*Problem Solving is a content-independent process of identifying and defining a gap between expectations and perceptions in a given situation, and then developing the means to minimize this gap to satisfy that situation's key stakeholders.*

## Defining and Teaching Problem Solving

In his book, *How to Solve It* (1945), Mathematician and educator George Pólya framed problem solving as a methodical and teachable process. His approach consisted of four broad steps:

1. Understand the problem.
2. Devise a plan for solving it.
3. Carry out the plan.
4. Review/extend the work.

Pólya went into much greater detail for each step, and his work and conception of problem solving as a general process still resonates with educators who strive to teach problem solving within their classrooms. Few would dispute the claim that problem solving is a skill that the majority of students lack. Scholars from McMaster's University spent 25 years surveying the need for students to develop problem solving skills, how problem solving is taught (even asking whether it **can** be taught), the methods used, and what works (as well as what doesn't). According to the authors,

> *(O)ur research showed that: 1) there is an identified, subject-independent skill set called problem solving, and 2) that students do not develop the skill in a four-year program by having teachers display how they solve problems, by giving out sample solutions, by using open-ended problems or by having peers show their problem solving.* (Woods, Hrymak, Marshall, Wood, Crowe, Hoffman, et al., 1997)

## Problems in Teaching and Learning the Problem Solving Process

Approximately halfway between the publication of Pólya's work and the project report from McMaster's is where we find Pacific Crest Software offering the software packages Point Five and PC:SOLVE. Both were systems created to help learners solve problems (see the **Role of Technology** section). After marketing Point Five for approximately six months, an important discovery was made: clients who used the software reported that they wished they had gained the level of problem solving expertise that the software helped them develop while they were still undergraduate or graduate students. Dan Apple, president of Pacific Crest recalls,

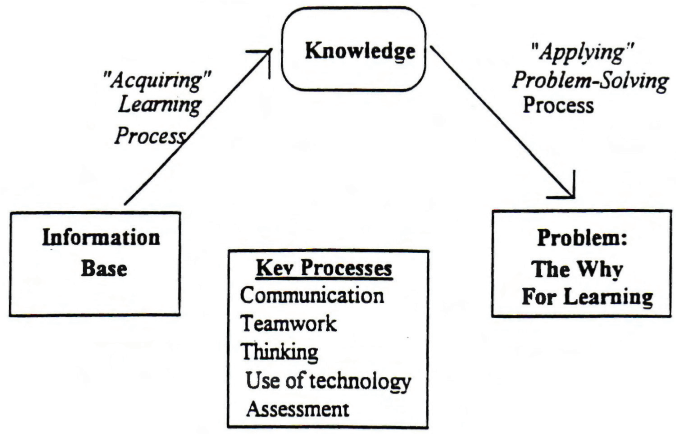
> *That's why we offered workshops on the problem solving process…the more workshops we held, the clearer it became that POINT FIVE and the problem solving skills it supported and built needed to be integrated into collegiate quantitative courses. By 1990, more than 500 colleges and universities had purchased a site license for PC:SOLVE (the upgraded version of Point Five), all in quantitative programs. In every case, the primary reason faculty had integrated PC:SOLVE into their courses was to target the problem solving process. (personal recollection)*

Sharing his own skills in solving large-scale public systems problems (Apple, 1980), Apple developed *An Introduction to Problem Solving Using PC:SOLVE* (1990) to teach students how to solve problems by using the Problem Solving Methodology (PSM), which represented an amalgamation of research, practice, and personal expertise (the current version of this methodology is shown in Figure 2). In doing so, he learned that putting a methodology into the hands of students, though helpful, wasn't enough; students needed to learn how to use the methodology, and faculty faced the very real struggle of how to teach problem solving from within the context of their discipline in a way that worked. The McMaster summary of teaching practices in problem solving strongly suggested that something else was needed to improve students' problem solving performance. The Problem Solving Across the Curriculum Conferences (1990-1996) helped faculty share scholarship and practices in learning and problem solving, thereby creating that "something else."

## Learning and Problem Solving: Interdependency

As noted in the **Learning Process Methodology** section, publication of *Learning Through Problem Solving (*Apple, Beyerlein & Schlesinger, 1992) was a formal result of the collaboration by faculty who had attended the 1990 conference. *Learning through Problem Solving* offered the Learning Process Model (a model of the learning process) and the Problem Solving Methodology (a model of the problem solving process). The relationship between these two processes is more than close; they are actually interdependent. The model in Figure 1 was presented in *Education as a Process* (Apple & Hurley-Lawrence, 1994), demonstrating that learning is the process of constructing knowledge **in order to solve given problems**. Learning produces transferable knowledge (acquisition process) while problem solving is the sophisticated usage of this knowledge in a specific situation (application process).

**Figure 1**




## Process Education Scholarship and Tools

Once we appreciate that learning and problem solving are wholly interdependent processes, we understand that nearly every aspect of Process Education is involved, to a greater or lesser extent, with problem solving. For example, every methodology can be reframed as an expression of the Problem Solving Methodology (see Figure 2), contextualized for an area of performance: the Communication Methodology allows us to solve the problem of miscommunication; the Reading Methodology allows us to solve the problem of inattentive or poor reading; the Personal Development Methodology allows us to solve the problem of personal stagnation or lack of growth. The critical point is that problem solving, even when accomplished by applying a methodology, is the **application** of knowledge gained through learning. As such, it should not be surprising that the degree or level of knowledge required before a learner can successfully solve problems is "Level III Application" knowledge according to the *Levels of Learner Knowledge* (Bobrowski, 2007). Bobrowski states, this is where,

> *…the learner has the skill to apply and transfer the particular item of knowledge to different situations and contexts, can recognize new contexts and situations to skillfully make use of this knowledge, and has taken the time to generalize the knowledge to determine ways to apply it, testing boundaries and linkages to other information. In other words, a learner with Level III knowledge is able to solve problems.*

It is for this reason that problem solving is Step 12 of the Learning Process Methodology (see the **Learning Process Methodology** section). During the problem solving step, Leise, Beyerlein, and Apple (2007) suggest that, "To enhance application of knowledge related to the learning objective, challenge yourself to solve more complex types of problems that are closer to those worked on by experts in the field." What if a learner attempts to solve problems without having developed Level III knowledge? As demonstrated in *An Evaluation System that Distinguishes Among Levels of Learning in Engineering and Technology* (Apple, Nygren, Williams, & Litynski 2002), without the requisite level of transferable knowledge, problem solving is elevated to a much more difficult research challenge.

While much of the scholarship in the *Faculty Guidebook* is as pertinent to the topic of problem solving as it is to learning, several modules stand out as addressing problem solving and the teaching of problem solving skills from a more global perspective. These include *Overview of Problem Solving* (Morgan & Williams, 2007), *Problem-Based Learning* (Duncan-Hewitt, 2007), *Developing Working Expertise (Level 4 Knowledge)* (Nygren, 2007), and *Distinguishing Between Problem Solving, Design and Research* (Cordon & Williams, 2007).

## Activity Design and Problem Solving

Problem solving is not only the process of applying knowledge gained through learning; it is a way of demonstrating understanding at the level of application/problem. That's why a challenge to solve problems is an important part of a high-quality learning activity (and thus the design of learning activities or curricula). Step 17 in the Activity Design Template (see the **Activity Design** section; Pacific Crest, 2008) is, "Problems to be addressed." This step is explained in *Designing Process-Oriented Guided-Inquiry Activities*:

> *These problems present new situations that require students to transfer, synthesize, and integrate what they have learned. The purpose is to move them to the problem-solving level of knowledge. The problems often have a real-world context, contain superfluous or missing information, have multiple parts, do not contain overt clues about the concepts needed to arrive at a solution, and may not have a right answer.* (Hanson, 2007)

For this reason, the vast majority of Process Education curricula offer problems to solve, learning challenges, or opportunities to demonstrate one's understanding. Examples include,

- *Learning to Learn: Becoming a Self-Grower*: Problems to solve are presented at the end of every learning experience (Apple, Morgan, & Hintze, 2013).

- *Quantitative Reasoning and Problem Solving*: Problem solving projects are presented for each chapter (Ellis, Apple, Watts, Hintze, Teeguarden, Cappetta, & Burke, 2014).
- *Foundations of Chemistry*: Many activities contain problems that, "require learners to synthesize ideas, transfer their learning to new contexts, and demonstrate their problem-solving skills" (Hanson, 2009).

## Problem Solving in Curricula

### *The Problem Solving Methodology*

*Foundations of Problem Solving* (Myrvaagnes, Brooks, Carroll, Smith, & Wolf, 1999) took the problem solving content from *Learning Through Problem Solving* and expanded it, including profiles (problem solvers, systems thinker, mathematical thinker, learner, and self-grower) as well as methodologies (10 in addition to the Problem Solving Methodology). The goal of the additional content was to support growth in quantitative reasoning as well as problem solving. By this time, the Problem Solving Methodology (as published in *Foundations of Problem Solving*) was the 10-step version used today and shown in Figure 2.

The *Student Success Toolbox* (Pacific Crest, 2011) offers numerous tools to support problem solving in the classroom, both for quantitative as well as qualitative contexts. The Problem Solving Methodology is well-represented among them:

- Holistic Rubric for Problem Solving
- Problem Solving Methodology (see Figure 2)
- Example of the Problem Solving Methodology
- Applying the Problem Solving Methodology (blank form)
- Addressing & Avoiding Errors form
- Profile of a Strong Problem Solver
- Learning Skills for Problem Solving

The Problem Solving Methodology appears in Chapter 5 of *Foundations of Learning* (Redfield & Hurley Lawrence, 2009), "Problem Solving Skills." This chapter offers many of the tools also found in the *Student Success Toolbox* (Pacific Crest, 2011), but they are contextualized with student examples and models. Even as students see the Problem Solving Methodology at work, they are challenged to identify a problem in their own life (personal or academic) and to solve it by applying the methodology. Sample problems in *Foundations of Learning* range from the purely qualitative (needing to meet someone, being unsure of the exact location of the agreed meeting place, and being unable to reach the other person by phone) to strongly quantitative problems (three students sharing a two-bedroom apartment and needing to determine equitable ways to assign rooms and split the rent).

Experience 6, "Methodologies: Unlocking Process Knowledge" in *Learning to Learn: Becoming a Self-*

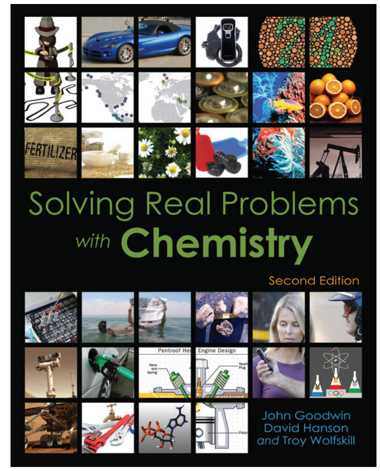
**Figure 2** Problem Solving Methodology

| Step | Explanation |
|---|---|
| 1 Define the problem | Identify and clearly state the problem. |
| 2 Identify key issues | Determine important issues associated with the problem. |
| 3 Collect data and information | Collect and assess available information relevant to the problem; determine what information is missing. |
| 4 Identify assumption | Clarify what assumptions are being made concerning the problem. |
| 5 Break the problem apart | Separate the problem into smaller sub-problems. |
| 6 Model sub-problems | Generate solutions for each sub-problem. |
| 7 Integrate solutions | Integrate the solutions from sub-problems into the main problem. |
| 8 Test and validate | Validate the solution; assess the quality of the solution. |
| 9 Generalize the solution | Determine how to generalize the problem solution for use in other situations. |
| 10 Communicate the solution | Present the solution in oral and/or written form along with documentation of the process |

*Grower* (Apple, Morgan, & Hintze, 2013) offers general information about the use of methodologies to facilitate and strengthen the learning process, but then immediately introduces the student to the Problem Solving Methodology as the prime example of learning and the application of knowledge. In the section of the experience entitled "In My Class," students are challenged with three different complex problem scenarios that satisfy the recommendations of a POGIL activity as noted previously ("…have a real-world context, contain superfluous or missing information, have multiple parts, do not contain overt clues about the concepts needed to arrive at a solution, and may not have a right answer"). Again, as in *Foundations of Learning*, students are then tasked with applying what they have learned of problem solving to solve a long-standing problem in their own life.

***Curricula in Service to Problem Solving***

*Solving Real Problems in Chemistry* (Goodwin, Slusher, Gilbert, & Hanson, 2009) is a special case and an example of curriculum specifically designed to increase student performance in solving chemistry-related problems in a real-world context. Each activity follows a process-oriented guided-inquiry structure with the sections shown in Figure 3.




The design of these activities is a world away from "having teachers display how they solve problems, by giving out sample solutions, by using open-ended problems or by having peers show their problem solving" (Woods, et al., 1997).

While *Solving Real Problems with Chemistry* truly is an outstanding example of how a disciplinary curriculum

**Figure 3** The Structure of an Activity in *Solving Real Problems with Chemistry*

| Activity Section | Purpose/Explanation |
|---|---|
| Introduction | Background information that frames the context for the problem |
| Prerequisite Knowledge | What students should be able to do before starting the activity |
| Applying Your New Skills | What students should be able to do after finishing the activity |
| The Problem | A statement of the problem |
| Information | Data and assumptions that may be helpful |
| Solve the Problem and Document Your Solution | A worksheet for teams to complete. The instructions for the worksheet reads as follows:<br><br>"Work with your team to solve the problem. Your instructor can provide three levels of help called gold, silver, and copper. *Au Help* presents a strategy that resembles the way experts think when they solve problems. The use of this strategy is illustrated and prompted to different degrees in *Ag Help* and *Cu Help*. As the semester progresses, you should move through these stages of *Help* to grow your problem solving skills. Your instructor will tell you what you need to do to document your solution."<br><br>(These Help pages are available online for instructors to share with their students.) |
| Does Your Answer Make Sense? | Critical thinking questions that prompt students to validate their problem solutions and process used |
| Building Your Problem-Solving Skills | Prompts for students to communicate, reflect on, and assess not only their problem solution, but the process they used to solve the problem |
| Got It! | Additional problems that require the student to take what they have learned in solving a problem and apply it to different problems in different contexts |

can be used to improve problem solving skills, the fundamental nature of the relationship between learning and problem solving means that problem solving informs every aspect of Process Education, not only its curricula, but its contexts, tools, and practices. And conversely, studying and elevating practices in every aspect of Process Education has the potential to improve the teaching and performance of problem solving.

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