Process Education Best Practices for Teaching Open-Ended Problem Solving in a Project Context

Jim Morgan[1] and Barbara Williams[2]

Abstract

This paper presents a plan for teaching open-ended problem solving, using Process Education methods and tools to facilitate the learning of problem-solving skills. A team- and project-based approach is used to support higher levels of learning, and to reinforce for the learners the need for using all the steps of the problem-solving process. Support is provided for instructor facilitation in the form of:

1. *a new rubric for evaluating team problem-solving performance*
2. *a new template for problem-based learning activity design*
3. *a sample facilitation plan with intervention and questioning strategies*

The Importance of Problem Solving

Many employers have long regarded problem solving, critical thinking, and the ability to work on teams as critical workforce competencies (SCANS, 1991). Despite the importance of problem solving, many educational analysts and industry representatives report that students leave higher education with an underdeveloped ability to solve open-ended problems (CAHE, 2005). In part, this arises because instructors of undergraduate courses prefer students to construct knowledge through single-answer analytical problem solving before they address more complicated open-ended problems that require higher levels of knowledge. However, constructivist research shows that students learn more effectively, and remember longer (Dochy, Segers, Van den Bossche, & Gijbels, 2003), if they are guided to construct their own knowledge such as in problem- or project-based learning.

Introduction

This paper demonstrates the design, implementation, and assessment of a team-based project-based activity to teach the problem-solving process. The context of the activity is environmental engineering, using an example case study suitable for a freshman engineering class. Environmental science and environmental policy learning objectives are also included to give examples of possible interdisciplinary connections. As such, this example activity is intended to be illustrative to college-level educators from any discipline. We are not aware of a comprehensive implementation paper for project-based learning that integrates:

1. activity design
2. facilitation planning that includes preparation for constructive interventions and inquiry questions
3. assessment of problem-solving skills
4. transparent use of rubrics which classify ranges of performance on specific skills
5. learner reflection to improve metacognition

In this paper, we integrate documented principles and approaches of Process Education™ (PE). PE is defined as "a performance-based philosophy of education which integrates many different educational theories, processes, and tools in emphasizing the continuous development of learning skills through the use of assessment principles in order to produce learner self-development" (Burke, Lawrence, El-Sayed, & Apple, 2009). This definition of PE overlaps well with the findings of Woods (2000) and others regarding effective means of developing problem solving abilities in students; including skills such as self-management, problem solving, interpersonal and group skills, assessment as a foundation for growth, change management, and lifetime learning. We employ best practices of PE whereby teachers, trainers, or coaches assess and document the development of higher levels of learning, paying explicit attention to the development of a broader range of skills; learners benefit by gaining a rich awareness of the utility of using the steps of the problem-solving process.

Problem-Solving Process

Problem solving (PS) is a process whereby a "best" outcome is determined for some situation, subject to certain constraints (Morgan & Williams, 2007). Many PS processes (methods) are found in the literature (Stice, 1987; Myrvaagnes, 1999; Woods, 2000). These models differ in their emphasis, disciplinary context, and in the sequence of steps employed. The PS process used in this paper builds on those described previously and is outlined as follows:

[1] Texas A&M University
[2] University of Idaho

1. Define the Problem – This includes the following steps:
   - Identify Key Issues
   - Collect/Assess Information
   - Identify Assumptions
2. Develop Alternative Solutions – Often brainstorming is a good way to generate an initial list of alternatives. In brainstorming, it is important to withhold judgments (or analysis of alternatives) and focus on generating a long list of ideas - thus, divergent thinking is employed. Many novice problem solvers seek to avoid the divergent thinking step, and go directly from problem definition to choosing one "correct" answer. When a list of alternatives is developed, this step is not completed until the list is filtered to eliminate solutions that do not meet all constraints.
3. Choose Best Solution – Most of the analysis takes place in this step. Often, the definition of "best" is an important part of this process. Once the variables included in "best" are fully defined (such as in terms of cost, time, social or political acceptability), then the selection of the best alternative may be the alternative that satisfies all of the constraints and has the most attributes in the definition of "best." Convergent thinking is employed here.
4. Implement Best Solution – As with defining the problem, the following steps can be useful in organizing the work:
   - Create and Follow Plan
   - Break Problem Into Parts
   - Model Sub-Problems
   - Integrate Solutions
5. Test/Validate – It is often surprising to those observing a problem solver that finding a solution is not the last step. Ordinarily the relief at obtaining a solution is cause for celebration, especially when the problem involves a new situation or unfamiliar territory. However, a good problem solver knows that the first solution is often not *really* the best solution.
6. Possibly Iterate to Earlier Step – If the solution fails the test in Step 5, then the wrong alternative was implemented in Step 4, or the alternatives identified earlier did not include the best solution, or the definition of the problem was incomplete or incorrect. This is a frustrating reality of solving real problems!
7. Generalize the Solution – A generalized solution is one that can be used in other contexts and other situations (like a module or subroutine in a computer program). The reflective process that allows generalization also leads to the highest levels of learning.
8. Communicate the Solution – It often is said, "If you can communicate (teach) a solution, then you really understand it." We would propose that *unless you can communicate the solution, you do not understand it.*

In order to teach the PS process in a constructivist manner, it is necessary to give students feedback on their performances at each step in the process, as well as for continuously occurring performances such as teamwork, assessment, and iteration. To accomplish this, we present a new Problem-Solving Skills Rubric (Table 1), building upon the previous work of Cordon, Beyerlein, and Davis (2007).

Problem-Based Learning

The problem-solving process described previously is best taught by solving a real problem; this is referred to as problem-based learning. Teaching the PS-process in the context of a real problem helps students to recognize the value of all the steps in the process. Problem-based learning was first introduced in the 1960s (Smith, Sheppard, Johnson, & Johnson, 2005) in professional disciplines such as business, medicine, and engineering, with ongoing refinement of best practices and measures. A recent meta-analysis of 43 investigations of the influence of problem-based learning on the acquisition of knowledge and skills primarily in medical fields (Dochy et al, 2003) suggested that students in problem-based learning are better at applying their knowledge than students trained in lecture classes. A significant finding of this study related to retention of knowledge is that problem-based learning students gained slightly less knowledge, but remembered more of the acquired knowledge. Efficacy of the problem-based learning methods developed by Woods in the chemical engineering program at McMaster University is summarized in Woods (2000). Woods, et al. (1997) found that faculty demonstrations of problem solving, asking students to solve many homework problems, and using open-ended problems are *not effective* at transferring problem-solving skills to students. However, workshops on explicit problem-solving skills did improve both the students' confidence and their skills. It should be noted that this instruction focused on a range of 37 skills including cognitive and other domains (including skills such as self-management, problem solving, interpersonal and group skills, self-assessment, change management, and lifelong learning). Problem-based learning has been applied in medical schools, and is promoted for its ability to "provide students with a rich learning environment

Table 1: Problem-Solving Skills Rubric, for assessing and evaluating team performance of problem solving

Performance Area	Expert Problem Solver	Graduate Problem Solver	Senior Problem Solver	Freshman Problem Solver	Novice Problem Solver
Problem Definition					
Identify needs	contrasted	ranked	complete	sees one	perfunctory
Establish requirements	comprehensive	nearly all	many	some	uncertain
Identify constraints	systematically	in groups	in pairs	one by one	disregards
Define functions	exhaustively	comprehensively	with detail	basically	vaguely
Listen, rephrase, check perceptions	facilitates	fulfills role	values role	occasionally	myopically
Activate Prior Knowledge					
Locate/Review resources	rich set	focused set	standard	basic	haphazard
Use of principles	customized	complete	well-known	obvious	inappropriate
Evaluate external information	correctly	critically	partially	by coaching	incorrectly
Internalized knowledge	authority	extensive	adequate	partial	superficial
Divergent Thinking *(for Develop Alternative Solutions)*					
Quantity of ideas	extensive	large	several	some	few
Distinctively unique	many	several	some	few	rare
Outside the box	consistently	often	occasional	seldom	irrelevant
Professional Analysis *(for Choose Best Solution, Implement Best Solution)*					
Use key parameters	distills essence	in context	frequently	occasionally	rarely
Toolbox/Usage	tool builder	power user	standard	limited	ineffectual
Estimating	valuable	useful	approximate	variable	inaccurate
Experimentation	creative	appropriate	adaptive	imitative	trial/error
System modeling	integrative	thoughtful	complete	partial	simplistic
Decision-Making *(for Choose Best Solution, Implement Best Solution)*					
Include stakeholders	empathetically	all	most	primary ones	unaware
Achieve consensus	consistently	often	occasionally	seldom	rarely
Cost-effective	efficient	controlled	reasonable	uncontrolled	oblivious
Use design criteria	consistently	frequently	periodically	minimally	sporadically
Justification	always	frequently	dependably	occasionally	randomly
Create and Follow Plan					
Define tasks	with vision	thoughtfully	partially	minimally	whimsically
Outline milestones	originates	modifies	executes	short range	unaware

Table 1 *(continued)*

Performance Area	Expert Problem Solver	Graduate Problem Solver	Senior Problem Solver	Freshman Problem Solver	Novice Problem Solver
Create and Follow Plan (continued)					
Organized & logical	directs	solid	mechanical	scattered	confusing
Track & revise plan	assesses	implement	support	passively	disjointedly
Document progress	comprehensive	complete	methodical	perfunctory	incoherent
Validate Solutions					
Interpret requirements	exceeds	meets	knows all	knows some	oblivious
Mediate requirements	effectively	successfully	somewhat	minimally	unaware
Build test plan	elegant	solid	generally	sketchy	attempts
Test against criteria	conclusively	reliably	inconclusively	incompletely	erratically
Stakeholder acceptance	assures	leads	supports	understands	unaware
Iterate *(among all steps of PS process, and particularly after the validation step)*					
Frequency	in parallel	continuous	consistent	methodical	irregular
Review previous cycles	integrates	extends	combines	most recent	seldom
Iterate effectively	masterfully	purposefully	frequently	occasionally	awkwardly
Assess *(for all steps of PS Process)*					
Assess design process	continuously	all steps	trouble steps	big steps	when done
Assess design solutions	to optimize	to revise	to finish	when done	after failure
Communication *(for all steps of PS Process)*					
Written reports	comprehensive	informative	mechanical	superficial	unintelligible
Oral communication	persuasive	purposeful	understandable	in context	inconsistent
Project documentation	thorough	substantive	useful	disorganized	incoherent
Visuals & graphics	interpretive	illustrative	supportive	elementary	confusing
Professionalism	polished	consistent	attempts	uncomfortable	unaware
Teamwork *(for all steps of PS Process)*					
Use of resources	mentors	recruits	requests	follows	misuses
Manages conflicts	grows	resolves	assists	observes	generates
Shared consensus	shapes	molds	sees	accepts	disregards
Belonging/ Commitment	committed	enrolled	believes	compliant	erratic
Performs roles	facilitates	fulfills	values	follows	misconstrues

that promotes the cognitive processes best suited to the medical profession" (Eshach & Bitterman, 2003).

Project-Based Learning

While there are differences between problem-based learning and project-based learning (PBL), PBL shares the benefits of problem-based learning in an environment that more closely mimics the real world for science, technology, engineering, math (STEM), and medical professionals. The point of PBL is to engage students in real-world projects through which they learn mathematics and science formulas and laws upon which our world is now increasingly built. Students find these projects to be exciting, engaging, fun, satisfying, and meaningful, and through this method they learn at a deeper level than they do with traditional teaching methods (Schneider, Krajcik, Marx, & Soloway, 2002). This integration motivates student learning, enhances the learning that occurs, and helps to provide a sense of the real world by emphasizing what professionals actually do in their jobs. For example, STEM professionals engage in complex problem solving, often with multiple possible solutions, requiring careful evaluation of the strengths and limitations for each solution. PBL provides the contextualized, real-world experiences necessary for the students to scaffold their learning and build meaningful and powerful connections. PBL requires students to think critically and analytically, and enhances higher-order thinking skills. A good introduction to PBL and its best practices is Capraro and Slough, (2009).

The evidence in support of PBL is extensive. PBL has been demonstrated to significantly improve learning for lower achieving student groups while also being of positive benefit to higher scoring students (Barron, Schwartz, Vye, Moore, Petrosino, & Zech, et al. 1998; Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Schneider, Krajcik, Marx, & Soloway, 2002). A recent study at Colorado School of Mines (Munakatta-Marr, Leydens, & Moskal, 2009) found statistically significant changes in the students' understanding of technical and nontechnical issues through use of PBL. This finding that PBL can be used as a means to broaden and deepen understanding of nontechnical issues, coupled with prior research on its effectiveness in mathematics and science education, makes a compelling case for including PBL in the arsenal of teaching tools.

Design of a Project-Based Activity to Teach the Problem-Solving Process – A Case Study

The following hypothetical case study is provided as a context for teaching the PS process using PBL.

<u>Project Challenge</u>: How to get salmon to return to Salmon Creek. The US Forest Service (client) statement of the problem is: Salmon Creek has fewer juvenile salmon surviving to migration each year. Students must plan a project, some or all of which will be undertaken, to address this challenge.

<u>Project Context</u>: In order for juvenile fish to survive to migration, the gravel beds upon which the eggs are laid must not be buried and intermixed with clay sediments; the eggs cannot thrive on a gravel bed if the gravel porosity is clogged with clay. Therefore human activities that increase erosion and sedimentation must be limited. Once the eggs have hatched, dissolved oxygen must be maintained within a tolerable range for the fish. High temperature causes dissolved oxygen to off-gas. Students must find out the relationship between temperature and dissolved oxygen solubility in the technical literature. Finally, algae blooms must be avoided or limited because dissolved oxygen is reduced after algae blooms, which then rob the water of oxygen when all of the algae decay and die. The way to prevent algae bloom is to restrict excess fertilizers, manure, septic tank leakage, and other sources of nutrients which cause algae bloom. Three factors land managers (students) can control (mitigate) are to minimize sedimentation of clay particles within the gravels, prevent algae bloom by limiting nutrients such as nitrates and phosphates (from fertilizer and manure runoff, septic tank leakage) and to limit direct sun heating of the creek with shade from reeds, brush ,and trees. Habitat protection or restoration, engineered features, and/or controlling human activities—each can be used to accomplish the resource management.

Before the PBL activity is designed, learning outcomes should be established. In the creation of learning outcomes, it is useful to first define a knowledge table, such as the one shown in Table 2 for this case study. It presents both the type of knowledge that is desired (whether factual, conceptual, procedural, or metacognitive), and the level of knowledge desired. This table is presented in a format resembling that of Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1965) and includes low levels (1, 2, and 3) which are hierarchical; and higher levels (4, 5, and 6) which are not necessarily hierarchical (for example "synthesize" often is presented as 5, and "evaluate" as 6). The exact format of the table is not essential, what is essential is conscious attention to what students need to know when they finish a project and how well they need to know it. It is one thing to be able to recite facts, and quite another to be able to use those facts to solve a problem. In particular, it is important to ensure that students have mastered their knowledge at Level 3 of Table 2 (Nygren, 2007a) before expecting that the students can master Levels 4 and higher (Nygren, 2007b) which will be required for PBL. This can be accomplished by intentional facilitation (Facilitation Plan and Exhibit 1), or by designing guided inquiry pre-activities (Hanson, 2007).

Other benefits of the knowledge table are that it helps one to ground a given activity in a continuum of learning (in a course or curriculum), helps to define the prerequisite knowledge, and is also useful to modify a given lesson plan for different levels of learners, or for a different instructor.

Once the knowledge table is complete, the activity can be designed. A new template for designing a PBL activity to teach the PS process (after http://aggie-stem.tamu.edu/documents/PD/checklist%20PBL.pdf) is provided in Table 3. For more detailed guidance on activity design, see Fink (2003), Pacific Crest (2009b), and Hanson (2007).

The first element of the PBL Activity Design Template (Table 3) is to determine the learning outcomes. Learner performance is more likely to improve if one is able to precisely define learning outcomes that state what is to be achieved along with how this performance can be documented at the end of a learning experience (Beyerlein, Davis, & Apple, 2007). Learning outcomes should be defined in terms of skills as well as content.

Examples of learning outcomes for a PBL activity include competencies, movement, accomplishments, experiences, and integrated performances. Beyerlein et al., (2007) define these terms as follows: "A competency is a collection of knowledge, skills, and attitudes needed to perform a specific task effectively and efficiently at a defined level of performance. Movement is documented growth in a transferable process or learning skill. Accomplishments are significant work products or performances that transcend normal class requirements and are externally valued or affirmed by an outside expert or client. Experiences are interactions, emotions, responsibilities, and shared memories that clarify one's position in relation to oneself, a community, or discipline. Integrated performance is the synthesis of prior knowledge, skills, processes, and attitudes with current learning needs to address a difficult challenge within a strict time frame and set of performance expectations."

The second step in the PBL Activity Design Template is to define *performance criteria* for each learning outcome. These are clear and measurable criteria,

Table 2: Knowledge Table for This Case Study

Level of Knowledge	1	2	3	4	5	6
Type of Knowledge	**Remember**	**Understand**	**Apply**	**Analyze**	**Evaluate**	**Synthesize / Create**
Factual	Definitions of erosion, pollution, eutrophication	Concept, implications, and interrelation of systems for erosion, pollution, eutrophication	Apply equations for dissolved oxygen as a function of temperature	Analyze nitrate and temperature data provided by USFS to see whether these fall in safe ranges for juvenile salmon		
Conceptual	1. How dissolved oxygen varies as a function of temperature. 2. Plant role in water balance and nutrient cycle. 3. Role of sedimentation of gravels		Apply conceptual knowledge (left) and data (above) to compare alternative solutions (below)	Identify constraints to problem solving, e.g., cost or time		Calculate # plants needed given a plant per area of streambank
Procedural	All steps in PS process	The various remedial actions one can take to ameliorate these environmental problems	Develop alternative solutions step of PS process	Compare alternative solutions step of PS process	Evaluate the quality of a solution or compare 2 solutions and choose the best	1. Choose a best solution 2. Implement best solution by integrating subparts for solutions
Meta-cognitive	Skills used for individual learning	Understand and apply skills used during the problem-solving process (cognitive, social, and affective)		Reflect on skills used during the problem-solving process (cognitive, social, and affective)		Predict transferability of solution to other contexts

Table 3: Project-Based Learning Activity Design Template for Case Study

Element	Streambank Restoration Example
Learning Outcomes Both skills and content (e.g., learning a concept, or developing proficiency in a process or use of a tool)	The following outcomes result from consideration of the knowledge table. Learning Outcomes (LO): LO #1: Implement the problem-solving process in the context of a team project LO #2: Apply conceptual knowledge in the areas of gas solubility as a function of temperature, temperature as a function of foliage shading, oxygen depletion resulting from eutrophication, eutrophication resulting from excess nutrients (e.g. nitrates and phosphates), erosion and sedimentation, and effects of sedimentation on fish eggs in river gravels LO #3: Perform integrated analysis of the effects on salmonid survival of: a) dissolved oxygen concentration; and b) sediment deposition on breeding gravels LO #4: Example Outcome for Engineering Students: Design a layout of streambank plantings (area and number and cost calculations) at a specific location to limit erosion, limit nutrient delivery to the creek, and to shade the creek from sun LO #5: Example Outcome for Environmental Policy Students: Develop a public survey and public education plan to get buy-in of creekside landowners to limit use of fertilizers within a certain distance from the creek, to limit erosion, to provide shade, etc
Performance Criteria (for each learning outcome)	LO #1: All performance areas of the Problem-Solving Skills Rubric (Table 1). LO #2: This is the content to be learned when meeting LO#1. An important element of PBL is that content is taught in the context of the project. The performance criteria for this will depend on the level of technical detail that the instructor wants the students to achieve LO #3: Especially the “Choose Best Solution” step of the problem-solving process, using several areas of the Problem-Solving Skills Rubric (Table 1). LO #4 and #5: Performance criteria for these integrated outcomes will use all steps of the Problem-Solving Skills Rubric (Table 1)
Engagement (motivate students)	Take students to a field trip to an algae-choked or otherwise dead stream or lake; especially effective in a community where hunting, fishing, and/or water recreation are very important
Prerequisite knowledge and skills	High school chemistry – gas solubility Environmental science – algae in water systems, sedimentation of clay particles Communication – written and oral technical presentations
Project or Case study Invoke problem-solving process, on a planned schedule (decide in advance how many hours, days, weeks)	- PBL context is a project where students are learning the PS process, and are learning general content information about fish habitat - Activity for a project like this salmon case study requires at least 4 in-class days, which leads to the production of 4 facilitation plans: 1) Problem Definition / Data Collection – shown below 2) Brainstorming Alternative Solutions / Choosing Selecting Best Solution 3) Break Project into Tasks / Complete Tasks / Ongoing Documentation 4) Plan Oral Presentation / Prepare Final Written Report - Interim products to support/enforce progress through PS process, as indicated by the major learning outcomes - Activity design must include a timeline for cooperative teamwork and interim products, including draft and final due dates
Closure	- Invoke the validation performance area of Problem-Solving Skills Rubric (Table 1) - Students should be prompted to reflect on the problem-solving process, their growth in problem-solving skills and their content knowledge, and transferability of their solutions to other contexts
Assessment tools (both formative and summarive) for key knowledge and skills, as per Bloom level	- All performance areas of the Problem-Solving Skills Rubric (Table 1) should be assessed - SII's for selected learning skills in the rubric should be done by instructor, team reflector, peers, or self-assessment at various stages in the PS process - SII's of interim products, including oral presentations, project documentation, and written reports - Instructor will use Problem-Solving Skills Rubric (Table 1) to evaluate (grade) mastery of the PS process at the end of the project.

presented perhaps in the form of a rubric. For this case study, we provide the Problem-Solving Skills Rubric (Table 1) to give the students a picture of what masterful performance looks like in all steps in the process, and in related teamwork and communication performances. Clarity of performance criteria is determined by whether the students have a clear understanding of their degree (level) of mastery for the learning outcome. Students should receive expert assessments over the life of the project (see "assessment," following). Students should be reasonably able to self-assess and peer-assess their performances, based on practice self-assessments completed over the life of the project.

The third step in the PBL Activity Design Template is to arrange for a significant engagement event or artifact, such as a field trip or a YouTube video, to motivate and excite the students. It is often useful to solicit the help of a peer student to gain insights as to what would be relevant and interesting to the target student population.

The fourth step in the PBL Activity Design Template is to activate the *prerequisite knowledge and skills* necessary for a successful attempt at the project. Sometimes, a list of prerequisite knowledge and skills is sufficient. More often, it is appropriate to include a pre-activity, or at least a discussion of the level of skill and knowledge required. The students will fill in gaps in their knowledge and skills while completing a well designed project. Nevertheless, it is very helpful for them to start with a list of known roadblocks and obstacles (there often will be other gaps, either overlooked by the instructor or assumed to fall into the "*everyone knows*" category).

The fifth element of the PBL Activity Design Template is the *project* or *case study*. A well-designed project guides student focus to issues and tasks that will address the desired learning outcomes. Since the context of this paper is *Teaching Problem Solving*, the projects should explicitly address the problem-solving process and give the students the opportunity to exercise and develop the skills related to problem solving.

The sixth element of the PBL Activity Design Template is *closure*. Solution of the problem is not yet the time for celebration. As mentioned before, after a solution is obtained it must be validated. The closure step is also a good opportunity to help the students build their reflection skills. Students need to learn that verification does not mean "*it looks reasonable*," and need practice developing the skills necessary to compare alternate solutions. Likewise, they need encouragement to reflect on their process and on the results obtained. Questions such as the following can help them to get the ball rolling:

- Isn't there a better solution?
- Isn't there an easier way to solve this problem?
- How do you know you have the best solution?
- What if I can only spend half as much as your solution costs? (or I need it in half the time your solution takes?)

Once students realize the power of reflection, it is enough to prompt them to reflect on the process they used; to ask them what they will change when facing a similar challenge in the future; and to predict how close their solution is to the best one that will be submitted.

The final element of the PBL Activity Design Template is *assessment*. This does not mean that assessment comes last in the process; rather, assessment is a continuous process. Often students receive a rubric, such as the Problem-Solving Skills Rubric (Table 1), before they receive the project assignment. Usually, instructors design the rubric before they complete the design of the project. Assessment will occur often, starting with the first in-class project activity (see Exhibit 1).

The tool we suggest for real-time assessments (expert, self, and peer) of the students as they work through the PBL process is the "SII," so-named for three assessment priorities: strengths, areas of improvement, and insights (Wasserman & Beyerlein, 2007). The SII tool can be used for any skill from the Problem-Solving Skills Rubric (Table 1). The SII is a powerful tool for self-assessment (Pacific Crest, 2009a), peer coaching, (Cordon, 2007), team assessment (Pacific Crest, 2009a), and facilitator assessment (Smith, 2007a, 2007b, 2007c; Leise, 2007; Minderhout, 2007). Use of the SII is most effective when the assessee and assessor maintain an assessment mindset rather than a judging, critical mindset; when the assessment is focused on a skill rather than content knowledge; and if the assessee has some say in the skill that will be assessed (Jensen, 2007; Apple & Baehr, 2007; Utschig, 2007). A comprehensive, evidenced-based review of the principles and practices relevant to assessment can be found online (Utschig & Apple, 2009). Specific SII templates that are customized for assessing team activities for collaborative learning can be found in the Student Success Toolbox (Pacific Crest, 2009a).

Facilitation Plan

The facilitator of PBL work should develop a facilitation plan to maximize the effectiveness of face-to-face time with students. Detailed guidance for facilitation plan design is provided by Minderhout (2007a), and Smith (2007a, 2007b, and 2007c). Specific challenges to facilitation of problem-based learning are outlined by Duncan-Hewitt and Butler (2007). An example PBL facilitation plan for this case study is provided as Exhibit 1.

Cooperative work by teams doing PBL should be arranged so that much of it occurs during class time, because that is probably one of the few times when everyone can meet, and because the instructor/facilitator will want to make real-time assessments and constructive interventions (Leise, 2007; Smith, 2007c; Minderhout, 2007b) on the teamwork process. In preparation for these interventions, facilitators should keep ears and eyes open for trouble spots such as one person dominating, or individuals who don't contribute. The Reflector or Team Leader can be invited aside to corroborate the observation, and can be coached to develop a proactive suggestion to the team that will change this dynamic. A strategy that works well once a cooperative classroom environment has developed is to empower all people in the class to be the eyes and ears for the group. A *tip line*, whether on anonymous note cards or on an automated web-based system, can be invaluable in bringing the intervention to a team before problems fester or explode.

The affective and social dimensions resulting from having to address an ill-defined gap or blockage are presented in Parnes' (1992) survey of creative problem solving. Activities such as objective finding, fact finding, problem finding, idea finding, solution finding, and acceptance finding are framed in terms of divergent and convergent questions that connect with individual and group values. Sample questions are posed in Table 4.

Questions posed by the instructor are a vital part of facilitating student growth. Questions posed by the learners can be used to monitor the progress of a class, a team, or an individual student. If students ask high level convergent questions, it indicates significant development of many of the skills listed earlier as compared to when students ask only directed questions. Likewise, a faculty member who asks "easy to answer" questions is not providing growth opportunities to the students. Facilitation is the art of stretching the students beyond where they might take themselves without pushing too far or too fast (leading to anxiety, frustration, anger, and disengagement). Walsh and Sattes (2005) provide a detailed resource on preparing questions, presenting questions, prompting student responses, processing student responses, teaching students to generate questions, and reflecting on questioning practice.

Directed, or closed-ended questions posed by the instructor require students to process and recall information. Such questions have a definite answer and build the foundation for more challenging questions, however, when answered by students, they do not always provide a complete picture of student understanding to the instructor. It is possible to answer directed questions by rote without understanding concepts.

Convergent questions require that students make connections and reach conclusions that are not obvious upon first examination (Hanson, 2007). Convergent questions have answers that are not directly available in the model, information, or resources; they require students to analyze and synthesize; they may have more than one correct answer; and the facilitator can use student answers to check for understanding. The level of difficulty should progress with the questions, and the questions should drive students to develop and understand the concepts presented in the activity (Hanson).

Divergent questions send students in different directions (Hanson, 2007). This type of question may have no right or wrong answer, but it requires students to ponder, explore, generalize, and expand upon their current knowledge. Divergent questions require the highest

Table 4: Cognitive, Affective, and Social Questions in Problem Solving – examples for this case study, to be posed by instructor, or by students.

Divergent Questions	Convergent Questions
What resources do we need to solve this problem? Why haven't other people already solved this problem – why isn't there a "cookbook" solution? What are some ways to do this differently? Are our client's criteria for success the best criteria? Necessary and sufficient? How will we know if our solution is good? Good enough? Better than other solutions?	What have other engineers done in the past (best practices) to solve this type of problem? What are the costs of labor and materials for each of the techniques we might use in possible solutions? What are the key decision points? How can we best use the expertise of our team? Which of our solutions can be met within our cost restrictions?

level of thinking and produce outcomes and conclusions that vary among teams and individuals. They may even launch research ideas (Hanson).

Managing Stress in Project-Based Learning

A key element of cooperative learning generally, and PBL in particular, is managing the stress (affect) of team members. If stress is properly managed, a team will experience increased creativity and productivity. This leads to an increase in higher-level learning by individual members of the team, often exceeding the expectations of team members (who may originally have thought the standard was too high), and sometimes exceeds levels that faculty thought achievable (Michaelsen, Knight, & Fink, 2004). If stress is not properly managed, students will experience anxiety, frustration, and even anger or disengagement which could impede their learning progress.

Available tools that can be used to manage stress include cooperative learning and an active learning environment. Cooperative learning also provides significant benefit to the PBL environment. In addition to providing positive peer pressure, especially when combined with teams, a cooperative environment provides a safety net for students (Smith, et al., 2005). In addition, an active learning environment can be used to move students outside their comfort zone, and places more challenge and more stress on students. Managed properly, this stress is highly effective in generating mastery and increasing student motivation for attempting tasks that exceed their current comfort level (Bandura, 1997).

Although the cooperative learners themselves should be coached to manage their own stress, the facilitator is also in a position to impose, or relax, the demands placed on the PBL teams in two ways: a) the design of the activity; and b) the actions taken in real-time facilitation of the students' in-class work. One can use the Accelerator Model, developed by process educators Morgan and Apple (2007) as a tool for visualizing and monitoring the level of challenge offered to the students. The Accelerator Model incorporates the cognitive skill set of students, the affective skill set possessed by students, and the degree of challenge initiated by the instructor.

According to the Accelerator Model, adding complexity or restricting time available for a learning activity will increase the demand for affective skills. One of the most important factors in the growth of your students is the development of their affective skill set for managing the stress. Until students discover "the pleasure of finding things out" and become self-growers, teachers need to manage the affect of their students and help them strengthen their skills in the cognitive, social, and affective domains. To more effectively use the Accelerator Model, especially during the development of a facilitation plan (see Exhibit 1), you should periodically reflect on the following questions:

- Are my learning outcomes appropriate for the developmental level of my students?
- What are the top three reasons for frustration in my course?
- What situations appear to cause movement from anxiety to frustration, anger, and disengagement?
- What actions can be taken to reduce the current frustration without compromising key course outcomes?

Conclusions

The tools developed by the cooperative learning and PE communities have proven very helpful in the design of a plan for teaching problem solving in a team and project-based environment. These tools also are appropriate and effective for students working on a project individually. Many are simply good ideas for any teacher in any learning environment. Including the consideration of cognitive, affective, and social dimensions strengthened both the process of developing and adapting the tools needed, and the process of designing the facilitation plan.

The use of the Problem-Solving Skills Rubric (Table 1) will also significantly impact the quality of a learning environment. Not only does the rubric bring clarity to students about the expectations the faculty have for the process and the product; further, the performance level descriptions in the rubric demonstrate the desired level of performance. The value of the PBL Activity Design Template is to chart a roadmap for an activity, including strategies for anticipated challenges that the teams will encounter. This template, plus the example case study make it much easier for an instructor to take the risk of implementing a PBL activity for the first time.

Future Work

Primary areas of future work include:

- Documenting improvements in student performance through in-class research. For example, an instructor could measure student learning of the problem-solving process with the tools outlined in this paper as compared to similar learning obtained through a more traditional approach to teaching.

- Refinement of the Problem-Solving Skills Rubric (Table 1). As various practitioners use the rubric, we can determine those criteria that are more or less helpful. Less helpful criteria will be refined or dropped. In addition, we will attempt to discover descriptions that are more or less helpful to the learners, and refine or replace descriptions that do not effectively communicate desired performance to the students. This iterative refinement of the rubric will help the instructor assess learning *and* will help the learner assess self growth. Involving students in refinement of the rubric increases their ownership of the rubric for early version student users, as well as providing a better tool for later version learners.
- Refinement of the PBL Activity Design Template (Table 3). As with the rubric, this template should be refined with use, and reviewed by users for elements central to Project-Based Learning across all contexts.

It is our hope that the reader will come to see the Problem-Solving Skills Rubric and the Project-Based Learning Activity Design Template as living documents.

Exhibit 1: Sample Facilitation Plan

Class Session 1 — Problem Definition

This example facilitation plan is constructed after Minderhout (2007a), and assumes a 90-minute class period.

1. **Outcomes** *(List 2-3 outcomes and underlying skills from different domains and describe anticipated evidence that each has occurred.)*
   - Implement the Problem Definition step (Step 1) of the problem-solving process in the context of a team project. For skills, see Problem-Solving Skills Rubric (Table 1) in the performance areas of Problem Definition, Activate Prior Knowledge
   - Produce two problem-solving documents:
     i) a problem statement, which is a rephrasing and extension of the Forest Service problem statement, and includes discussion of the known causes for why the juvenile salmon migration rates are decreasing each year
     ii) a two-page information document in the areas of gas solubility as a function of temperature, temperature as a function of foliage shading, oxygen depletion resulting from eutrophication, eutrophication resulting from excess nutrients (e.g. nitrates and phosphates), erosion and sedimentation, and effects of sedimentation on fish eggs in river gravels
   - Produce a reflector's report summarizing and analyzing SII's prepared in 2 of the following areas of the Problem-Solving Skills Rubric (Table 1): Problem Definition, Activate Prior Knowledge, Assessment, and Teamwork.

2. **Activity Type:** Project-Based Problem Solving - Step 1: Define the Problem

3. **Roles** (See Smith, 2007)

   Captain   *Recorder*

   Reflector   *Spokesman and Skeptic*

4. **Preparation Assessment Plan** time allotted 10 minutes
   - Meet with the reflectors from each team, review the SII process with them
   - Direct reflectors to decide with their teams as to which of the skills in the Problem Definition, Activate Prior Knowledge, Assessment, and Teamwork areas of the Problem-Solving Skills Rubric (Table 1) they will be focusing on
   - Each team will pick 2 skills in each performance area to be aware of during the 1.5 hour group work time
   - Reflector will assess the team, Facilitator will assess the reflector's assessment

5. **Activity Set-Up Plan** time allotted 10 minutes
   - Meet with the whole class, briefly review team roles

- Explicitly describe the specifications for the written products (See outcomes, previous)
- Tell the students that you will be moving around the room and doing SII's on the reflector's SII for the performance areas they have selected

6. **Group Work** time allotted__50-60 minutes_____
   - Use SII forms to complete assessments as agreed upon
   - Ask prepared probing questions – See Table 4
   - Also perform constructive interventions as needed
   - Anticipated interventions on content – in general, intervene more on process than on content. However, for this case study, depending upon the technical background of the students, there could be some confusion about the process of eutrophication, and how that influences dissolved oxygen content in the water.
   - Anticipated interventions on problem-solving process:
     - Process Generally: During the Problem Definition stage, the "listen, rephrase, perception check" step is expected to be performed at a low level by some participants. Use techniques on question development (e.g. Walsh and Sattes, 2005) to model good rephrasing behaviors
     - Cognitive: The "Identify constraints" element of the Problem Definition stage will require students to operate at Level 4 knowledge (Table 2). To facilitate this, review Nygren (2007b) for guiding growth to Level 4.
     - Social: The experienced facilitator will soon realize that the students need more help in the social and affective skill areas than the (cognitive) steps of the problem-solving process, or in the technical content to be covered. Use the Problem-Solving Skills Rubric (Table 1), particularly the performance area of teamwork, to be aware of social skills that may require constructive intervention
     - Affective: The Teamwork skill of "manages conflict" may be performed at a low level by individuals, and by the team. The Reflector or Team Leader can be invited aside to corroborate the observation, and can be coached to develop a proactive suggestion to the team that will change this dynamic, including by reviewing conflict management sites on the Internet
   - Extra challenge, additional question for team that finishes early – Be prepared to engage early finishing teams in additional work that they will be excited about, including a challenging guided inquiry, or a discussion with you about topics (observed by you) about which they were excited in the previous 50 minutes.

7. **Closure** time allotted____10-20 minutes_______

   A typical closure for this activity would be to have the spokesman from each team report out to the group on two topics:

   1. Summary and justification for their refined problem statement
   2. SII of their team performance.

Facilitation Plan—During/After Class

Within 24 hours after the activity, the facilitator should allocate at least 30 minutes to:

1. Perform a self-assessment by doing an SII on priority facilitation skills
2. Review his/her observation notes on SII forms of student work, and consider how to induce improved performance in the next class
3. Review constructive intervention notes on facilitation form to see whether trouble spots were predicted, and addressed. New trouble spots should be noted for the next iteration of the facilitation plan. Expert colleagues should be contacted for fresh perspectives on addressing such challenges

REFERENCES

Apple, D. K., & Baehr, M. (2007). Assessment methodology. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 449-452). Lisle, IL: Pacific Crest.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: W. H. Freeman.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., Bransford, J. D., & The Cognition and Technology Group at Vanderbilt. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *Journal of the Learning Sciences*, 7(3&4), 271-311.

Beyerlein, S., Davis, D., & Apple, D. (2007). Learning outcomes. In S. W. Beyerlein, C. Holmes & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 245-248). Lisle, IL: Pacific Crest.

Bloom, B.S., Engelhart, M.D., Furst, E.J., Hill, W.H., & Krathwohl, D.R. (1965). *Taxonomy of educational objectives: The classification of educational goals. Handbook 1: Cognitive domain.* New York: David McKay.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, 26(3&4), 369-398.

Burke, K., Lawrence, B., El-Sayed, M. & Apple, D. K. (2009). Process Education™ – Past, present and future. *International journal of process education*, 1, 35-42.

CAHE - Commission on Accountability in Higher Education. (2005). *Accountability for better results: A national imperative for higher education*. Boulder, CO: State Higher Education Executive Officers.

Capraro, R.M. & Slough, S. (Eds.) (2009). *Project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach*. Sense Publishers.

Cordon, D. (2007). Peer coaching. In S. W. Beyerlein, C. Holmes, & Apple, D. K. (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 471-474). Lisle, IL: Pacific Crest.

Cordon, D., Beyerlein, S., & Davis, D. (2007). Measuring quality in design. In S. W. Beyerlein, C. Holmes, & Apple, D. K. (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 83-86). Lisle, IL: Pacific Crest.

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.

Duncan-Hewitt, W. & Butler, S. (2007). Problem-based learning. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 391-394). Lisle, IL: Pacific Crest.

Eshach, H., & Bitterman, H. (2003). From case-based reasoning to problem-based learning. *Academic Medicine*. 78(5), 491–496.

Fink, L., & Dee. (2003). *Creating significant learning experiences: An integrated approach to designing college courses*. San Francisco: Jossey-Bass.

Hanson, D. (2007). Designing process oriented guided inquiry activities. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 281-284). Lisle, IL: Pacific Crest.

Jensen, S. (2007). Performance levels for an assessor. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 457-458). Lisle, IL: Pacific Crest.

Leise, C. (2007). Constructive intervention. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 365-368). Lisle, IL: Pacific Crest.

Michaelsen, L. K., Knight, A. B., & Fink, L. D. (2004). *Team-based learning: A transformative use of small groups in college teaching*. Ridley Park, PA: Stylus.

Minderhout, V. (2007a). Creating a facilitation plan. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 359-362). Lisle, IL: Pacific Crest.

Minderhout, V. (2007b). Facilitation tools. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 373-376). Lisle, IL: Pacific Crest.

Morgan, J., & Apple, D. K. (2007). The accelerator model. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 503-506). Lisle, IL: Pacific Crest.

Morgan, J., & Williams, B. C. (2007). Overview of problem solving. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 181-184). Lisle, IL: Pacific Crest.

Munakata-Marr, J., Leydens, J. A., & Moskal, B. M. (2009). Beyond technical issues: A case-study approach to introducing environmental engineering students to nontechnical wastewater engineering constraints. *Proceedings, 39th ASEE/IEEE Frontiers in Education Conference, October 18 - 21*, San Antonio, TX.

Myrvaagnes, E., with Brooks, P., Carroll, S., Smith, P. D., & Wolf, P. (1999). *Foundations of problem solving*. Lisle, IL: Pacific Crest.

Nygren, K. (2007a). Elevating knowledge from level 1 to level 3. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 165-168). Lisle, IL: Pacific Crest.

Nygren, K. (2007b). Developing working expertise (level 4 knowledge). In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 169-172). Lisle, IL: Pacific Crest.

Pacific Crest. (2009a). *Student success handbook*. Lisle IL: Pacific Crest.

Pacific Crest. (2009b). *Activity design institute handbook*. Lisle IL: Pacific Crest.

Parnes, S. (1992). *Source book for creative problem solving: A fifty-year digest of proven innovation processes.* Buffalo, NY: Creative Education Foundation.

SCANS: Secretary's Commission on Achieving Necessary Skills. (1991). *What work requires of schools: A SCANS report for America 2000.* Washington, DC: Department of Labor.

Schneider, R. M., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. *Journal of Research in Science Teaching*, 39(5), 410-422.

Smith, K.A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education*. 94, 87-101.

Smith, P. (2007a) Overview of facilitation. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 343-346) Lisle, IL: Pacific Crest.

Smith, P. (2007b) Facilitation methodology. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 351-354) Lisle, IL: Pacific Crest.

Smith, P. (2007c) Constructive intervention techniques. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 369-372). Lisle, IL: Pacific Crest.

Schneider, R. M., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Performance of students in project-based science classrooms on a national measure of science achievement. Journal of Research in Science Teaching, 39(5), 410-422

Stice, J. (Ed.). (1987). *Developing critical thinking and problem-solving abilities: New directions for teaching and learning #30*. San Francisco: Jossey-Bass.

Utschig, T. (2007) Moving toward an assessment culture. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 453-456). Lisle, IL: Pacific Crest.

Utschig, T., & Apple, D. K. (2009). Keys to improving academic assessment. *International Journal of Process Education*. 1:43-52. Retrieved January 30, 2010, from http://www.processeducation.org/ijpe/pdf/keys_assessment.pdf.

Walsh, J.A., & Sattes, B. D. (2005). *Quality questioning: Research-based practice to engage every learner.* Thousand Oaks, CA: Sage.

Wasserman, J., & Beyerlein, S. W. (2007). SII method for assessment reporting. In S. W. Beyerlein, C. Holmes, & D. K. Apple (Eds.), *Faculty guidebook: A comprehensive tool for improving faculty performance* (4th ed. pp. 465-466). Lisle, IL: Pacific Crest.

Woods, D. R. (2000). An evidence-based strategy for problem solving. *Journal of Engineering Education*, 89, 443-459.

Woods, D.R., Hrymak, A. N., Marshall, R. R., Wood, P. E., Crowe, C. M., Hoffman, T. W., Wright, J. D., Taylor, P. A., Woodhouse, K. A., & Bouchard, C. G. K. (1997). Developing problem-solving skills: The McMaster Problem Solving Program, *Journal of Engineering Education*, 86,75-91.