Solving Problems or Problem Solving
What Are We Teaching Our Students?

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Abstract
Beyond engineering and engineering technology, employers in all fields want employees who can think critically and solve problems. Faculty in problem-solving courses have undoubtedly responded to the question, "Will the test be like the homework?" This raises the question of whether or not the test should be like the homework, and if not, how close should it be. Are students modeling their approach to problem solving or are they developing deep level processing and strategic approaches? How does homework reinforce the skills that we want students to develop? How are the various problem-solving courses working together to reinforce approaches to problem solving? Why do students do well with the homework at the end of a chapter and struggle with a test over several chapters? Why do students hate word problems? Students are not only charged with the responsibility of getting correct answers, they must also realize that sometimes there is more than one correct answer. Students must look beyond checking the answer in a solutions manual to the day that they will become the solutions manual. This calls for students to develop competence and confidence in their competence. Are we leaving the synthesis of problem solving skills to the student or are there approaches that we can utilize to reinforce student skills? This presentation will explore the answers to the questions raised in the preceding paragraph. There will also be a discussion on how students can become strategic problem solvers. It will further explore how homework, tests, and collaborative learning contribute to this process. Topics include skills acquisition, problem recognition and definition, strategic problem solving, extended applications, effective homework strategies, speed drills, test-taking, and study groups.

Beyond Critical Thinking

Most activities do not require creative thinking or application. Habit and routine are generally more than sufficient to accomplish day-to-day tasks and challenges. Too many people accept the notion that they are not creative, and that the best ideas belong to other people. Sometimes, creative thinking is equated with intelligence. Intelligence alone, however, does not assure good thinking. Intelligence may be more aptly associated with the capacity for creative thought rather than the extent to which that capacity is utilized. Knowledge may be the foundation of the creative thought process, but knowledge is not what makes a person creative. Critical thinking is emphasized frequently as a goal in education, but the ability to think critically is only one dimension of the creative thought process that students should develop. Thinking is more than an analytical exercise designed to produce a correct answer. It is not a random, undisciplined, serendipitous process that some genetically favored segment of the population enjoys while others are relegated to a mundane intellectual struggle. Creative thinking requires an attitude and an approach to manipulating knowledge and experience that facilitates the development of new ideas. The key is thinking about knowledge in new ways. Creative thinking can be taught and reinforced, but the process demands more from students and teachers than memorization and regurgitation of facts and formulas.

Thinking is often hard work and it will produce its share of results, however, it is the process of creative thinking and the enjoyment of the process that matters most. Debono (1995) describes a dozen diagnostic, analytical, and evaluative processing skills that contribute to creative thinking[1]: (1) recognition, (2) interpreting clues, (3) concept formation, (4) generating possibilities, (5) judgment, (6) developing alternatives, (7) comparison & choice, (8) analysis, (9) perception, (10) values & feelings, (11) design, and (12) problem solving.
Recognition is the process of attaching labels and a set of instructions to things that may be encountered. Recognition is a minimal requirement for the more challenging prospect of sorting into categories that have been created. Sorting tends to simplify life and the more categories there are, the easier the sorting becomes. There is a limit to the number of categories, however. Too many categories can make the sorting process less meaningful. The ability to sort is based on past knowledge and experience. Sometimes recognition is inexact and one may have to depend on clues or a preponderance of evidence to complete the sorting process. In other cases, new categories may have to be developed. The process of recognition, linking, and sorting gives rise to the development of concepts. Conceptualization facilitates sorting by reducing relatively complex distinctions to a readily accessible set of instructions. Programming a computer to recognize a previously unseen furry four-legged mammal as a cat, a dog, or neither is a much more complex process for the machine than it is for the human mind. Developing concepts that are broad, narrow, embedded or nested is part of the creative thought process.

Beyond conceptualization, the creative mind considers possibilities. Possibilities are considerations of old or new things that can be experienced in different ways. Vance & Deacon (1995) use the term "sensanation" to describe an experience that is broader than visualization in that it may use combinations of the senses in raising possibilities[2]. Guessing and developing hypotheses fall in this domain of creating possibilities. The brain sees what it has been trained or prepared to see so it must be prepared to see new patterns or new ideas. There is a difference between understanding how or why something has happened and creating a method or process that will cause something to happen. The former is a process of discovery while the latter represents creation. Possibilities may lead to probabilities, certainties, or dead ends, but they are a vital part of creative thinking. Experience and the sense of possibilities provide mental pictures of how things could or should be. This invites the process of judgment which is matching whether or not something is right, or consistent with experience, feelings, or expectations. Judgment is not always easy or comfortable, but it is a necessary part of decision-making. Therefore, it is important to know as much as possible about the criteria and the nature of the judgment.

The ability to create possibilities and exercise judgment are important parts of creative thinking, particularly when it comes to developing alternative resolutions to a problem or challenge. Alternatives may vary with circumstance, but they need to serve the same purpose. The goal is to seek better alternatives and that means resisting the temptation to stop searching for additional alternatives as soon as a viable one is presented. Time constraints generally prohibit exhaustive searches for all possible alternatives, so the creative mind must strike some balance in this process. The consideration of alternatives operates on two levels. One level pursues alternatives that satisfy given criteria or logic, but there is another level that questions the possibility of alternative criteria. Both levels require careful comparison of similarities and differences before making judgments and choices. The comparison process may often reveal that seemingly different objects may have surprising similarities, and similar objects may display remarkable differences. The actual choice of an alternative involves judgment on the short- and long-term consequences as well as the needs, taste, context, priorities, values, and objectives of the decision maker. Judgment requires some type of metric, but the creative thinker strives to be multi-metric. In fact, it may even be helpful to move outside the judgment system. Instead of applying a judgment system to an idea to determine its value, find a judgment system that brings value to the idea being considered. It is better to make a carefully and creatively reasoned choice than to be forced into defending or retracting a decision as a result of information that had not previously been considered.

Analysis is the process of breaking down complicated situations or ideas into simpler ones. Critical thinking which consists of analysis and judgment is frequently seen as the mainstay of thinking, but possibilities and creativity are the real engines of human progress. Analysis can often become embroiled in dialectics that seek to defeat competing ideas rather than generate new ones. Analysis may also stumble when the behaviors of complex systems or ideas are not determinable through examination of their elemental parts. Sometimes analysis reveals the true components of a situation or concept, but there are also times when analysis depends heavily on perception.

Perception is the way an individual sees the world at any particular time. It is based on experience, mood needs and thinking skills. The purpose of perception is the recognition of patterns that can be used to address recurring situations with minimal thinking. This actually liberates the mind to focus on other issues requiring deeper thought. Part of perception is selection or what a person chooses to see. Another part of perception is direction or where a person's attention is focused. Perception that is limited to a single view may miss additional correct answers or aspects of truth, so the challenge is finding a way to see the same thing in different ways. The person who consistently sees the world in a different way may be credited with some remarkable insight while still being caught in the trap of rigid thinking. Debono (1994) describes "lateral thinking" as the ability to continually shift perception and communicate those views in ways that are others can value[3].

The values and feelings a person brings to a particular endeavor ultimately determine the objectives. The problem with values and feelings is that they differ from person to person and group to group. Another problem is that the value of a particular concept, idea, or object may change with the context of the situation. The biggest problem, however, may be the seductive and mythical belief that creative thinking can occur without values and feelings playing some role in the process. The creative thinker is therefore challenged to consider how values and feelings impact possibilities, alternatives, judgment, and choice.

The ultimate end of creative thinking is design and problem solving. Design is a process of putting things together to achieve some objective. The questions in the design process are related to consideration of objectives, relevant factors, and available resources. A problem is a difficulty that an individual or group wants to eliminate or overcome. Whenever the path leading to some desired outcome is not easy or routine then moving along that path is considered a problem. Problem solving is a process of removing the cause of a problem or designing a way to move forward anyway. There is a great deal of literature on effective strategies or approaches to problem solving[4]. Regardless of the strategic approach, the process will be enhanced if creative thinking skills are applied.

Von Oech outlines several factors that tend to diminish how effectively students perform as creative thinkers[5]. One stumbling block is the often mistaken idea that there is only one right answer. While this may be true for relatively simple math problems, it is not the case for many of the complex problems students will face in the twenty-first century. Having a blind allegiance to the "rules" often prevents a thinker from exploring all the possibilities. Adhering to the artificial constraints that demand logic and seriousness while prohibiting foolishness and playfulness may destroy any opportunity for a breakthrough idea. In creative thinking ambiguity is far from fatal, and mistakes may, in fact, be helpful if students are prepared to learn from them. Creative thinking is not a linear process and the elements discussed in this paper are not sequential steps. It is important to have these processing skills available at all times and through all the steps that may be suggested in a problem solving or design strategy. Preparing students to be more creative thinkers is a matter of helping them understand that creative thinking is much broader than critical thinking. To the extent that faculty and staff provide opportunities for students to practice many of these skills in and outside of the classroom, students will become better thinkers and ultimately better problem solvers.

The Problem with Problem Solving

Educators work on a variety of challenges and one of the perennial challenges in technical subjects is problem solving. It seems surprising at times to consider the number of students who pursue engineering and technology majors while they are flustered at the thought of doing word problems. The main challenge is bringing students to a level of organized strategic thinking in attacking a problem. If their basic approach as problem solvers changes with every course then students lose the opportunity for reinforced practice. It is not enough that students muddle through somehow on their way to matching the answer in the back of the book. Students need to approach problems with a feeling of confidence in their ability to find solutions.

There are hundreds of approaches to problem solving and most of them offer a somewhat linear and sequential approach. The first key to becoming a more accomplished and confident problem solver is the expansion of creative thinking skills. Solving word problems is a thought process that requires multiple skills. Knowledge, experience, and insight are applied to new problems that may fall on a continuum that runs from very familiar to totally unfamiliar. Problem solving in engineering and technology is more than listing givens and unknowns then solving simultaneous equations. Students often struggle because they don't know when to name an unknown or how to set up the equations that will be helpful in finding a solution. Solving word problems involves the process skills of recognition, concept formation, judgment, comparison & choice, analysis, and a nested level of problem solving. It is not a linear process, but it is still strategic.

The difficulty is that students are not taught problem solving strategies. The thinking part of the problem is generally left to the student. How to recover from wrong turns or bad assumptions never appear. In the student's world all approaches are correct, direct, and blessed with impeccable logic. With all the solution manuals, answers in the back of the book, exercise problems, and problems worked in class, students are not given enough instruction and practice in problem solving methodology. Many books and educators provide a cursory view of the approach to solving a problem, however, the process is not clear to the confused student. Homework is assigned and if a student works diligently, then, perhaps, a strategy will emerge. By then, however, the class is on another chapter. The training in thinking is what students need most. Without it, struggling students may be left with the belief that problem solving requires some special aptitude that they do not possess. This notion may lead them away from developing the facility in problem solving that will serve them well in an engineering or engineering technology career. Too many students take an unorganized approach where they see numbers, variables, and a chance to move them around until something happens. Perhaps they read for key words, but they don't take it any further. Impatience leads them to a shallow surface level understanding of the problem and the hope is that manipulating numbers will clear a path. Students become frustrated when surface level problem solving fails to result in a stronger grasp of problem solving methodology[6].

Science and engineering courses approach their problems through mathematical insights that are embedded in word problems. Students frequently fall into the trap that the major goal in working assigned problems is obtaining the answer in the back of the book. The disdain that students have for carrying units throughout a problem, deprives them of the benefit of understanding how they can manipulate dimensional units to assure that they can arrive at a correct answer[7]. Students are also encouraged to proceed logically and to check the answer to see if it is reasonable. This is another idea that may be helpful, but sometimes intuition fails as the student examines a result. When a student's intuition is not helpful, the level of frustration over the effort tends to rise.

Problem Solving Approaches

There are numerous approaches to problem solving. Polya (1973) describes a four-step process for problem-solving that includes[7]: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back. The process steps are generally clear, but it is not enough to suggest these steps to students without providing some direction on what they mean, and how they apply. Over the years dozens of approaches have been devised, and the literature is filled with acronyms. Woods (2000), who examined over one hundred approaches to problem-solving, reports that students show significant gains in grades, confidence, problem-solving skills, attitude toward life-long learning, and self-assessment when they use problem solving strategies[4]. He elaborates on a six-step process where students:

(1) Engage: Reduce anxiety, Motivation to take risk
(2) Define stated problem
(3) Explore: Create internal idea of problem
(4) Plan a solution
(5) Do it: Carry out the plan
(6) Evaluate: Check and look back

Woods details the six steps and offers some guidance on internalizing them. The number of steps is probably not as important as whether or not a process is taught to students in a way that they can internalize. It is doubtful that the average student will read Polya's book or Woods' article. This leaves it to the academic community to provide some direction. The ultimate challenge is teaching problem solving to students as opposed to rewarding that smaller number of students who have learned on their own.

Beyond the Approach

For any problem solving approach to work students must broaden their creative thinking skills and they must also develop content skills. As students work with tables, develop concepts, or learn equations, they must learn to turn them inside out. Faculty should routinely ask students "what if" questions so that they begin to envision possibilities at the point of concept formation. Creative thinking, concepts and equations are tools and students will find it difficult to become masters at their craft if they are comfortable with their tools. Skills need drills and putting students in drill teams can facilitate the process.

Students struggle with problem recognition. Engineering and technology students have learned to do problems at the end of a section or chapter, but they struggle when the test is over multiple chapters. As students work problems they should ask what the clues are in the problem that suggest a particular strategy for attacking it. The question is generally unasked. Students should not only have a general problem solving strategy, they should develop more specific strategies for categories of problems. Students can create a set of diagnostic questions that they can refine by doing homework. If they do homework in this manner, they will develop a comfort level with their questions. The typical approach is for students to keep working problems and hope that a strategy emerges. Students should work problems for the benefit of extended application which means working problems they haven't seen previously. If students take a tested and comfortable strategy to a problem, it will not matter nearly as much that the test doesn't look like the homework.

Students should also be encouraged to participate in classroom speed drills. The object is to read, recognize, and map a strategy as quickly as possible. Students struggle on tests because they don't practice for speed. Problem solving can be treated like chess to the extent that there can be a relatively fast opening game, followed by the thought-provoking and challenging middle game, and concluding with a fairly predictable end-game where the problem has been reduced to math.

Whether students use the strategy suggested by Polya, by Woods, or some other strategy, their ultimate goal is to develop confidence in their competence. To be confident students must be confident in their understanding of the problem. They must be confident in the tools and the analysis that they apply to the problem. They must be confident in the accuracy of their computations, and they must feel confident in their ability to repeat the process. At some point students must emerge as the solution manual rather than relying on it.

To develop this confidence, their first challenge is to read the problem on multiple levels. They need to read beyond key words, givens and unknowns. They need to read all words for details, implications, clues, concepts, similarities, and differences. They need to read for how the problem can be broken into smaller problems. They need to read for missing or extraneous information, and they need to read for assumptions. If they haven't read for these things, they haven't read enough. This is referred to as becoming a "technodetective" Their mission is to ultimately turn the problem into sketches and equations that fully represent the words. From here they can select a strategy and there are many that will work.

This process can be reinforced if students are encouraged to work in study groups. Students can be encouraged to set up groups under the following conditions:

- Identify 3-5 students in your subject class who appear to be serious students. This determination may be made by noting seating, attendance, class participation, attitude and/or grades.
- Approach those students to organize or join a study group that will operate under the following commitments:
    - Three to four members (No more than five)
    - Regular meetings
    - Set an agenda for each session to narrow the focus.
    - Each member reads, prepares and attempts problems prior to the group session.
    - Each member uses other resources outside of the group sessions.
    - Share any information or knowledge obtained outside the group with other members of the group.
    - Challenge other group members to explain and defend theory and problem solutions.
    - Provide encouragement and support to group members

Motivation

Any approach is only as good as the level of motivation that students bring. The following tips can help students to sustain their motivation**:**

- Visualize your success and reinforce the visualization by sharing it with someone.
- Surround yourself by a good team (mentors, coaches, practice partners, and cheerleaders).
- Clarify the expectations. Use curiosity as a motive for learning.
- Concentrate on the tasks rather than becoming distracted by fear of failure.
- Help your teachers to know you and something about your goals.
- Find ways to cooperate rather than compete (Study Groups). Your adversary is ignorance.
- Portray effort as investment rather than risk.
- Portray skill development as incremental, focus on mastery and deep level processing.
- Use words and self talk stated in a positive fashion.
- Bring energy to class. Become involved in classroom activities.
- Find out how and when you learn best. Manage your time.
- Find rewards that you control. Find a source of smiles, nods, and encouragement.
- If you can make learning fun, then by all means do it!
- Respond to frustration by retracing steps to find mistakes or by determining alternative ways of approaching problems (don't quit). Develop a stress management strategy
- Attribute failures to insufficient effort, lack of information, or reliance on ineffective strategies rather than to lack of ability.
- Become a cheerleader for someone else.
- Keep a sense of humor.

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