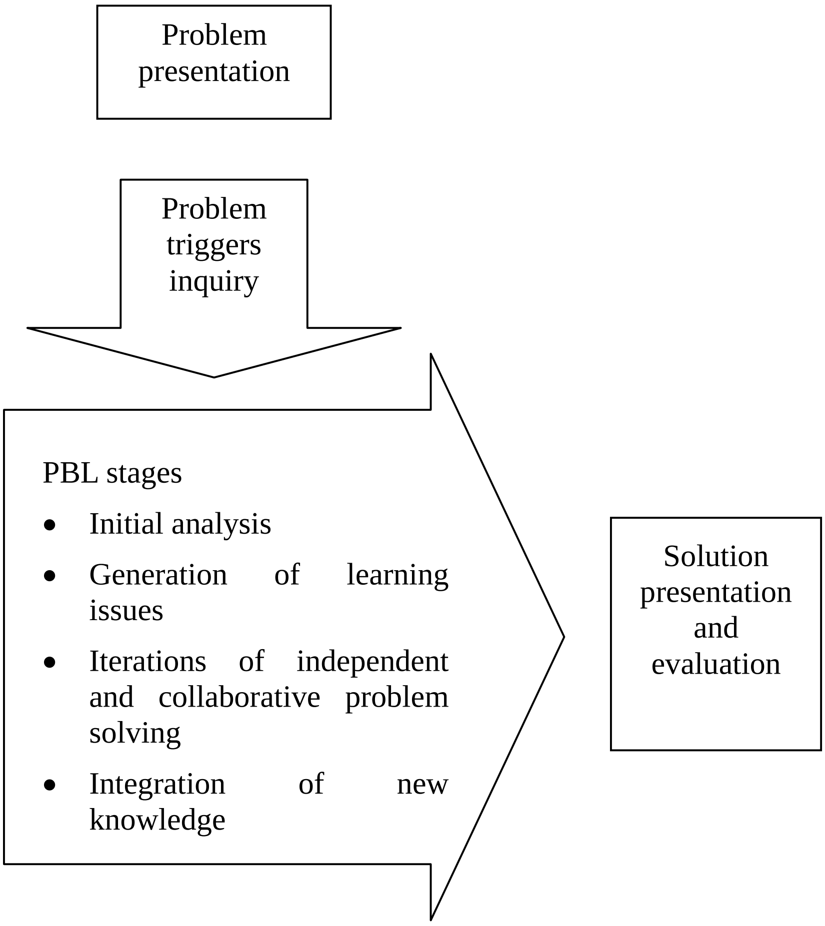

Figure 1: *Components of the PBL approach*
Source: Tan, O.S. (2003, p. 32) Problem-based Learning Innovation: Using problems to power learning in the 21st century. Singapore: Thomson Learning

Problem-based learning architecture typically involves a shift in three loci of educational preoccupation, namely, (i) content coverage to problem engagement, (ii) role of lecturing to role of coaching, (iii) student as passive learners to that of active problem-solvers. (Whilst PBL is a promising approach to educational innovation, implementation deficiencies often occur in problem design, facilitation processes and student readiness and preparation.) PBL curricula also emphasizes the acquisition of process skills, development problem-solving skills, reflective and evaluative thinking (Tan & Ee, 2004; Tan, Tham & Hoe, 2005). The hallmark of learning in all of these is the use of inquiry. There is, however, much development needed in this area of cognition in PBL.

Jerome Bruner, at one time Director of the Harvard Center for Cognitive Studies, wrote a famous classic entitled *The Process of Education*. In it Bruner (1960) argued that the knowledgeable person is a problem solver, one who interacts with the environment in testing hypotheses, developing generalizations and engaging in learning to arrive at solutions. According to Bruner, the goal of education is to further the development of problem-solving skills and the process of inquiry and discussion.

In many PBL approaches, the student confronts a situation where he or she needs to accomplish an objective, and the means (i.e. the information, process and actions to be taken) is something new or unknown to the student. In many ways, the pedagogy of PBL helps to make "visible" or explicit the thinking and the richness of the cognitive structuring and processes involved.

Figure 2 illustrates how PBL problems affect cognition and learning. A problem triggers the context for engagement, curiosity, inquiry and a quest to address real-world issues. What goes on in the mind of the learner (cognition) and the probable changes in behaviour (learning) include those listed in the right-hand box of the figure.

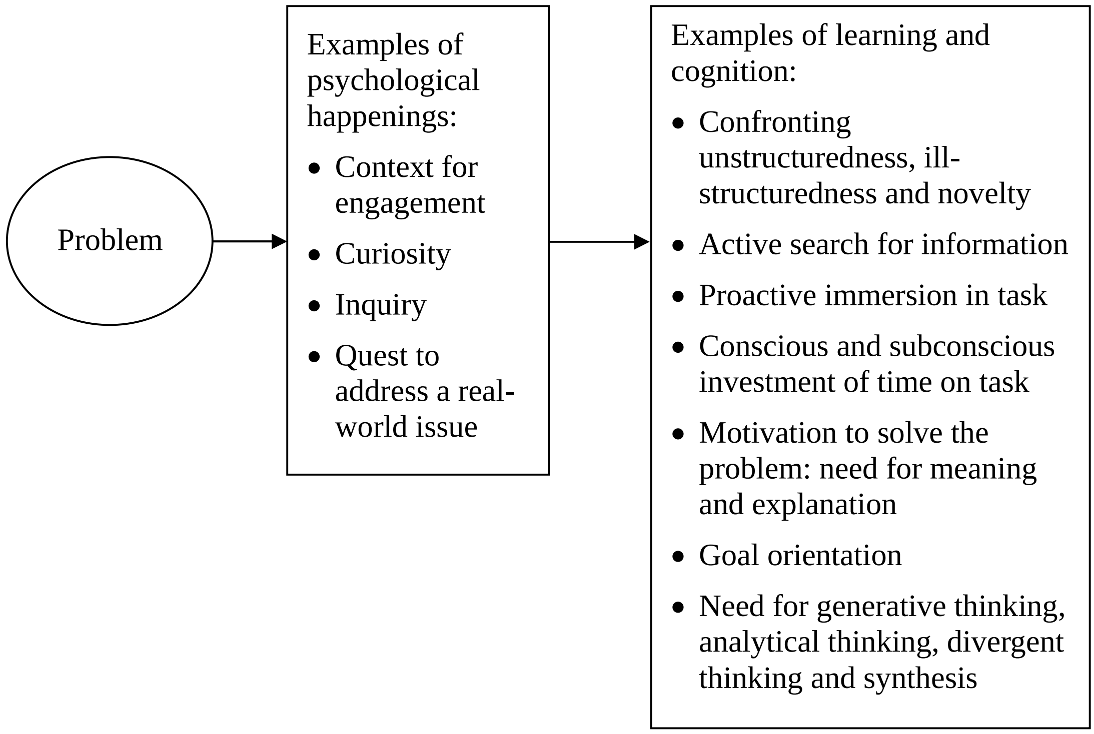

Figure 2: *PBL and cognition*

PBL and Possible Effectiveness in Education

The goals of PBL include content learning, acquisition of process skills and problem-solving skills, and lifewide learning. PBL in education is more about the ability to be flexibility in the use of knowledge base (Chung & Chow, 2004), building on prior knowledge and connecting meaningfully to real-life situations (Tan, 2003; Carder, Willingham & Bibb, 2001). Breton (1999) found that students were also able to relate theory to practice and developed greater ability to remember and re-use what they have learnt in the case of PBL in accounting education. In nursing education, for example, prior knowledge was utilized in relation to the problem and was seen as beneficial as students became more confident and were able to use the knowledge gained for practice (Darvil, 2003). It has been found that by reflecting upon prior learning, students are able to analyse and synthesise the contextual information, acquire further knowledge and assimilate it into their existing knowledge base (Nelson et al., 2004).

In their meta-analysis, Dochy Segers, Van den Bossche and Gijbels (2003) showed that PBL has a significant effect on the knowledge application skills of students. Tan (2003, 2004) explained that through PBL cycles students learn to connect information to prior knowledge, prior experience, theory, new facts and ideas, other people's perspectives and the real-world context. As such, this develops their capacity to apply knowledge gained to a variety of problem situations. Major and Palmer (2001) found that students trained in PBL were more likely to use versatile and meaningful approaches to studying, compared to non-PBL students.

The development of problem-solving skills and problem-solving acumen are important objectives in PBL. PBL develops problem solving skills by enabling students to transfer the problem solving strategies that were modelled for them in PBL to a similar problem on an related topic (Pedersen & Liu, 2002). Tan and Ee (2004) observed that cognition, metacognition and self-regulation characterize effective PBL. Chung and Chow (2004) found that PBL promotes ability to apply appropriate meta-cognitive and reasoning strategies. In PBL students learn to critically question and draw their own conclusions (Nelson et al., 2004). Bechtel, Davidhizar and Bradshaw (1999) found that PBL is helpful in developing proficiency in problem solving skills and overcoming the theory-practice gap. PBL also helps promote critical thinking (Weissibger, 2004; Cooke & Moyle (2002). I would also like to point out that PBL provides a learning environment where cognitive immersion happens. Traditional approaches and didactics are not able to provide for opportunities of learning where intuition and insights can occur.

Morrison (2204) argues that PBL creates an intrinsic interest and enhances self-directed learning skills. Students develop strategies for coping with challenges to their self-efficacy; they also reflect on their learning and information-seeking strategies (Hmelo-Silver, 2004). As Tan (2003) noted, PBL creates goal-direction; goal mediation is also an important PBL process (Tan. 2004c). Self-directed learners become proactive in achieving their goals, adapting their personal strategies according to the situational demands. According to Hmelo-Silver (2004) the more reflective learners become, the greater the likelihood that they are able to adapt their self-directed learning strategies. The strategies adopted interact with students' previous learning knowledge, self-regulated strategies, self-efficacy and the features of the learning environment. Students are able to transfer hypothesis-driven strategies from problem solving into their self- directed learning as they plan their learning using their hypotheses.

Lee and Tan (2004) highlighted the advantages of collaborative and communicative inquiry in PBL. Explaining one's ideas is important for productive collaboration and also serves to enhance learning (Chung & Chow, 2004). Evidences appear to support the usefulness of PBL in encouraging students to learn to work as a group (Sharp & Primrose, 2003; Barrow et al., 2002; Shelton & Smith, 1998). Through group dynamics students learn to deal with dysfunctional aspects of a group and address them in a constructive manner (Sharp & Primrose, 2003). To become effective collaborators, students as team members learn to establish a common ground, resolve discrepancies, negotiate group action and develop consensus. These tasks require learning to dialogue, and transparency and openness in the exchange of ideas.

Many studies have shown that students enjoy PBL and are positive of its practical application (Sharp & Primrose, 2003; Price, 2000; Carey & Whittaker, 2002; Michel, Bischoff & Jakobs, 2002; Shelton & Smith, 1998). Baker (2000) found a decrease in learning-environment stress, increased student satisfaction and graduate satisfaction. In a number of studies, students had higher satisfaction using PBL, with no negative effect on academic grades (e.g. Nalesnik, Heaton, Olsen, Haffner & Zahn, 2003; Michel et al., 2002).

Conclusion

PBL is further supported by today's environment of Internet communications technologies. To solve a problem we often need to manage a large amount of information and data. Today we can capture a problem scenario richly and re-present it in multi-modal ways for retrieval across time and space. Good problem solving is about connectivity. The ability to connect data across domains, prior knowledge, contexts and perspectives is key to problem resolution and creative problem solving. Connectivity is what the e-world provides with great expedience in many situations. Connectivity can be enhanced if we can scaffold reasoning processes and skills and make them more "visible", like the ways things are cleverly displayed in a supermarket. Computers today enable us to take note of key information and at the same time store them as hypertexts of detailed information with easy accessibility in a variety of format such as texts, graphics, photo and video clips. One of the powerful ways to solve a problem is to replicate the situation in some ways for analysis and study – in short to simulate reality. In other words, technology today provides us with a different perspective to deal with real-world problems. In dealing with a complex problem where we have to manage large quantities of diverse data, human memory has its limitations. If learning systems can help with memory capacity, we can enhance reasoning capacities in problem solving. It is common knowledge that human cognitive capacity is limited in nature and remembering certainly has to take up the available working memory capacity if external representation in any form is not available. As such, when learning systems help capture problem representation, we have greater capacities for higher order thinking (Tan, 2006b).

Whilst PBL is a useful innovation, PBL approaches should be underpinned by sound educational and cognitive psychology. One major reason for the PBL confusion is a failure to understand the psychological basis of learning when infusing problem-based learning approaches into the curriculum. More consideration should be given and research done in these areas. We need more informed knowledge of the developments in learning, psychology and pedagogy to refine the practical models of PBL (Tan, 2005b).

PBL provides excellent opportunities for the psychologizing of education. In the last few decades the challenge of pedagogy has progressively changed from making content knowledge visible to learners (by enhancing clarity of explanations and elucidating difficult terrains of knowledge), to making teachers' thinking visible (through pedagogy that supports and models process skills, problem-solving skills, and thinking skills), and then to making students' thinking visible (through design of learning environments and processes that enable students' ways of thinking and knowing to be manifested in active, collaborative, and self-regulated learning).

Progress in cognitive science has given new support for the use of problems in learning. For example, seeing configurations (the whole is more than the sum of its parts), understanding perceptions, cognitive dissonance, problem solving, and insightful learning are important aspects of learning (Tan, 2004c). It can perhaps never be overemphasized that insightful, flexible, inventive, and breakthrough thinking develops best when people are immersed in solving a problem over an extended period of time. The pedagogy of PBL helps make visible or explicit the thinking as well as the richness of the cognitive structuring and processes involved.

References

Aristotle. (1926). The art of rhetoric (J.H. Freese, Trans.). The Loeb Classical Library, Cambridge, MA: Harvard University Press.

Bechtel, G. A., Davidhizar, R. & Bradshaw, M. J. (1999). Problem-based learning in a competency-based world. *Nurse Education Today, 19*, 182-187.

Berliner, D.C (1993). The 100-year journey of educational psychology: From Interest, to disdain, to respect for practice. In Fagan, T.K. & VandenBos, G.R. (Eds.). *Exploring Applied Psychology: Origins and critical analyses*. APA Books.

Berkson, L. (1993). PBL: Have the expectations been met? *Academic Medicine, 68,* 79–88.

Biley, F. (1999). Creating tension: undergraduate student nurses' responses to a problem-based learning curriculum. *Nurse Education Today, 19*, 586-591.

Blackford, J. & Street, A. (1999). Problem-based learning: an educational strategy to support nurses working in a multicultural community. *Nurse Education Today, 19*, 364-372.

Bourne, L.E. Jr, Dominowski, R.L., & Loftus, E.F. (1979). *Cognitive processes*. Englewood Cliffs, NJ: Prentice Hall.

Bransford, J., Brown, A. & Cocking, R. (1999) (Eds.). *How people learn: Bridging research and practice*. Washington, DC: National Academy Press.

Breton, G. (1999). Some empirical evidence on the superiority of the problem-based learning (PBL) method. *Accounting Education, 8(1),* 1-12.

Bruner, J. (1960). *The process of education*. Cambridge, MA: Harvard University Press.

Carder, L., Willingham, P. & Bibb, D. (2001). Case-based, problem-based learning information literacy for the real world. Research Strategy, 18, 181-190.

Carey, L. & Whittaker, K. A. (2002). Experiences of probleth-based learning: issues for community specialist practitioner students. Nurse Education Today, 22, 661-668.

Chen, A. Y., & Tan, O. S. (2002). Towards a blended design for e-learning. *Centre for Development of Teaching and Learning Brief, 5*, 6–8.

Chi, M. T. H., Siler, S. A., Jeong, H., Yamauchi, T., & Hausmann, R. (2001). Learning from human tutoring. *Cognitive Science*, *25*, 471–533.

Chin, C. A., & Brewer, W. F. (2001). Models of data: A theory of how people evaluate data. *Cognition and Instruction*, *19*, 323–51.

Chung, J.C.C. & Chow, S.M.K. (2004). Promoting student learning through a student-centered problem-based learning subject curriculum. Innovation in Education & Teaching International, 41(2), 157-1 68.

Cicero (1942) De Oratore, Books I-II (W. Shutton & H. Rackham, Trans.). The Rhetorical considerations.

Costa, A. L., & Lowery, L. F. (1989). *Techniques for teaching thinking*. Pacific Grove, CA: Midwest.

Cooke, M. & Moyle, K. (2002). Students' evaluation of problem-based learning. Nurse Education Today, 22, 330-339.

Darvill, A. (2003). Testing the water — problem-based learning and the cultural dimension. Nurse Education Today, 3, 72-79.

Dewey, J. (1910). *How We Think*. Lexington, MA: Health.

Dochy, F, Segers, M., Van den Bossche, P. & Gijbels, D. (2003). Effects of problem-based learning: a meta analysis. Learning and Instruction, 13, 533-568.

Evans, J. B. T., Venn, S., & Feeney, A. (2002). Implicit and explicit processes in a hypothesis testing task. *British Journal of Psychology*, *93*, 31–46.

Gijselaers, W. H. (1996). Connecting problem-based practices with educational theory. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bringing problem-based learning to higher education: Theory and practice* (pp. 13–21). New directions for teaching and learning, No. 68. San Francisco: Jossey-Bass.

Grabowski, B., Kim, Y., & Koszalka, T. (2004). Toward a model for web-enhanced problem-based learning. In Tan, O.S. (Ed.).*Enhancing thinking through problem-based learning approaches: International perspectives*, p.167-202. Singapore: Thomson Learning.

Green, C. J., van Gyn, G. H., Moehr, J. R., Lau, F. Y. & Coward, P. M. (2004). Introducing a technology-enabled problem-based learning approach into a health informatics curriculum. International Journal of Medical Inforniatics, 73, 173-179.

Hmelo-Silver, C.E. (2004). Problem-based learning: what and how do students learn? Education Psychology Review, 16(3), 235-266.

Lee, G. C. Moira and Tan, O.S. (2004). Collaboration, Dialogue, and Critical Openness through Problem-based Learning Processes. In Tan O.S. (Eds.). Enhancing Thinking through Problem-based Learning Approaches, p. 133-143. Singapore: Thompson Learning.

Lee, O.K., Ee, J., Tan, O.S. (2006). *Educational research with a calling: 20 years of ERAS*. Singapore: Educational Research Association of Singapore.

Liu, M. (2004). Examining the performance and attitudes of sixth graders during their use of a problem-based hypermedia learning environment. Computers in Human Behaviour, 20, 357-379.

Loewe, M. & Shaughnessy, E.L. (1999). The Cambridge History of Ancient China: From the origins of civilization to 221 BC. Cambridge University Press.

Major, C. H. & Palmer, B. (2001). Assessing the effectiveness of problem-based learning in higher educatioit lessons from the literature. Academic Exchange Quarterly, 5, 4-9.

Manktelow, K. I. (1999). *Reasoning and thinking*. Hove, East Sussex: Psychology Press.

Marincovich, M. (2000). Problems and promises in problem-based learning. In O. S. Tan, P. Little, S. Y. Hee, & J. Conway (Eds.), *Problem-based learning: Educational innovation across disciplines* (pp. 3–11). Singapore: Temasek Centre for Problem-Based Learning.

Michel, M. C., Bischoff, A. & Jakobs, K. H. (2002). Comparison of problem- and lecture-based pharmacology teaching. TRENDS in Pharmacology Sciences, 23(4), 168-170.

Mok, E., Lee, W. M. & Wong, F. K. (2002). The issue of death and dying: employing problem-based learning in nursing education. Nurse Education Today, 22, 319-329.

Morrison, J. (2004). Where now for problem based learning? The Lance 1, 363, 174.

National Research Council (1999). *How people learn: Bridging research and practice*. Washington, DC: National Academy Press.

Nalesnik, S. W., Heaton, J. 0., Olsen, C. H., Haffner, W. H. J. & Zahn, C. M. (2004).

Incorporating problem-based learning into an obstetrics/gynecology clerkship: impact on student satisfaction and grades. American Journal of Obstetrics and Gynecology, 290, 1375-81.

Nelson, L., Sadler, L. & Surtees, G. (2004). Bringing problem-based learning to life using virtual reality. Nurse Education Today, 3, 1-6.

Norman, G. R., & Schmidt, H. G. (2000). Effectiveness of problem-based learning curricula. *Medical Education*, *34*, 721–28.

Pedersen, S. & Liu, M. (2002). The transfer of problem-solving skills from a problem-based learning environment: the effect of modelling an expert's cognitive processes. Journal of Research on Technology in Education, 35(2), 303-320.

Perrenet, J.C., Bouhuijs, P.A.J., & Smits, J.G.M.M. (2000). The Suitability Of Problem-Based Learning For Engineering Education: Theory And Practice. *Teaching in Higher Education*, 5 (3), 345-358.

Price, B. (2000). Problem-based learning the distance learning way: a bridge too far?

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451–502). San Diego, CA: Academic Press.

Nurse Education Today, 20, 98-105.

Piaget, J. (1956). *The psychology of intelligence*. Totowa, NJ: Littlefield, Adams and Co.

Piaget, J. (1959). *The thought and language of the child*. London: Routledge and Kegan Paul.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child*. New York: Basic Books.

Raucent, B. (2001). Introducing problem-based learning in a machine design curriculum: result of an experiment. Journal of Engineering Design, 12(4), 293-308.

Resnick, L. B. (1987). *Education and learning to think*. Washington, DC: National Academy Press.

Segers, M., Van den Bossche, P. & Teunissen, E. (2003). Evaluating the effects of redesigning a problem-based learning environment. Studies in Educational Evaluation, 29, 315-334.

Sharp, D. M. M. & Primrose, C. S. (2003). The "virtual family": an evaluation of an innovative approach using problem-based learning to integrate curriculum themes in a nursing undergraduate programme. Nurse Education Today, 23, 219-225.

Shulman, L.S. (1991). Pedagogical ways of knowing. Keynote address delivered at the International Council on Education for Teaching (ICET) 1990 World Assembly, Singapore. Singapore: Institute of Education.

Skinner, B. F. (1953). *The science of human behavior*. New York: Macmillan.

Skinner, B. F. (1987). *Upon further reflection*. Englewood Cliffs, NJ: Prentice Hall.

Skinner, B. F. (1989a). *Recent issues in the analysis of behavior*. Columbus, OH: Merrill.

Skinner, B. F. (1989b). The origins of cognitive thought. *American Psychologist*, *44*, 13–18.

Sternberg, R. J. (1990). *Metaphors of mind: Conceptions of the nature of intelligence*. New York: Cambridge University Press.

Sternberg, R. J., & Davidson, J. E. (Eds.) (1995). *The nature of insight*. Cambridge, MA: MIT Press.

Tan, O. S. (2000a). Reflecting on innovating the academic architecture for the 21st century. *Educational Developments*, *1*, 8–11.

Tan, O.S. (2000b). Intelligence enhancement and cognitive coaching in problem-based learning. In C.M. Wang, K.P. Mohanan, D. Pan & Y.S. Chee (Eds), *TLHE Symposium Proceedings*. Singapore: National University of Singapore.

Tan, O. S. (2001). PBL innovation: An institution-wide implementation and students' experiences. In P. Little, O. S. Tan, P. Kandlbinder, A. Williams, K. Cleary, & J. Conway

(Eds.), *On problem based learning: Experience, empowerment and evidence*. Proceedings of the Third Asia Pacific Conference on Problem Based Learning (pp. 318–33). Newcastle: Australian Problem Based Learning Network.

Tan, O. S. (2002). Project management in educational development: A Singapore experience. In M. Yorke, P. Martin, & C. Baume (Eds.), *Managing educational development projects: Maximising impact* (pp. 153–70). London: Kogan Page.

Tan, O.S. (2003). *Problem-based learning innovation: Using problems to power learning in the 21st century.* Singapore: Thomson Learning.

Tan, O.S. (2004a). Editorial. Special issue: Challenges of problem-based learning. *Innovations in Education and Teaching International, 41 (2),* 123-124.

Tan, O.S. (2004b). Students' experiences in problem-based learning: Three blind mice episode or educational innovation. *Innovations in Education and Teaching International, 41 (2),* 169-184.

Tan, O.S. (2004c). Cognition, metacognition, and problem-based learning. In Tan, O.S. (Ed.).*Enhancing thinking through problem-based learning approaches: International perspectives*, p.1-16. Singapore: Thomson Learning.

Tan, O.S. (2005a). Problem-based learning approaches in management education, p. 289-308. In Wankel, C. and DeFillippi, R. (Eds.).*Educating managers through real world projects*, Greenwich, CT, Information Age Publishing.

Tan, O.S. (2005b). Problem-based learning: The future frontiers., p.17-32. In Tan, K., Lee, M., Mok, J. & Ravindran, R. (Eds.). Problem-based Learning: New directions and approaches. Singapore: Learning Academy, TCPBL.

Tan, O.S. (2006a). Development of a thinking programme for engineering students. *Innovations in Education and Teaching International, 43(3),* 245-259.

Tan, O.S. (Ed.).(2006b). *Problem-based learning in e-learning breakthroughs*. Singapore: Thomson Learning.

Tan, O.S. and Ee, J. (2004). Project work through problem-based learning approach. In Ho, B.T., Jo-Ann, N.S., and Chang, A.S.C. (Eds.). Managing project work in schools: Issues and innovative practices, p. 174-184. Singapore: Prentice-Hall.

Tan, O. S., Little, P., Hee, S. Y., & Conway, J. (Eds.) (2000). *Problem-based learning: Educational innovation across disciplines*. Singapore: Temasek Centre for Problem-Based Learning.

Tan, O. S., Parsons, R. D., Hinson, S. L., & Sardo-Brown, D. (2003). *Educational psychology: A practitioner–researcher approach (An Asian edition)*. Singapore: Thomson Learning.

Tan, O.S., Tham, Y.C. & Hoe W.M. (2005). Singapore's leading STAR (Special Talents and Achievement Recognition). The Specialist Schools and Academies Trust Journal of Innovation in Education, 3 (3), 13-17.

Vygotsky, L. S. (1962). *Thought and language* (E. Hanfmann & G. Vakar, Eds. & Trans.). Cambridge, MA: MIT Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds. & Trans.). Cambridge, MA:

Harvard University Press (original works published 1930–33).
Weissinger P.A. (2004). Collaboration, Dialogue, and Critical Openness through Problem-based Learning Processes. In Tan O.S. (Eds.). Critical Thinking, Metacognition, and Problem-based Learning, p. 39-61. Singapore: Thompson Learning.