Problem-based Learning applied to Team Environments: A Visual Literature Review

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Abstract: The purpose of the literature review is to document observations and research findings about the value of problem-based learning (PBL) experiences, especially for programs in Information Technology education. The focus reveals ways that facilitated PBL exercises benefit virtual teams who are collaborating, designing and producing an effective solution. This paper shares some relevant published evidence that active problem solving by learning teams contributes to critical thinking and effective team communications, which can be carried forward into professional roles in the work place. The curiosity and inspiration that inspired this conference paper was a research question "How does facilitated problem-based learning benefit a team of distributed learners when collaborating on designing and producing a practical solution?" This paper accompanies a visual literature review presentation to prepare for a live break out session to consider the complex problem of BYOD (bring-your-own-device) to a learning event.

What is the Agenda for Problem-Based Learning (PBL)?

A significance of a literature review and research design for Problem Based Learning (PBL) is leveraging learning accomplished in higher education with the talents needed in the workplace for technology professionals. Knowing how to think about problems and solve them is a key. According to Yeo, a "juxtaposition of complexity and systematization is realized in the dynamics subsumed within each distinct phase of problem solving" (Yeo, 2008, p. 324). As illustrated in Figure 1, Yeo's composite framework reflex the Kolb framework, marked with an X in the middle of overlapping domains of knowledge, to reveal that "strategy ultimately helps to create for the workplace an intrinsic source of competitive advantage" (Yeo, 2008, p. 322). The insight, which Yeo offers, is that, in the real-world, explicit knowledge is translated into a set of defined competencies and capabilities enabling individuals to approach multifaceted problems. The design of PBL lessons strengthens ways of thinking about problems in all four phases of a problem context.
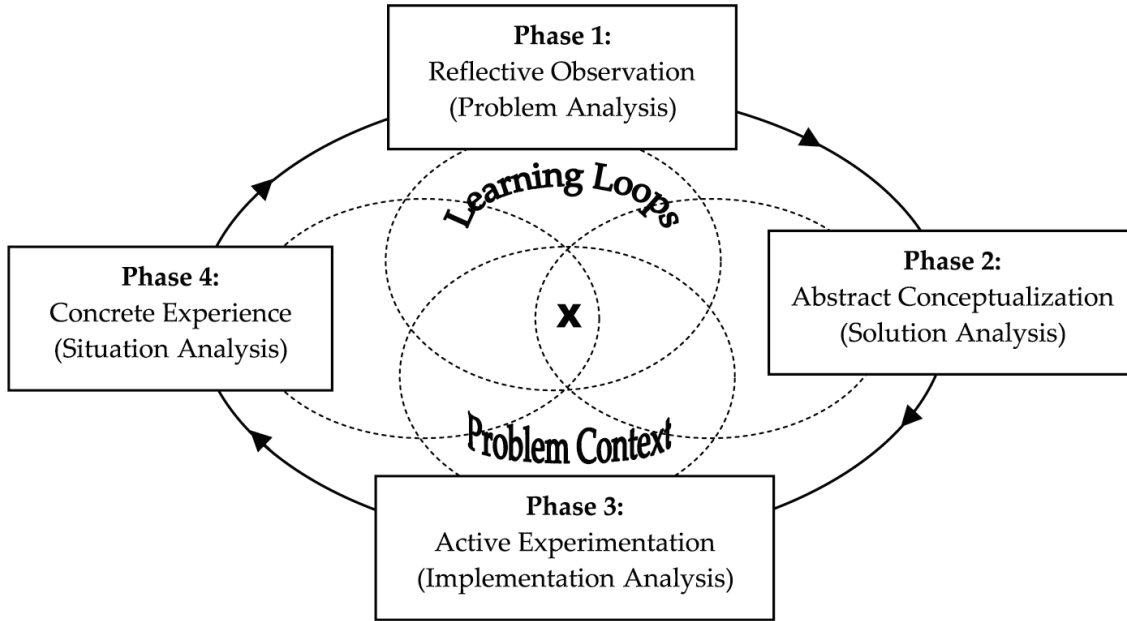
Figure 1. An integrated model of PBL in workplace contexts. Adapted by Yeo, 2008, p. 324 from Kolb, 1984, Cockerill et al., 1996.

A basic and simple overview of the PBL Process is illustrated in Figure 2, which starts with a buy-in decision that the PBL protocol will add value to a lesson agenda and ends with the problem being solved and documenting a lesson learned. A seen by the arrows, steps are looped until the results are satisfying. Reflection by students is a time of pause to decide to stay in the loop or to complete the exercise because enough is known, or the time has expired.
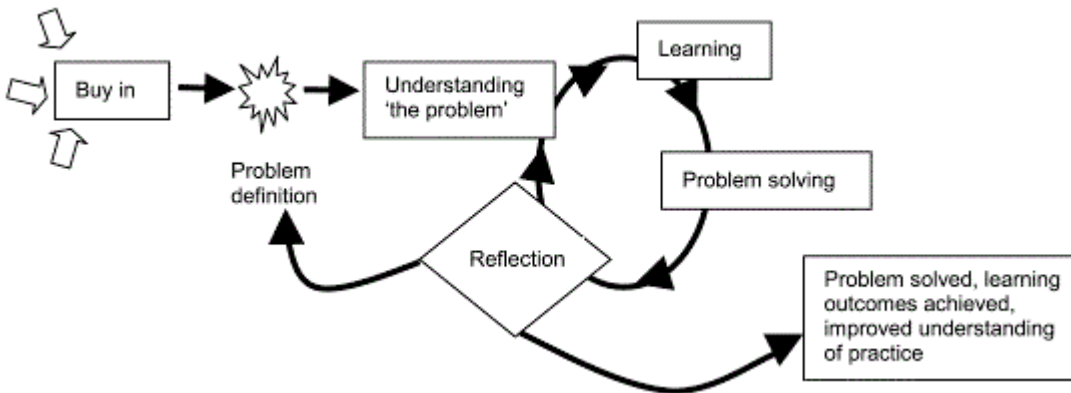

Figure 2. Basic problem-based learning overview (Stonyer & Marshall, 2002).

The nature of PBL lessons anticipate that a big picture will be relevant at predictable time frames while participants are gaining critical thinking skills. The Mediterranean Virtual University project, a collaborative venture, described a "pragmatic approach to design of online courses in computer science" which specifies learning objectives, yet, allows a broader framework for strategies based on activity based learning (Bygholm, 2009, pp.

13-14). The Aalborg project states that the core belief about a problem-based approach is that it is specifically designed for learners to achieve two specific goals: 1) to acquire a "deep understanding" of relevant content knowledge, and, 2) based on guided problem-solving exercises, to practice "higher order thinking skills" (Bygholm, 2009, pp.16-17). The concept model extending the Alborg model is shown in Figure 3. This TCC conference paper focuses on the right hand side of this quadrant, the experience of a guided problem exploration.
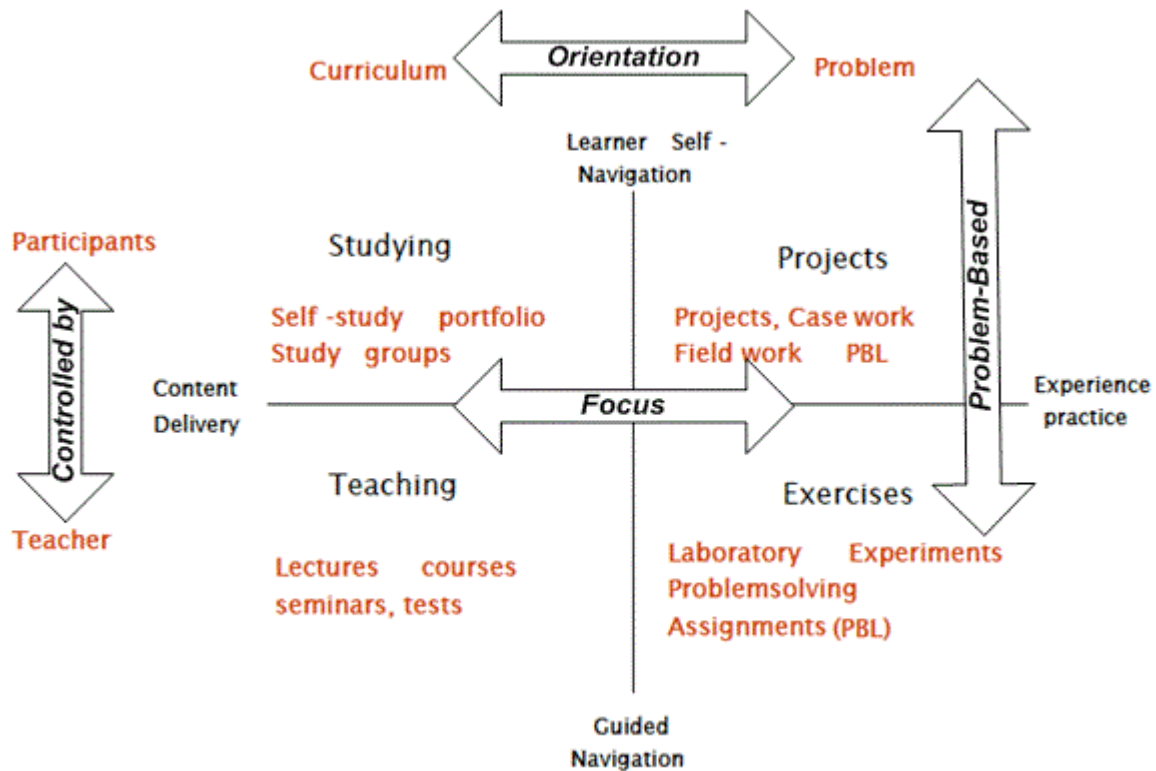

Figure 3. Extended multiple learning strategies. Adapted from Bygholm, 2009, p. 19.

An and Reigeluth (2008) offers guideline for designing and implementing PBL in an online environment which shares some practitioner's advice to other practitioners, for instance, "provide tailored and flexible structure" and "provide tailored instruction or cognitive scaffolding when appropriate" (p. 18). Likewise, McLaren (2008) emphasizes an imperative that specific learning outcomes are well understood and agreed upon by practitioners before project profiles are composed to be assigned to learning teams. Fee, et al. (2010) explores PBL within a context of constructivism applying PBL lessons at the level of curriculum, specifically for capstone projects. Han and Bhattacharya (2011) apply the principles of constructivism to a student centered environment with learning outcomes based on "authentic and real life experiences with multiple perspectives" (p. 1) and compare the features of projects that share attribution with PBL.

PBL Instructional Design and Facilitators' Influence

Measuring the extent of components mapped to real-world learning opportunities is the content of a course, or the added value brought to the experience by instructors. Brundiers, Wiek and Redman (2010) modeled competencies in sustainability: problem-solving skills, ability to collaborate with experts field of sustainability. ChanLin and Chan (2007) reported findings from a case study exploring a web-based course within an electronic forum to provide support for a self-directed PBL environment, Online interactions and written reflections, concluding that meta-cognitive support and affective support are both needed to facilitate the process of learning. In the ChanLin and Chan study, students interacted with peers, a teacher, a facilitator and experts in order to enhance knowledge and to complete a group project (2007) which contributed to the literature about self-directed, web-based learning in a PBL context. Chiriac (2008) reported on a case study that originated a framework to utilize Steiner's and Bion's taxonomies to test, describe, interpret and explain group dynamics, to "sustain a scope as time passes for interventions between and among case studies" (p. 511). Clark (2009) contributed a design to accelerate expertise with scenario-base learning, in which participants solved carefully constructed, authentic job tasks or problems and were guided to learn concepts, procedures, and heuristics of expert performers.

The PBL Protocol

Many scholars and practitioners have described and endorsed a sequential process for conducting a PBL investigation. The earliest literature illustrated the process with a simple structure with arrows connecting steps suggesting that there would be a loop back to repeat or refine assertions from earlier steps. A typical structure is shown as a generic PBL-Protocol, Figure 4, from one of the seminal authors, Schmidt (1993), who has been frequently cited and adapted for curriculum planning and course or seminar exercises. The starting place is when a tutor presents a complex and somewhat ill-structured problem scenario, then guides a team to explore a problem's complexities, and then refines a problem statement after seeking additional information. The verbs on Schmidt's process model remind us of the keywords of the Bloom's taxonomy. A PBL lesson often ends with the team reflecting on the learning gained by working through the process.
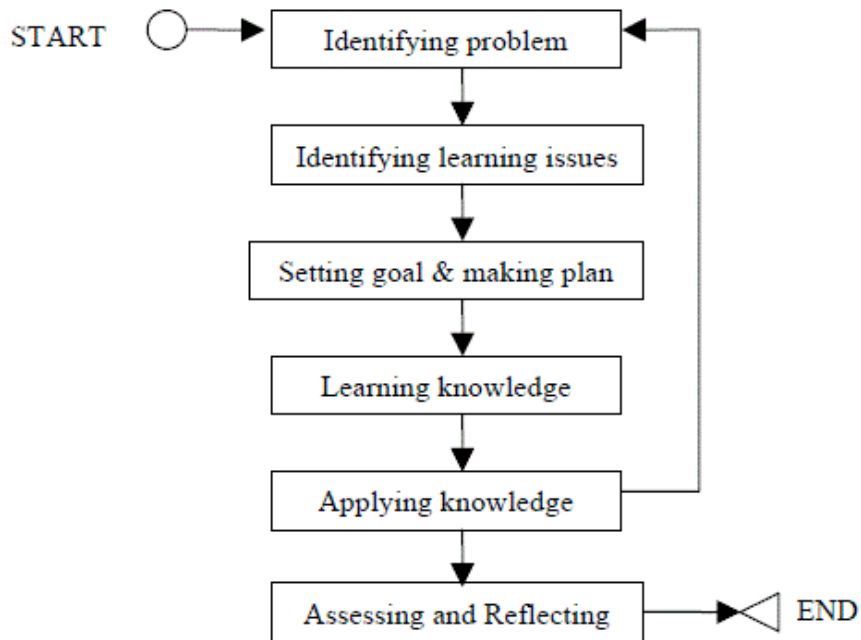
Figure 4. Generic PBL-protocol processes (Schmidt, 1993, p. 233).

Schmidt's early generic PBL-protocol serves as a baseline from which many scholars and teachers have expanded upon educational practices to start with a problem before applying past and new knowledge and focusing research to solve the problem in a practical way. The PBL protocol is often known as the "Severn Steps".

Problem-Solving Competencies

A model in the style of a radar diagram of the PBL Protocol was published by one of the seminal authors, Biglow (2004) who captured measurements of before and after gain comparing responses at the beginning of PBL course with average ratings of students at the end-of-semester (Biglow, 2004, p. 606), shown in Figure 5. Biglow gives credit to improvement in abilities go through the problem-solving steps-and in doing so, to develop credible and implementable solutions" (2004, p. 606). The technique of using a radar chart to illustrate measurements along spokes of a wheel, from the center outward to the named criteria on the parameter. The clockwise numbered labels on the boundary are Biglow's abbreviated names for the seven steps. The call out labels indicate the parameter of a dark grey area for before the lesson started and light grey area for measurements taken after PBL lessons. The gap shows an increase in knowledge by a group of participants.
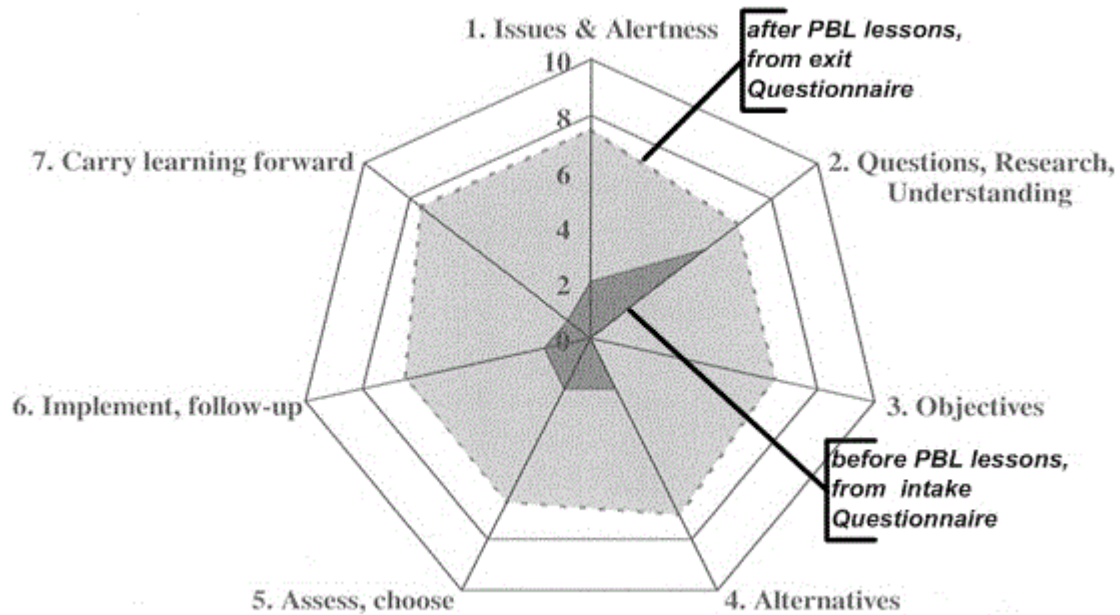
Figure 5. Competencies in solving unstructured problems. Adapted from Biglow, 2004, p. 606.

**Guidance for distributed Problem-Based Learning (dPBL)**

McConnell's study examined the ways that two distributed groups "implicitly and explicitly" sustain themselves as a "community of learners" (2002, p. 59). Further, McConnell (2002, p. 63) distinguished collaborative from cooperative distributed PBL (dPBL) as self-managed virtual learning teams tackle ill-defined problems, sharing resources and ideas offered by a tutor. The practice known as "networked learning" is amenable to collaborative group work typical of PBL challenges. In both variations of dPBL, the groups negotiate interpretations of the problem, the alternatives worth establishing a team's focus on a project and/or a product as an outcome. McConnell considers the absence of face-to-face contact to be an intriguing feature of dPBL (2002, p. 71). The communication tools of a fully functional *synchronous* meeting environment such as WebCT and LotusNotes (in his day) provides support for success of dPBL. The achievement of milestones, a point when "something pivotal" takes place, is a way that a researcher explains the meaning of events (McConnell, 2002, p. 72). According to McConnell (2002), the placement of the focus of dPBL, as if a fulcrum, between identity of a group and professional practice is illustrated at the beginning of a course and after PBL experiences, Figure 6. To the team this experience would represent an evolving synergy between members during encounters as the problem is defined, then solved.

Figure 6. Before and after dPBL lessons, identity in group and professional practice.

Instructional Best Practices for PBL

PBL has an origin in theoretical principles and a long history of supporting learning of medical training and engineering field disciplines. The framework illustrating Kolb's learning cycle is familiar to scholars and to practitioners. Yoe reveals a practical way in which familiar and proven academic ideas can be adapted to the complexities of the workplace. The four phases illustrated in Figure 7 are Yoe's adaptation of Kolb's theory for workplace actions, a continuous process supported by action learning theory, proceeding to conceptualization, then having an active dialog followed by concrete situation analysis. The problem context is intended to make abstract solutions more explicit (Yoe, 2007c, pp. 45-46) in order to work on them and build a product.
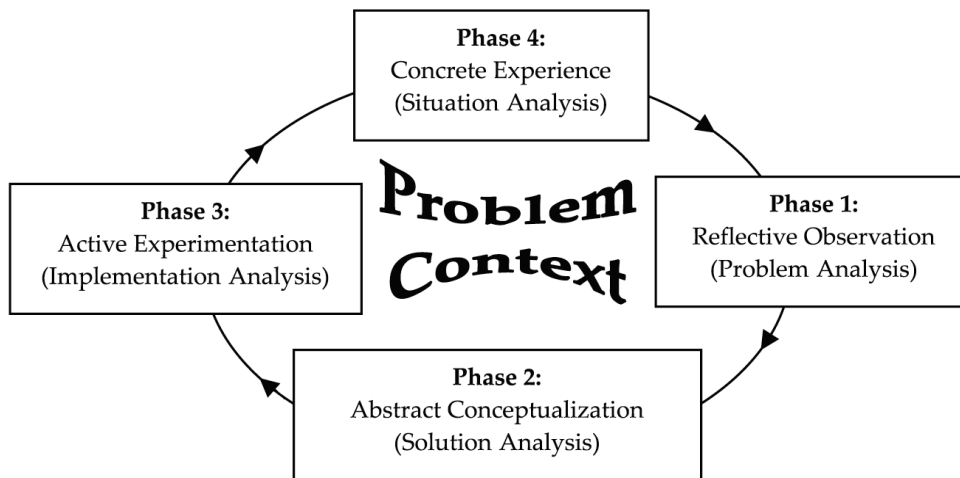
Source: Adapted from Kolb (1984) and Cockerill *et al.* (1996)

Figure 7. PBL operating in workplace context (Yeo, 2007, p. 45, citing Kolb, 1984 and Cockerill et al. 1996).

To handle dynamics of business challenges, Yoe introduces complimentary concepts of double loop learning, see Figure 9. Often a problem is not resolved during a single loop. It may take several iterations. The nature of peer tutoring and knowledge sharing provide a "repository of information through various systematized activities to facilitate shared learning" (Yoe, 2007, p. 308). The dynamics of how the people work together makes a difference, meaning that iterations might lead eventually to an acceptable resolution.
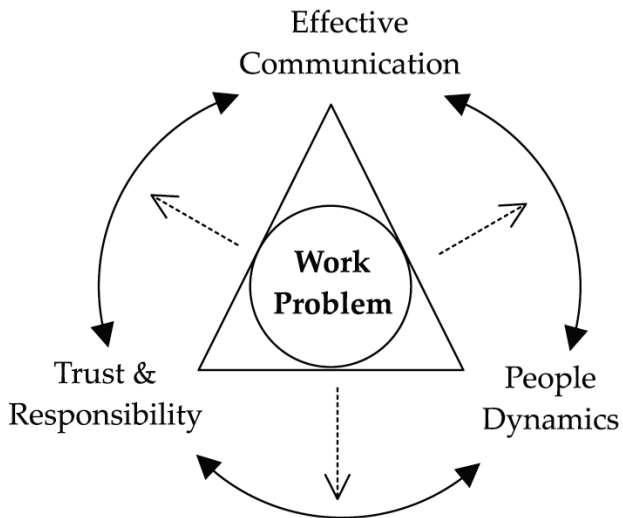
Figure 8. Problem-based double-loop learning (Yoe, 2007, p. 48).

In the workplace, a typical PBL cycle involves both ideas and actions of employees "acting as change agents [who] are consciously engaged in a variety of such activities as active communication, questioning, reflection and task execution" (Yoe, 2007, p. 309). People dynamics is an important attention area for practitioners of the PBL Protocol. In fast paced agile environment, team resources, dynamic allocation of resources based on skill is evidenced in the formation of teams of people who are both available and ready to commit to a project's duration and scope to achieve a specified end result or product.

Complementary Strengths, Scaffolding

A challenge will be to quickly adapt courseware to reflect "real world" problems. According to Muukkonen et al. in support of Inquiry Learning Process and Distributed Expertise, the discussion module of Future Learning Environment (FLE) tools had seven "build-in scaffolds: problem, working theory, deepening knowledge, comment, metacomment, summary and help" (1999, p. 4). According to Ali, (2005) distinct characteristics of *scaffolding* are: learners' current difficulties and concerns, immediate assistance, optimum level of specificity matching learners' competence, and carefully structured around an expert model. The concept of *scaffolding* uses a metaphor of "stepping stones and building blocks on which learners can comfortably construct new knowledge and expertise" (McLaren, 2008) moving along a set of prescribed achievement levels and gradually leading students into a learning process. An and Reigeluth (2008) extend the orientation to *cognitive scaffolding* provided by an instructor's "persistent efforts to facilitate cognitive dialogue" (p. 5) which shifts from passive listening to enabling open expression of new ideas, providing critical feedback, and raising important issues. Considering PBL to be a democratic learning environment, Pritchard (2007) acknowledges that using digital instructional technologies increases motivational levels, positive behaviors, and supports media objects to engage learners. Applying his knowledge of biological life cycles to the learning cycle, Pritchard

emphasizes "active feedback and multi-source expert evaluation" to "authentically assess student achievement" (Pritchard, 2007).

PBL Action Steps

Whereas some important lessons are the enriching experience of critical thinking, other lessons lead directly to a capstone project that translates the proposed solution into a design for an end product. An and Reigeluth practitioner's advice included for the environment, "provide both synchronous and asynchronous communication media" and for assessments, "assign a considerable portion of the grade to learning and the problem-solving process" (2008, p. 13). How to do that? The answer can be inferred from the advice "help students divide tasks properly so that they can collaborate rather than cooperate" (An & Reigeluth, 2009, p. 13) that a course facilitator works closely with the PBL teams, observe the behaviors and outcome generated from the approach. Figure 9 synthesizes several scholarly and practitioner sources describing the PBL process seven steps with a simple model of four constructs useful for studying assessments, conceptual knowledge, contents and problem solving ability (Masse et al., 2009, p. 3).
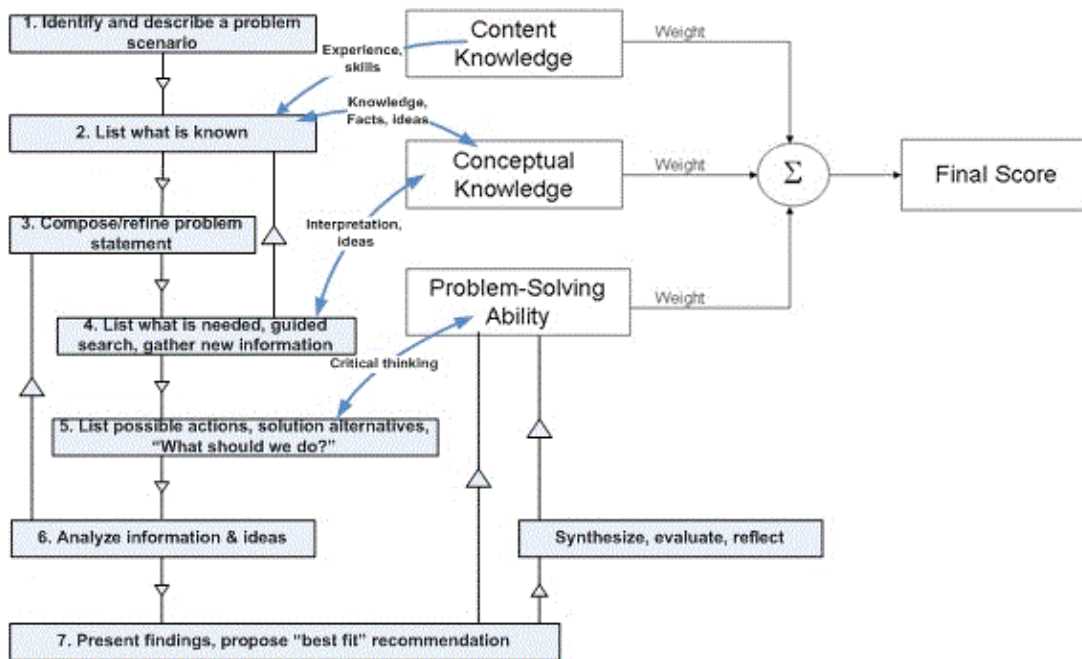

Figure 9. PBL action steps, integrated with course assessment.

The translation of the work from scholars gives practitioners a chance to structure useful lessons that apply the "real-world" scenario. Table 1 lists seven phases for scenario planning for a well designed PBL research project. These phases listed by Allert et al. (2002) apply the protocol to studying the PBL processes within the curriculum when the planned lesson is go beyond the basic formulae offer by text book publishers.

Table 1. Phases of PBL for scenario planning. Adapted from Allert et al., 2002.

Phase	Purpose
Goal Description	Define a problem scenario to demonstrate course learning outcomes. Establish an ultimate goal for team project.
Specify Criteria	Specify criteria to be met. What is the focus of the testing? How will you know when you have reached your target?
Background Knowledge	Identify knowledge needed to accomplish the goal. Ask experts? Research and adapt best practices?
Generate Ideas	Brainstorm & generate ideas.
Implement Solution	Generate, develop and implement an adapted solution for verifying the requirements or validating the system.
Reflect	Evaluate & reflect on your solution(s) and on the process we went thought, the lessons learned.
Generalize	Conceptualize, integrate, and generalize previous knowledge about systems and new learning.

Characteristics of Problems

In his 2010 conference paper, "Research Issues in Problem Solving", Jonassen suggests further research. Jonassen offered a list of nine problem types mapped to seven kinds of cases, Table 2, as a reference for practitioners to plan original research.

Table 2. Case components and scaffolds for problem solving (Jonassen, 2010, p. 12).

Problem Type	Case Components, Problems are …	Cognitive Scaffolds
1. Story Problems	worked examples, analogues	Problem schema, analogical, causal, questioning, argumentation, modeling
2. Rule Using/ Rule Induction	worked examples, analogues	Problem schema, analogical, causal, questioning,
3. Decision making	case studies, alternative perspectives	Causal, argumentation, modeling, mental simulation
4. Troubleshooting, Diagnosis solution	prior experiences, alternative perspectives	Causal, argumentation, modeling
5. Strategic performance	prior experiences, simulations	Problem schema, analogical, causal, mental simulation (scenario construction)
6. Policy analysis	case studies, prior experiences, alternative perspectives	Analogical, causal, questioning, argumentation, modeling
7. Design	prior experiences, alternative perspectives	Causal, argumentation, modeling
8. Dilemmas	alternative perspectives	Argumentation, scenarios

In traditional education, well-structured problems are encountered in formal planned courseware which relies on standard curriculum and the contributions of text book publishers. These structured problems "typically present all elements of the problem; engage a limited number of rules and principles that are organized in a predictive and prescriptive arrangement" (Jonassen, 2010, p. 3). For the instructor, the convenience is that the set of course problems "possess correct, convergent answers; and have a preferred, prescribed solution process" with an instructors' guide (Jonassen, 2010, p. 3). In this discussion, recognition is given by Jonassen to ill-structured problems which may have many alternative solutions, and may be vaguely defined with goals that the students must originate, with hidden constraints and possibly multiple solution paths; and mixed or vague criteria for evaluating the possible solutions; so the problem are difficult to solve. Problems also have differences in level of difficulty and complexity. Problems can be classified somewhere on a continuum of how well-structured or how complex they are, as illustrated in Figure 10 indicating that some problems are ideal for lessons conducted by a tutor that may introduce simple problems and then move upward to more complex problems. The topology represents a practice within the field of teaching medical procedures and diagnostics and in engineering. The challenge now is to apply the scholars' insight to teaching of skills to students ambitious to become IT professionals: software, infrastructure, networking and user interfaces.
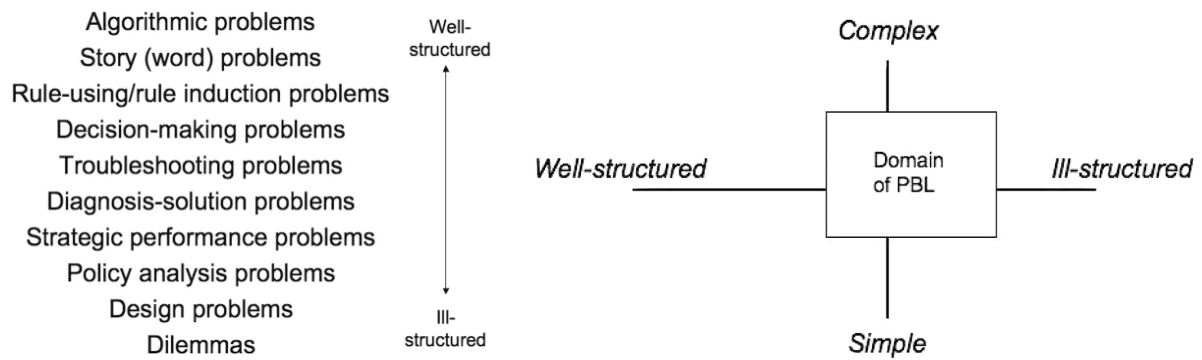
Figure 10. Topology of problem types and domain of PBL (Jonassen, 2010, p. 12, 16).

Pierrakos et al. (2010) took on the challenge criticism that science, technology, engineering, and mathematics (STEM) education initiative did not focus sufficiently on authentic problem solving. Their research focused on undergraduate research experiences for PBL implementations in dynamic interdisciplinary team environments. The study measured several coding themes of relevant to capstone projects, namely time constraints, team dynamics, learning new knowledge and skills, student-mentor relationships, independence and taking initiative (Pierrakos et al., 2010, p. 51). The strength of their findings was a decomposition of the complexity or structuredness of problems based on an earlier model (Jonassen & Hung, 2008) confirming the recommendation that PBL problems should be "authentic by being contextualized to real-world workplace setting" (Pierrakos et al., 2010, p. 36, 55). Figure 11 illustrates the model of problem difficulty based on external factors. The decomposition make visible

two paths, one the complexity the other the way in which problem are or can become structured.
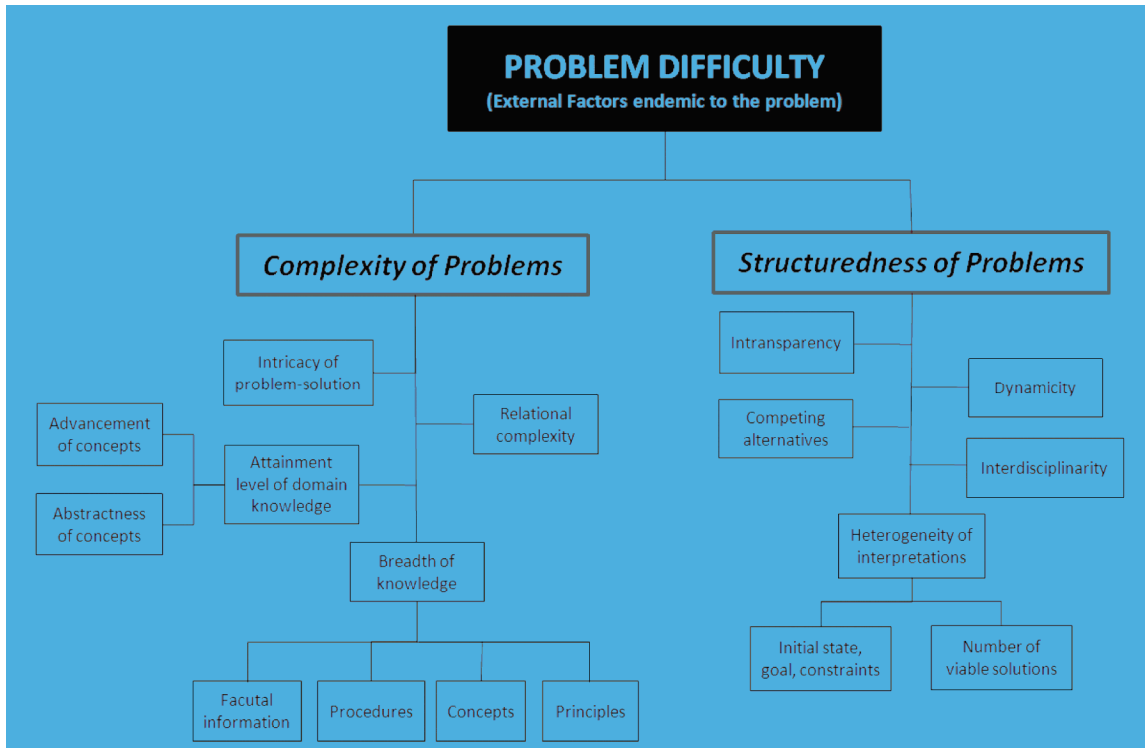

Figure 11. Problem difficulty classification framework (Pierrakos et al., 2010, p. 40)

Conclusion

Today's challenge is a genuine opportunity to be engaged as learners to respond to perceived complexity of problems with curiosity rather than resistance, armed with a set of questions that help to reveal the dimensions of a problem and then to handle the situation strengthened by learning based on the PBL approach. Under graduate academic research on applying authentic and real-world problem solving experiences is valued highly but is too rarely evidenced within the regular curriculum. Under graduate programs most often oriented toward a lens of discovery about new technology, or new methods, or someone else's new knowledge after being published. It is time to support under graduates to become independent critical thinkers who can work on virtual teams. Inspired by the overarching research question voiced by Pierrakos, Zilberberg and Anderson (2010, p. 37), a practitioner's task would be to provide tutoring and scaffolding opportunities for under grads to learn to think critically. Facilitated problem-based learning experiences based on prepared text book lessons may benefit a team of distributed learners while they are collaborating on designing and producing a practical solution. An interesting area to examine is look through a lens of PBL theory, applying the PBL protocol, and to explore what under graduates can gain by understanding the complexity and structuredness of problems. Others have and are contributing to this area of research (Pierrakos et al., 2010; An & Reigeluth, 2008; Ali, 2005; Yeo, 2007a, 2007b,

2008; Chiriac, 2008). As practitioners, for those of us who do teach in on-campus or virtual class rooms, it is finally time to contribute our practitioners' minds and our hands-on experiences into course content and to proactively facilitate solving interesting real-world, or, at least, realistic facsimiles of real-world problems.

This visual literature review has documented some of the most graphic ideas from both scholars and practitioners on the concept of Problem-base Learning approach and the processes that enliven team collaborative learning in a virtual world. There is much yet to learn and to do to bring into our classrooms and online learning environments the PBL protocol as a learning opportunity. Success can prepare learners to become problem solvers and critical thinkers in the professional world of business and technology solutions. A strength of the PBL approach is to bring clarity of understanding about complex problems before attempting to solve them. A best practice is to fully articulate and understand a problem before acting on ways that it can be solved, ways which may be too strongly influenced by the old habits or ambitions of team members to practice skills that they have recently learned. The critical thinking gained from the PBL approach can fit the solution to the problem instead of force-fitting the problem to the solution.

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