

# PROBLEM-SOLVING STRATEGIES

The following JETS competition resource is an excerpt from “Total Quality Learning® (TQL®): A Team Development Workbook for Thinking Skills Sports.” The techniques presented in this resource will enable a team of high school students to perform effectively in team competitions such as the Tests of Engineering Aptitude, Mathematics and Science (TEAMS) and The National Engineering Design Challenge (NEDC) competitions.

The logo for JETS is rendered in a large, bold, black, italicized sans-serif font. The letters are thick and slanted to the right, with a white outline or shadow effect that gives it a three-dimensional appearance. The 'J' and 'S' are particularly prominent due to their size and the slant.

**Promoting Interest in Engineering,  
Science, Mathematics, and Technology®**

# PROBLEM-SOLVING STRATEGIES

## **Problem-Solving--A Rigorous Process**

For JETS programs—TEAMS and NEDC—the Problem-Solving process is deliberately disciplined. Following the formal Problem-Solving process—at least until the entire team is comfortable and familiar with it and is able to effectively follow the steps—increases the team's chance for success.

Teacher-Coaches learned a process similar to formalized Problem-Solving during college and in their first year as teachers. Preparing formal written lesson plans—including instructional and behavioral objectives, general strategies, specific activities, materials and resources, and evaluation methods (and frequently more categories)—is generally considered a tedious and somewhat unproductive activity. However, once the formal thinking process that the lesson plan technique forces is learned, it becomes part of the normal routine and thinking process teachers go through in their daily planning. After a relatively short period, the steps of a properly sequenced and effective lesson become a normal part of the teacher's preparation. So too does the formal Problem-Solving process become a natural and easily-used technique for Quality Teams—once it is learned.

## **The Scientific and Engineering Methods**

Most schools teach the scientific method. Few teach the difference between the scientific method and the engineering method. While there are similarities, and some steps are the same, the two methods have different purposes and outcomes.

The **scientific method** takes a problem and seeks information through research, for the purpose of seeking new knowledge. This new knowledge may or may not be applied to the development of a new product. A new product that may be developed by using the scientific method is not the primary motivation for using the scientific method.

The **engineering method**, on the other hand, is not used for the primary purpose of gaining new knowledge. The engineering method, which is applicable to the TEAMS and NEDC competitions, applies knowledge to a problem and produces a new solution or product. The result of the engineering method is usually a new product or process. Knowledge gained during the engineering method is not the primary purpose for using the method.

For example, the scientist may discover that a particular combination of chemicals produces a new molecular structure that is non-polluting and appears compatible with gasoline under certain conditions, but at this time there is no proven use for this new structure. The finding is interesting and potentially useful.

The engineer, however, would seek ways to use this new molecular structure to enhance the performance of gasoline, to manufacture the structure, and to ensure its continued effectiveness over a long period. Engineers would also ensure that it is environmentally sound and cost-efficient. The structure, and the knowledge gained from its discovery, can now be used to benefit humankind.

## **The JETS Problem-Solving Process**

There is considerable debate regarding the number of steps in a Problem-Solving process. Some authors list only 4 steps, while other noted experts list anywhere from 7 to 20 steps. Other writers identify as many as 50 discrete sub-steps under a smaller number of major headings in the Problem-Solving process.

### **JETS has defined a system with seven major areas of focus:**

- Determine why acting is necessary.
- Define the exact problem.
- Decide how to approach the problem.
- Focus on an appropriate solution.
- Implement the solution.
- Test the solution.
- Evaluate and refine the solution.

Under these seven major steps, there are additional sub-steps. The large number of sub-steps enables you and your team to see the flow of the total process. Some sub-steps may be eliminated by your team or not consciously worked through.

For example, in a TEAMS competition, the key element of success is for the team to correctly solve as many problems as possible in a short period of time. Detailed research during the TEAMS competition is unlikely, as is Brainstorming creative answers to the problem (since the scope of the problems' answers are somewhat defined by the nature of the test). However, the ability of some team members to immediately determine whether a textbook must be referenced or if someone else on the team has this knowledge may give a well-prepared team the edge. Many answers to TEAMS problems come from intuitive insights, specific facts that aid in the solution, and by quickly building off team input to iterate a solution. Obviously, many of the steps in the detailed engineer's Problem-Solving sub-steps listed below would not be used during the Competition, but the team should work through most of the sub-steps as part of its training process.

For TEAMS, the team may practice all of the steps of the strategy during training. At the competition, the entire process, if properly practiced beforehand, will be condensed into an organized and efficient one that enables each question to be answered in a few minutes.

Success in the NEDC is enhanced when teams use most of the steps of the Problem-Solving process during their preparation for the competition. Again, at the competition they will not be using this process, but preparing by rigorous application of the process will make a significant difference in the team's level of quality of the solution and presentation.

## **THE ENGINEER'S PROBLEM-SOLVING STEPS**

### **Determine Why Acting is Necessary:**

1. Determine that there is a need to act.
2. Verify the need to act by gathering facts.

### **Define the Exact Problem:**

3. Define the problem.
4. Analyze the problem.
5. Determine the problem's scope and limits.
6. Gather resources that may help clarify or enhance your understanding of the problem or sub-problems.

### **Decide How to Approach the Problem:**

7. Generate a wide range of ideas about how to address or go about solving the problem or sub-problems.
8. Plan and select an approach or solution framework by which to initiate a formal Problem-Solving process.
9. Generate alternatives and elaborate on proposed solutions.

### **Focus On an Appropriate Solution:**

10. Focus.
11. Intensify data and resource search and analysis.
12. Evaluate and select the best alternative.

### **Implement the Solution:**

13. Design, build or implement the best solution.

### **Test the Solution:**

14. Test the implementation.
15. Refine and optimize the solution.

### **Evaluate and Refine the Solution:**

16. Evaluate performance and track effectiveness.
17. Maintain and sustain improvement.
18. Repeat the process to improve the new solution.

## THE ENGINEER'S PROBLEM-SOLVING STEPS

For TEAMS and the NEDC, many steps are pre-defined by the program developers.

### **Step 1. Determine that there is a need to act.**

The ultimate concern of engineering is for utility and for fulfilling the needs of humankind. Action for no defined purpose is wasted energy.

- Why do the work?
- Who has determined that a need exists and by what criteria?
- Are the needs purely physical or economic, or is there a social dimension?

Is there a need for a new or improved product or, under the current or likely future conditions, will the prior product perform adequately? This is NOT to say "If it ain't broke, don't fix it!" For example, propeller aircraft work very well and the concept was never "broke." However, someone determined that the field of aerospace needed to provide better and faster services and this could be done by applying jet principles to commercial aircraft.

For TEAMS, your team may have determined that the benefits gained from participating in TEAMS will help them understand the types of problems engineers face or to see how mathematics and science relate to real-world problems. By electing to participate, the team has determined that a need of some sort exists.

### **Step 2. Verify the need to act by gathering facts.**

The concerns of one person or a small group, while important, should not color a team's perception of the need to address a problem.

- Is the problem sufficiently important to justify action based on various constraints?
- Is the problem one that will have an impact on a sufficiently large percent of humankind to justify it being addressed?
- What are the facts and do they justify proceeding at all or perhaps only in a specific direction?

Entrepreneurs sometimes make the mistake of thinking that the whole world needs, and wants, their better gizmo. Based on this often false assumption they spend considerable time, effort and money developing a better gizmo that, in reality, only they and a few others really wanted or could afford.

In some cases, this is caused by a lack of broad-based preliminary market research or just a failure to look honestly at the situation.

### **Step 3. Define the problem.**

State the problem with respect to exactly what needs to be developed or accomplished, or what customer needs will be satisfied by solving this problem.

It is important that all team members agree on and are comfortable with the definition of the problem. Misinterpreting the problem statement is likely to cause the solution to be rejected.

- Is the statement of the problem clear?
- Does the statement of the problem set a clear objective? If not, and the problem can not be restated by the team, can the team agree on how they will define the outcome or objective?
- Are specific potential solutions ruled out by the parameters of the definition?
- Are sub-problems included and can they be addressed separately? Analysis of sub-problems is addressed in a later step.
- Does the problem define the population to which the solution will be applied?

At this stage the team is refining its thoughts on exactly what the team Members must do and what they can or cannot do. Interpretation of the problem must come after careful analysis of the problem statement.

*For example, if the problem is:*

"Design a robot which will move 10 feet, remove three ping-pong balls from a box, put the balls in a bag, return to the starting place with the bag of balls and signal when it is done."

*The team must determine the exact parameters of the problem statement. They may ask:*

- Must the robot walk? (No)
- Must the robot pick up the balls? (No)
- Must the robot hold the bag? (No)
- Must the robot talk? (No)

In the NEDC, the problem is clearly stated. A failing of many teams during the presentation of their NEDC solutions is that they often focus on items, problems or things they learned that are valuable to them, but that are neither required nor scored in the competition. For example, telling the judges the details of how they learned about the characteristics of different types of composites is interesting but this time would be better used focusing on the required outcomes (judging and scoring criteria) as specified in the NEDC rules and regulations.

In TEAMS the students have also been provided with a clear problem statement—solve correctly as many problems as they can in a given time period. The TEAMS competition is an outcome event. The results are determined by successfully answering the greatest number of questions. While the thinking process behind each answer is important to the team's ultimate success, and is the critical learning element of this process, having others know of this process at the competition is not part of the event.

**Step 4. Analyze the problem.**

Problems normally have underlying causes or factors that may or may not be obvious. Determining what these factors or causes are is essential to addressing the problem properly.

For example, if, in an industrial setting, a company decides to increase the use of robots the decision may be made for various reasons. The factory may be in a location where there are insufficient numbers of reliable or trained workers (a personnel problem), the Federal Government may have implemented new safety standards for workers and the only way to meet them is to have robots replace humans (both a personnel and regulatory problem), or profits are decreasing and the company must increase its production output to retain profitability (a financial problem) and the only way to do this is to supplement workers with robots. Each underlying reason could have a different impact on the type and number of robots that are designed for this business.

**Step 5. Determine the problem's scope and limits.**

*Identify sub-problems that may exist or that must be solved, and clarify restrictions and the realm of allowable solutions.*

- What, if any, sub-problems exist?
- Can we break the problem down into a sequence of sub-problems?
- In what priority should the sub-problems be addressed?
- What bounds are established by time, cost, space, safety, production capabilities and processes, aesthetics, energy costs, ecology, or the need to recycle?
- Are bounding conditions independent? Are they absolute or can there be trade-offs and adjustments?
- What limits are imposed by standards or codes?

*Using the robot problem above, the sub-problems would include:*

- The robot must move a distance of 10 feet.
- The robot must remove 3 ping pong balls from a box.
- The robot must place the ping pong balls into a bag.
- The robot must move 10 feet back to the starting place.
- The robot must transport the bag of balls back to the starting place.
- The robot must signal when finished.

*As TEAMS teams practice, they need to ask questions such as:*

- Does this problem require a broad or narrow knowledge of science?
- Does the problem require considerable computation, maybe with a calculator?
- Does the problem require knowledge of mechanics or the ability to visualize an object in three dimensions?

**Step 6. Gather resources that may help clarify or enhance your understanding of the problem or sub-problems.**

Proposing solutions without a somewhat broader understanding of the problem as it is provided to a team can often lead to "wheel spinning." Your team may decide to approach an engineer or others and ask them how they "read" or interpret a problem and its underlying assumptions or causes.

- Have others tried to solve this problem before? Who, when, how and where?
- What problems did others find in trying to solve this problem?
- What do we have to find out to solve this?
- Is there a single resource document or place where this type of information might be located? If so, might it save us a lot of time?

For TEAMS, team members will need to know what resource books or notes they will have with them, what those references contain, and where the information can be found in them. Having all team members bring all of their texts is generally not a useful strategy since there will be too many for them to reference.

**Step 7. Generate a wide range of ideas about how to address or go about solving the problem or sub-problems.**

At this point, a mini-Brainstorming session might be helpful. The purpose here is to get the team members thinking in a broad way, to expand their thinking "beyond normal boxes," and to think both about the problem itself and about methods of solution.

For example, the team members might list ways in which they could go about solving the problem. These might include designing a new device, searching catalogs to buy a somewhat similar device and modifying it, or even taking the chance of redefining the problem to fit their vision of what this device should do. However, the latter is generally not recommended.

Using the robot problem, the team might determine that in order to move a distance of 10 feet, the robot could walk, roll, fly, be dragged or be pushed.

The purpose here is not to propose detailed solutions, but to expand the team's thinking about possibilities.

**Step 8. Plan and select an approach or solution framework by which to initiate a formal Problem-Solving process.**

Determine what activities the team must go through to solve the problem and in what order the parts of the problem should be approached. Now that the group has defined the problem, has some ideas and knowledge of available resources, and may even have some unique possible solutions, it will have to figure out what steps to take to bring this information together and to accomplish a task or set of tasks that will develop a quality solution to the problem.

The problem may need to be approached in a "parallel" fashion rather than by using a "serial" approach. (A serial approach is when every step is dependent on the completion of the preceding step and multiple steps cannot be accomplished simultaneously. Parallel processing is when individuals, sub-teams or the full group addresses multiple problems and activities at the same time by organizing time and resources into a Matrix of opportunities.)

- Can one group of NEDC team members visit a site where this problem exists so that they can talk to potential users while another group researches what materials are the strongest for similar applications?
- What parts can be built independent of other parts?
- How can we identify and distribute TEAMS problems quickly and efficiently so that our "physics-math" sub-team can have the most time to work together and also maybe have time at the end to assist other sub-teams?

**Step 9. Generate alternatives and elaborate on proposed solutions.**

At this stage, an NEDC team should expand and add "meat" to their proposed solutions. The team provides itself with a "picture" of the broadest possible attack on the problem. As this process moves forward, the team is likely to add new alternatives to the list because team members will find that ideas presented and discussed for one solution can be combined with other ideas or even eliminated. Is one solution better than the others? Is this better solution "doable?" During this stage, some ideas will quickly prove inadequate because they do not lend themselves to becoming a fully developed solution.

For TEAMS, the team may determine that a problem or set of problems can be deduced intuitively and without calculation because of some unique mathematical or scientific principle a team member knows that virtually eliminates most of the answer choices given.

**Step 10. Focus**

Having used the techniques presented in the previous chapter, the students can now determine the one or two solutions that have the greatest potential for success.

TEAMS students often skip quickly to this step. Since they have practiced solving problems and know where specific important data can be found, they may quickly read the problem and be able to discard three possible answers immediately. They can then focus their efforts on deciding which of the two remaining answers is better.

**Step 11. Intensify data and resource search and analysis.**

At this point, an NEDC or TEAMS team should be dealing with no more than two reasonable answers or approaches to a solution. The team should do a relatively quick but rigorous search of resources to help them decide on the final choice.

- If data is known, where do we find it?
- If data is unknown, what research do we have to perform and should we perform it?
- What guesses or estimates do we have to make, and do we feel comfortable with those?
- What is the validity of the information used?

**Step 12. Evaluate and select the best alternative.**

The results of the team's resource search can be discussed and used as supporting information or to help define criteria. The group may elect to use a Rule of Reduction, Multi-Voting, or Matrix approach to make the final decision on which option to pursue or which way to proceed.

The basic decision is to determine which idea or approach will actually best solve the problem.

- What criteria are the most important?
- If validation tests are required, which test do we select?

**Step 13. Design, build or implement the best solution.**

Using all the prior data, the team should have a broad understanding of what is needed to complete the NEDC solution or to make the final answer choice on a TEAMS problem. Remember, in TEAMS getting to this step may have taken only 30 seconds to as long as a few minutes; in NEDC, the process may have taken weeks. In some industries that make billion-dollar decisions, this process may continue for a decade.

In the NEDC, the Problem-Solving process now repeats itself for each stage of the NEDC implementation process. For TEAMS, it gets applied to the next TEAMS problem. However, while this process repeats, the original process is not yet complete. For the NEDC the solution, design or product must be tested, refined and optimized. Its performance must be evaluated. Aspects yielding positive performance will be retained and weak areas must be re-addressed. Most important, the improvements noted from implementing this solution must be sustained and become the new standard from which to improve. Then the process begins again.

In TEAMS, this process may be summarized by having sub-teams check other sub-teams answers or by checking work within one sub-team. For both activities, the process is applicable to discussing and evaluating your Team's performance and designing an improvement plan for next year.

**Step 14. Test the implementation.**

In some ways the analysis of this step is obvious. Did the solution work? To what degree did the solution work?

- Does the product or solution work as anticipated?
- Does it solve the problem?
- To what extent is the final real object, process or system different from the concept?
- What are the "errors of translation?"
- What is the effect of every part on the whole?
- Was the answer right?
- Was our thinking process flawed?

**Step 15. Refine and optimize the solution.**

Some people refer to this step as "tweaking," or informally searching for ways to improve the solution quickly.

- Is the solution performing adequately?
- Are there parts of the solution that can be improved without major changes or costs?
- Can the solution be easily made to perform better?
- For TEAMS, could other sub-teams approach this problem in the time remaining?

**Step 16. Evaluate performance and track effectiveness.**

This is the stage where the Team will formally test the design when subjected to the environment of actual service. This could be a field test or pilot test. However, those preliminary tests have usually already been completed.

This stage is not only the engineering test, but it is the marketing test as well. The design may be excellent and flawless, but unless the product solves the problem and unless people, including NEDC judges and TEAMS scorers, determine that your solution meets their needs or those defined by the problem or question the product or solution cannot be considered as being as effective as it could be.

- To what degree does the product satisfy the original design requirements?
- Can the product still be improved?
- Did the design process anticipate the nature or effect of the service environment?
- How many unanticipated problems came up?
- Did the product sell as expected?
- Did the judges see the presentation, solution or product in the same way the team did?

- Did the TEAMS test developers interpret the physics question the same way we did?

**Step 17. Maintain and sustain improvement.**

Change or improvement is measured by degree and duration. Solutions that only work for a short period of time or those that narrowly address the problem are not usually as valuable as those that can be sustained and have a broader impact on the target population.

To sustain the impact of the better solution, standardization must ensue. The improvement becomes the new minimum standard of success. The improvement is now looked at not as the ultimate result but a new foundation on which to repeat the process.

**Step 18. Repeat the process to improve the new solution.**

**Quality is the continued rethinking and refining of products and services to meet the needs of the customers.**

