D. H. Stamatis

SIX SIGMA AND BEYOND

Problem Solving and Basic Mathematics

St. Lucie Press

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to
Timothy,
the entrepreneur

Preface

Problem solving is an attempt to understand the nature of human interaction and the differences in cognitive functioning of individuals which are observed again and again. This volume is specifically designed to address the issue of cognitive functioning by reviewing selected literature on the topic, to provide a generic approach to problem solving, and to review the basic mathematics that most people would use in the process.

In all walks of life, at some time, all of us will likely use the process of problem solving. While we all talk about it and we all use it, chances are we all mean different things by it. In this volume, I have attempted to organize the topic and provide a structured approach based on the scientific method.

In conjunction with six sigma methodology, I believe that it is fundamental to understand the process, not only because as a black belt one would use "an" approach to solve a specific concern, project, problem, etc., but because problem solving will help define the problem as well.

This volume is intended to be a manual rather than a text for understanding the investigation process of problem solving. Toward that end, it is written to nontechnical as well as technical individuals. I have assumed that some readers may not have post high-school education or speak fluent English. The exception is the Introduction. In the Introduction, I dwell on the theoretical aspects of problem solving. If it is too cumbersome, the reader may skip this section without losing any understanding of the process. The literature review may enhance understanding, but it is not essential for use of the approach as explained in the following chapters.

One may challenge this assumption and claim that anyone pursuing six sigma should have a basic understanding of problem-solving techniques and processes. From my experience, I can vouch that Fortune 500 companies have employees who are not familiar with the process or techniques. (In fact, very recently, I was with a client when I noticed that a training class of *basic math* was offered specifically for engineers. It was this experience that became the impetus for this volume, especially the inclusion of the basic mathematics in Part II.) The intent is not to embarrass or humiliate anyone; rather it is to help facilitate the process of solving problems with a basic commonality of understanding. If the reader is already proficient, obviously the math portion of this volume may be skipped without any loss of continuity.

So, let us examine the issue of "problem solving." The ability to solve problems is a central prerequisite for human survival, but the mechanics of the process itself often remain a puzzle for most of us — a puzzle because problem solving is a very complex cognitive process, not necessarily a behavior that can be observed. Perhaps the reason why several people find different, similar, or even the same solution to the same problem.

This is a very important issue and it is the reason why this volume is in the form of a manual rather than a text. My hope is that readers will recognize the stage of the process they are involved with and as a consequence will pick the right spot for their analysis. In each step of the process, a variety of questions and flow charts are provided to facilitate understanding. By no means do I believe that all options have been exhausted; rather I believe that an initial generic guideline to provide a solution for a given problem has been created.

D. H. Stamatis

About the Author

D. H. Stamatis, Ph.D., ASQC-Fellow, CQE, CMfgE, is currently president of Contemporary Consultants, in Southgate, Michigan. He received his B.S. and B.A. degrees in marketing from Wayne State University, his Master's degree from Central Michigan University, and his Ph.D. degree in instructional technology and business/statistics from Wayne State University.

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With more than 30 years of experience in management, quality training, and consulting, Dr. Stamatis has served and consulted for numerous industries in the private and public sectors. His consulting extends across the United States, Southeast Asia, Japan, China, India, and Europe. Dr. Stamatis has written more than 60 articles, presented many speeches at national and international conferences on quality. He is a contributing author in several books and the sole author of 12 books. In addition, he has performed more than 100 automotive-related audits and 25 preassessment ISO 9000 audits, and has helped several companies attain certification. He is an active member of the Detroit Engineering Society, the American Society for Training and Development, the American Marketing Association, and the American Research Association, and a fellow of the American Society for Quality Control.

Acknowledgments

In a typical book, an author has several, if not many, individuals who helped in the process of completing it. In this mammoth work, so many individuals have helped that I am concerned that I might forget someone.

Sometimes, writing a book is a collective undertaking by many people. However, to write a book that conveys hundreds of thoughts, principles, and ways of doing things would truly be a Herculean task for one individual. Since I am definitely not Hercules or Superman, I depended on many people over the years to guide me and help me formulate my thoughts and opinions about many things, including this work. To thank everyone by name who has contributed to this work would be impossible, although I am indebted to all of them for their contributions. However, there are some organizations and individuals who stand out. Without them this series would not have been possible.

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I would like to thank the Six Sigma Academy for granting permission for use of some of its material in comparing the classical approach to the new approach of defects as well as the chart of significant differences between three sigma, four sigma, five sigma, and six sigma; the American Marketing Association for granting permission to summarize the data articles from *Marketing News*; the American Society for Training and Development for granting permission for use of the table, the Most Likely Influences of Program Development Practices, from *Training and Development*; Tracom Co. for granting permission for use of the material on the four social styles model; and the American Society for Quality (ASQ) for granting permission to summarize some key issues about teams from "Making Perfect Harmony with Teams" published in *ONQ* magazine and some definitions and characteristics of quality from *The Certified Quality Manager Handbook* (1999).

Additionally, I would like to thank Mr. C. H. Wong for his persistence over the last four years to write this book. His faith in me and encouragement will never be forgotten; Dr. J. Farr for his thoughtful suggestions throughout the writing process and his insight on teams; Dr. W. Landrum for teaching me what teams are all about and why we must pursue the concept in the future. His futuristic insight has been an inspiration. His practice of teams has been a model for me to follow; my colleagues Dr. R. Rosa, Mr. H. Jamal, Dr. A. Crocker, and Dr. D. Demis, as well as

Mr. J. Stewart and Mr. R. Start for their countless hours of discussions in formulating the content of these volumes in its final format; and J. Malicki, C. Robinson, and S. Stamatis for computer work on the early drafts and final figures in the text.

I want to thank Ford Motor Company and especially, Mr. B. Kiger, Mr. R. H. Rosier, Mr. A. Calunas, and Ms. L. McElhaney for their efforts to obtain permission for using the questions of the Global 8D. Without their personal intercession, the book would be missing an important contribution to problem solving.

As always, I would like to thank my personal inspiration, bouncing board, navigator, and editor, Carla, for her continued enthusiastic attitude during my most trying times. Especially for this work did she demonstrate her extraordinary patience, encouragement, and understanding by putting up with me.

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Finally, my greatest appreciation is reserved for the seminar participants and students of Central Michigan University. Through their input, concerns, and discussions, I was able to formulate these volumes to become a reality. Without their active participation and comments, these volumes would never have been completed.

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Part I

Problem Solving

Introduction

The six sigma methodology requires that a project be selected and an appropriate resolution be achieved in such a way that both the customer and organization will benefit — not a bad expectation. However, this is easier said than done. To select a project presupposes a need for improvement. The implication for that improvement is that either the customer and/or the organization is not satisfied with the product and/or service or status quo of whatever is happening "right now" in the organization.

To select the problem is only half of the task. The other half is to resolve it. In Volume II, the focus is on the process of "how" to go about solving "a" problem, recognizing that more often than not, the solution is going to be through a team. Therefore, whoever is involved must understand the dynamics of team formation and performance. (This may be a good time to review Part II of Volume I.)

From a problem-solving perspective, a team is an entity made up of individuals who have some ownership of the problem, complement each other on the skills necessary to resolve the problem, and have knowledge of the process (both the problem solving process and the process where the problem exists).

For the team to have positive results, three basic strategies must be understood and planned for:

- *Solving the problem.* Solving the problem comprises eight coping strategies (seek organizational support; focus on the specificity of the problem with excellent operational definition; physical interaction with all members; seek cooperative diversion; invest in excellent to good intrarelationships within the team; seek to belong in a winner environment; be willing to work hard and achieve results based on set criteria on a *a priori* basis; and focus on success) and represents a style of coping characterized by working at a problem while remaining optimistic, fit, relaxed, and organizationally connected.
- *Nonproductive coping*. Nonproductive coping comprises eight strategies (worry; seek to belong; wishful thinking; to not cope, ignore the problem in the sense of postponing the due date for any reason; reduce tension; keep to self; blame self). These strategies reflect a combination of nonproductive avoidance behaviors which are empirically associated with an inability to cope. When this happens, the project falls apart.

- *Reference to others*. Reference to others contains four strategies (seek organizational support; seek professional help; seek spiritual support; seek social action) and can be characterized by turning to others for support whether they be peers, professionals, or deities.

To facilitate these strategies, Chapter 1 provides a somewhat detailed rationale and a theoretical explanation of the problem-solving process. Also introduced are some generic terminology and a path for problem solving.

In Chapter 2, the focus is on problem solving from a quality perspective. Introduced is the definition of a problem. Then progressively some of the issues involved with quality problem solving are addressed.

Chapter 3, addresses some of the key concepts in team dynamics as they relate to problem solving. A discussion on the problem solving cycle follows and the point is made that most of us keep regurgitating problems without really resolving them. Also emphasized is the process improvement cycle. Some of the issues involved are reviewed and a flow chart to show the continual improvement cycle is introduced.

Chapter 4 introduces some basic tools that are used in problem solving. Only an overview is given in this volume, recognizing that some of these tools will be fully developed in Volumes III and IV and some additional advanced tools will be introduced in Volumes V and VI.

In Chapter 5, a version of the methodology used in the automotive industry, specifically at Ford Motor Company, and known as the 8D methodology is introduced. It is called the Global Problem Solving (GPS) process, since its application may be used in any industry. It is a very simple methodology, but demands a tremendous amount of time to identify and recommend a solution. However, it is very effective, when used properly.

Chapter 6 introduces some concepts and approaches of problem solving specific to the six sigma project methodology.

In Part II (Chapters 7 to 21), for the convenience of the reader who may not be familiar with some of the basic math required in problem-solving environments — especially at the root-cause level, or the "floor" level — some basic math will be explained.

The intent of this volume is to ensure that the reader becomes familiar with the process of problem solving, not necessarily with the actual use of specific tools. Explanation and use will be described in Volumes III, IV, V, and VI. Therefore, in essence, this volume attempts to identify the problem-solving process and, in fact, to crystallize the notions that problem solving (1) must be based on fact; (2) must be creative; and (3) must be based on the experience of people.

1 Theoretical Aspects of Problem Solving

This chapter introduces the problem solving process from a theoretical perspective. It addresses some fundamental issues that must be understood by anyone who is involved in solving a problem. It also establishes the rationale for a structure.

Problem solving can be broadly defined as meeting challenges. Indeed, this is the core of what the six sigma methodology proposes to do, i.e., to reduce variability and increase profitability for the organization employing the initiative called "six sigma." Looking further into the definition of a "problem solver," the *Oxford English Dictionary* notes that a problem solver "is challenged to accomplish a specified result, often under prescribed conditions."

It is our task, then, to find a consistent approach that can be repeated again and again when a concern — an opportunity — arises. To appreciate this consistency, we must recognize that the way a situation is approached depends on a flow of information similar to Figure 1.1.

In Figure 1.1, one can see that the response or decision is a function of the input (Sensory Input). But that is not all! That input has to be interpreted (Recognized) and that is the problem. Interpretation is a function of perceptual, cultural, and intellectual as well as emotional attributes that an individual brings with him/her to the table of problem solving. It is this interpretation of the inputs that will guide the team into a fruitful evaluation of the facts and data and ultimately the appropriate decision. (For the reader who is interested in more detail about the scientific background of the model of understanding, the following readings are suggested: Wundt, 1973; Koffka, 1935; Kohler, 1925; Wertheimer, 1929; Chomsky, 1965, 1967; Newell and Simon, 1972; and many others.)

How do we go through this basic model? Generally, four steps are followed:

Step 1. *Preparation:* When the problem solver becomes involved with the problem and searches for and accumulates relevant information

Step 2. *Incubation:* When there is no conscious effort to deal with the problem, but although the subject is not aware of it, work on the problem continues

Step 3. *Illumination:* The result of a successful incubation

Step 4. *Verification:* When some elaboration of reality testing of the solution takes place

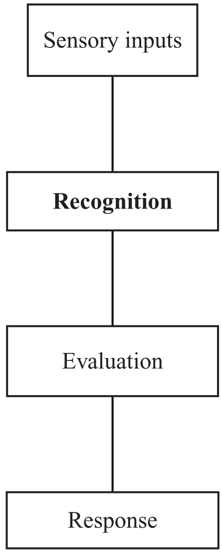

FIGURE 1.1 Understanding “a” situation.

These four stages have been empirically and experimentally validated through the work of many investigators including Wallas (1926), Anderson (1975), Aiken (1973), and Skemp (1971). Table 1.1 presents some typical examples of supported research generalizing the stages of problem solving.

The term “problem solving process” has traditionally been applied to the characteristics of problem solving performance. However, this is troublesome because it is a matter of choice as to how one pursues this process. For example, the behaviorists usually focus on situational variables, the Gestaltists focus on built-in mechanisms in the subject, and information processing specialists study the characteristic requirements of the task itself. To be sure, all three dimensions are important, but to have the utmost result, all dimensions must occur simultaneously.

How does one prepare and ultimately go through the process of problem solving? The literature is abundant with references from Plato and Aristotle, who focused on the notion of the human mind as the most important element of the process; to Medieval theology and Descartes, who pushed for the notion of the nature of man; to Hobbes in the 17th century; to Locke, Berkeley, and Hume in the 18th century; and to James and John Mill in the first part of the 19th century, who pushed the notion of reason as the foundation for problem solving.

In 1927 it was Kohler who as one of the founders of Gestalt psychology sought to explain the notion of “insight.” He used the term to describe the capacity shown by members of the human race to restructure a given problem situation to their advantage or to solve a task through recognition of the relationships and interactions between its component parts.

In this volume the Gestalt approach to problem solving has been selected as the most appropriate and user friendly of most applications. (By no means does this suggest that the other approaches are not significant.) The choice of the Gestalt

TABLE 1.1
Generalized Stages of Problem Solving

Researcher	Approach
Helmholtz (1984)	1. Investigation of performance in all directions
	2. Not consciously thinking about performance
	3. Appearance of "happy idea"
Dewey (1910)	1. Felt difficulty
	2. Location and definition
	3. Possible solutions
	4. Reasoning
	5. Acceptance or rejection
Wallas (1926)	1. Preparation
	2. Incubation
	3. Illumination
	4. Verification
Rossman (1931)	1. Observation of difficulty
	2. Analysis of the need
	3. Survey information
	4. Proposed solutions
	5. Birth of the new idea
	6. Experimentation to test promising solution; perfection by repeating some or all previous steps
Young (1940)	1. Assembly of material
	2. Assimilation of material
	3. Incubation
	4. Birth of the idea
	5. Development to usefulness
Polya (1945)	1. Production
	2. Incubation
	3. Illumination
	4. Accommodation
Hutchinson (1949)	1. Preparation
	2. Frustration
	3. Insight
	4. Verification
Mawardi (1960)	1. Abstract thoughts (A)
	2. Instrumental thoughts (I)
	3. Metaphonic ideas (M)
	4. Orientation (O)
Osborn (1963)	1. Think of all aspects
	2. Select subproblem
	3. Gather data
	4. Select relevant data
	5. Think of possible help
	6. Select attacks
	7. Think of possible tests
	8. Select soundest test
	9. Imagine all possibilities
	10. Decide final answer

TABLE 1.1 *(Continued)*
Generalized Stages of Problem Solving

Researcher	Approach
Skemp (1971)	1. Assimilation
	2. Accommodation
Newell and Simon (1972)	1. Input translation
	2. Internal representation
	3. Method selection
	4. Implement and monitor
	5. Reformulate
Johnson (1972)	1. Seek information
	2. Represent and transform
	3. Organize and reorganize
	4. Judgmental processes
Anderson (1975)	1. Preparation and production
	2. Incubation and eureka or "aha" experience
Sternberg (1980a)	1. Encoding
	2. Inference
	3. Mapping
	4. Application
	5. Justification (verification)
	6. Response (communication)

approach is based fundamentally on the notion of such greats as Kohler (1927), Maier (1970), Durkin (1937), and others who contend that the lack of success in problem solving is (1) biologically determined from an inability to integrate previous experience and (2) a result of functional fixedness, a tendency to think of objects as serving only in a limited "set," which may have been established by previous experiences, but may be inappropriate to a particular problem situation. It is amazing that Durkin (1937) actually demonstrated that a solution to a complex puzzle was facilitated by prior experience with simpler ones.

It would be unfair to not also mention the efforts of the behaviorists in this discussion. Indeed, C. L. Morgan (1894), Thorndike (1898, 1917), Woodworth and Schlosberg (1954), and Alexander Bain (1855, 1870) suggested that given a genuine problem, there must be some exploratory activity, more or less in amount and higher or lower in intellectual level. This, of course, is another way to express the old familiar statement about problem solving as the "trial and error" method. The works of Gofer (1961), Dulany (1968), Kendler and Kendler (1961, 1962), Skinner (1966), Staats (1968), and others support the notion that problem solving is dependent upon previously acquired stimulus.

Although an ideal process of sequential operations might theoretically be assumed on the basis of the structure of the problem itself, at least for some well-defined tasks such as mathematical problems, this "ideal" process may bear little resemblance to the structural elements which operate when individuals solve problems. Processes which are presumed to operate on the basis of task requirements alone must be regarded as incomplete because they fail to take person- and environment-related process determinants into consideration. Different individuals might address the same task differently. They may differ in the amount of consideration and reflection on different solution possibilities and their utilization of external or internal cues or perhaps in the capacity or use of memory storage and retrieval processes. Therefore, different methodologies have been developed to accommodate each of these situations. The reader may want to explore some of these through the writings of Lazerte (1933), process tracing; Maier (1931b), introspection; Ghiselin (1952), retrospection; Binet (1903), Bloom and Broder (1950), Luer (1973), Newell and Simon (1972), and Simon (1976), protocol analysis (thinking aloud).

Earlier a generalized format of problem solving was discussed; however, we must also recognize that research continues to identify the best and most efficient way of solving problems as well as the root causes. One such approach has been the innovation of Osborn (1963), who suggested that there is a difference between "idea creation" and "idea evaluation." This, of course, is what is now called the "brainstorming" technique. According to Osborn, there are ten steps. Steps 1, 3, 5, 7, and 9 are the creative thought process and Steps 2, 4, 6, 8, and 10 are evaluative:

Step 1. Think of all phases of the problem.
Step 2. Select the subproblem to be attacked.
Step 3. Think of what data might help.
Step 4. Select the most likely sources of data.
Step 5. Dream of all possible ideas as keys to the problem.
Step 6. Select the ideas most likely to lead to a solution.
Step 7. Think of all possible ways to test.
Step 8. Select the soundest ways to test
Step 9. Imagine all possible contingencies.
Step 10. Decide on the final answer.

For the process of problem solving to be effective, perhaps the most important ingredient in that process is the operational definition. In problem solving terminology, an operational definition is one that specifies the meaning of the concept by denoting the measuring operations and suggests a criterion of whether or not a so-called empirical concept is a scientific concept (repeatable and reproducible by others) and whether or not it has been operationally defined. It must be understood that the definition in operational terms is not a theory, nor is it scientific in itself, but it provides the essential basis for the measurements which make possible initially the identification of the phenomena for subsequent scientific investigation. Excellent operations defining a particular phenomenon serve to differentiate it from other phenomena.

DEFINITION OF TERMS

Just like anything else, problem solving has some important definitions. Everyone involved should be familiar with them. Therefore, this section provides some key definitions, general terms, terms related to the gathering of data, and terms related to the interpretation of the data.

Problem Solving

The lack of a generally acceptable definition of this term in the literature and the broad and apparently indefinite scope of its use led Ernst and Newell (1969) to note: "Behind this vagueness … lies the absence of a science of problem solving that would support the definition of a technical term" (p. 1). Traditionally, the term *problem solving* has been used to describe the behaviors applied by a motivated subject, attempting to achieve a goal, usually in an unfamiliar context, after initial lack of success (Johnson, 1972). Definitions of the term tend to maintain that a problem exists when an individual is confronted by a "difficulty" (Dewey, 1933), a "gap" (Bartlett, 1958; Kohler, 1927), a "conflict" (Duncker, 1945), "disequilibrium" (Piaget, 1968), or a "deviation" from a familiar situation (Raaheim, 1974). While this type of description would seem to be equally suitable to define such terms as searching, understanding, or learning, "much contemporary research continues to reflect the basic Gestalt view that problem solving, by virtue of its emphasis on response discovery is something apart from learning" (Erickson and Jones, 1978, p. 62).

Historically and to the present day, the term *problem solving* has been used with considerably greater frequency in reference to outcomes or products, particularly the success/failure aspect of the activity, rather than the process per se. Problem solving as a process became the focus of research with the weakening of interest of research workers in the perceptual and experiential aspects of thought, as had been pursued by associationists and Gestalt psychologists.

As was noted earlier, the Gestalt approach to research into problem solving might be described as subject oriented. The more recent, important contributions of the information processing and artificial intelligence studies, though concerned with the investigation of the problem solving process itself, focused primarily on the demand characteristics and structure of certain problem solving tasks (e.g., Newell and Simon, 1972; Scandura, 1973, 1977; and Wickelgren, 1974). The term problem solving can refer to all overt and covert activities that take place to reach a solution or otherwise accomplish a goal or purpose in a problem solving situation.

For the purposes of the six sigma methodology, the term *problem solving* is used to broadly describe the results of the interaction of components from the following five domains of variables:

- Step 1. The problem or task, T
- Step 2. The problem solver or subject, S
- Step 3. The situational circumstances or the environment in which the problem is presented or presents itself, E
- Step 4. The behaviors or processes which take place between the point of initial contact with the problem by S and the solution produced by S, X
- Step 5. The solution or product of the problem solving activity, P

Regardless of the type of problem or the manner in which task (T), subject (S), environment (E), and process (X) variables interact, the product (P), whatever form it might take, is always a function of the interaction of variables from the remaining domains. This relationship can be expressed by the mathematical function:

$$P(T) = f(T + S + E + X)$$

where every variable may be represented by a number of domain components.

It is imperative to not think of the product P as the dependent variable. Instead, the aim is to investigate structural components of the problem solving process X, which in turn must be expected to be a function of variables from the remaining domains; hence

$$X = f(T + S + P + E)$$

Although it is accepted that during problem solving the above suggested sets of variables may interact in many intricate ways, it seems legitimate and necessary to define each of them separately.

Problem or Task

These terms are used interchangeably. The term *problem* has traditionally served as a label for a variety of phenomena, ranging from mathematical tasks to problems in real life. A common characteristic of all problems seems to be that they involve an aim which the problem solver wishes to accomplish, the means for which (i.e., the required knowledge, skills, techniques, or behaviors) are not at his or her disposal.

To be confronted with a problem means to be faced with a difficulty or an obstacle that cannot be solved or dealt with in an already known or habitual manner; thus a reasonably general yet meaningful description of a problem or task might be that it may arise from any stimulus situation in which an appropriate response is not readily available. This definition is similar to many explanations of the term found in the research literature. A problem is described as:

- Whatever — no matter how slight or commonplace in character — perplexes and challenges the mind so that it makes belief at all uncertain (Dewey, 1933, p. 13)
- A question for which there is at the moment no answer (Skinner, 1966, p. 225)
- When a person is motivated toward a goal and his first attempt to reach it is unrewarding (Johnson, 1972, p. 133)
- A stimulus situation for which an organism does not have a ready response (Davis, 1973, p. 12)
- When a system has or has been given a description of something but does not yet have anything that satisfies the description (Reitman, 1965, p. 126)

The definition of a problem as a phenomenon that may arise in any stimulus situation in which an appropriate response is not readily available is broad enough to cover physical, emotional, intellectual, and social problems. It can refer to problems of varying complexity, to defined and ill-defined tasks, and to structured and unstructured problems. It serves to prevent the problem solver from avoiding or ignoring the problem, but does not require the individual to recognize the task "objectively." The "objective" problem is the task as perceived by the individual. This position acknowledges that what is a problem for one person may not be for another. The latter individual, in this case, has an appropriate response readily available in a stimulus situation which might present a problem for the former person. In summary, it is suggested that the above presented definition of the term "problem" or "task" subsumes all types of problems without, however, obscuring the differences that may exist in different problem solving situations.

A further point of definition may require clarification. It would follow from the above definition that a problem that does not elicit any reaction from the individual or a task that has been solved would cease to be a problem. The English language unfortunately does not provide an alternative term to cover these types of situations. Frequently occurring tasks, such as the simple arithmetic "problem" 1 + 1 = 2, which elicit well-rehearsed, often automatic responses, do not fall into the problem category defined above. Other languages provide alternative terms for these "problems" (e.g., in Greek one would use "askese," in German one would use "die Aufgabe," and in French one would use "la tache") which permit a clearer distinction between a "problem" which requires at least some effort in terms of productive thinking on the part of the subject and what may be described as a simple exercise or routine stimulus-response association. The term "problem" as used in this volume does not include simple stimuli presented for automatic response.

Problem Situation

This concept was first used by Wertheimer (1923), who regarded it as consisting of two ingredients. These are the aim or solution, i.e., "that which is demanded," and the stimulus or materials, knowledge, skills, etc., i.e., "that which is given." The process of problem solving commences when what is given is brought into association with that which is demanded. This will include, for example, considerations of how the givens might lead to a solution. For example, the "functional value" (Duncker, 1945; Kohler, 1917) of the givens might be assessed as done by Kohler in the case of the sticks utilized by a chimpanzee to reach bananas.

Subject

This term refers to the individual who is attempting to solve a problem. The problem solver cannot be considered to be a neutral agent. All variables — many of them unknown, some known, but not yet measurable, others constant — that determine the subject's behavior make up this domain. Obvious examples of these variables are motivation; memory; intelligence; general background and experience, including experience with problems of a certain type; and social and personality variables.

Environment

The total problem solving environment includes physical, psychological, and sociological variables. The physical environment provides many perceptual cues and memory associations that might be used by the problem solver to define, analyze, and understand the problem and to enlarge the set of available approaches to the task.

On the other hand, physical, psychological, and sociological variables and factors resulting from their interaction may place certain constraints on the task, the solution, or the problem solving activity and directly or indirectly influence the process as a whole. The problem environment contains, of course, the experimenter with all of his or her characteristics. Task directions, definitions, etc. form part of the problem or task.

Process

Problem solving is often referred to as a process. Yet the evidence for the occurrence of this process is based on an examination of the end product, performance. The outcome of problem solving, i.e., the results of the process (or processes), not the processes themselves, are described.

The problem solving process, which begins with presentation of the problem, is terminated when the subject arrives at a correct solution; when the subject arrives at an incorrect solution believed to be correct; or when the experimenter ends the session.

Product or Solution

These terms are used interchangeably for the result of the problem solving activity. The term *product* would appear to be more suitable for research purposes because of the connotation of the term *solution*. One would, generally, expect a solution to be "correct." In the six sigma methodology, both terms are used for the result or outcome of the problem solving attempted by subjects. The terms apply to both "correct" or "incorrect" outcomes.

Problem-Solving Behavior or Operation and Problem-Solving Strategy

Again, these terms are used interchangeably to denote any response or any part of a response pattern that is observed during the subject's problem solving activity, i.e., can be identified on the basis of the subject's problem solving protocol. It is acknowledged that many behaviors are unobservable and therefore will not be contained in the protocol. The difference in processing rate per time unit between thought and speech and the inability of speech to reflect parallel processes result in the fact that "thinking aloud" protocol contains a reduced version of the problem solving process, no matter how perfect the experimental conditions. Strictly speaking, use of the term "strategy" should perhaps be restricted to dynamic processes involved in performance which are made up of several operations or behaviors. On the other hand, the repeated use of a specific operation over time may well be conceived as a strategy rather than an operation.

Dynamic processes that perform specific operations are called "strategies." The idea is that elementary mental operations may be assembled into sequences and combinations that represent the strategy developed for a particular task. It is often difficult to determine whether the elementary mental operations isolated are strategies or whether they are structures.

The chess master, for example, who has developed a strategy for analysis of the chess board over many years of practice, may be unable to modify it; thus it becomes more structural in character. Indeed, high levels of skill seem to be characterized by the development of a structural basis for what in most of us is a painfully assembled strategy. Perhaps, this is precisely the reason why "problem solvers" are generally sought after rather than planners. It is the cumulative experience that the "problem solver" brings into the situation to resolve the issue at hand. More often than not, a good problem solver operates from a pattern of processes rather than sequential ones. In fact, it is the pattern association of past experiences that drives new solutions.

TERMS AND ISSUES RELATED TO DATA GATHERING

Definitions of the following terms are provided in an endeavor to increase the clarity of the description of the method and importance of data gathering.

STIMULUS PASSAGE

This term refers to a single sheet of paper containing a diagram, a typed sentence, a paragraph, or paragraphs presenting the subject with the task. A typical stimulus passage may be a flow chart of the process or some measurements of a process. The rationale of stimulus passages is to provide the means by which the subject may be acquainted with each task.

VERBALIZATION OR "THINKING ALOUD"

The terms are used interchangeably to refer to the subject's verbal expressions and descriptions of his or her ongoing problem solving activity. Typically this is a version of brainstorming.

PROTOCOL

A verbatim written transcript of the cassette recording made of all verbalizations produced by subjects during the problem solving session is produced. The protocol contains a complete record of the description of problem solving provided by the subject's "thinking aloud." It also contains evidence of any other verbal or verbally reported activities that occurred. A protocol, then, provides a description, keeping time sequence intact, of problem solving performance as it occurred. On the other hand, not every description of performance of a task constitutes a protocol.

A description of a task consisting of goals and outcomes is not sufficient. The problem solving protocols provide information, not only concerning the answers the subjects provided, but also, and more importantly, they provide an indication of the sequence in which the problem solving behaviors occurred. Subjects may ask questions, refer to the stimulus passage, compute, etc. in a particular order.

This approach to gathering data may be very helpful in customer surveys and market research studies as well as when someone is interested in identifying very specific tasks and interpretations of a particular job, project, etc.

Process components are identified on the basis of the amount of use made by each subject of certain problem solving behaviors or strategies and by investigating transition sequences of these behaviors at various temporal stages of the problem solving activity.

Behavior or strategy use is measured by the activity of the process as a whole in addition to the individual participation of team members. This participation is of paramount importance, and it depends on the leadership of the team as well as on the appropriate cross-functionality and multidiscipline of the team members. It is this behavior and strategy that ultimately will (1) select the likely potential cause; (2) prevent recurrence; and (3) define the roles and team orientation.

Select the Likely Potential Causes

Once the problem has been described and the potential causes have been identified, the team should be evaluated. Are the right members on the team to investigate the potential causes? Are technical advisors required to assist in any special studies? Are new team members needed? Is the authority to pursue the analysis of the potential causes well defined? All of these questions must be answered to ensure that the team will be successful in investigating the potential causes and determining the root cause.

A typical tool that is used is the cause-and-effect diagram, in conjunction with brainstorming, to identify the potential causes to be investigated. What is the probability that a potential cause could be responsible for the problem? Identify all potential causes that could have been present and might have caused the problem.

Once all potential causes have been agreed on, choose several potential causes to investigate. If only one potential cause is investigated, a lot of time may be lost if that potential cause is not the cause of the problem. To expedite the investigation of potential causes, investigate several causes at the same time. Parallel actions on several potential causes will expedite the process.

If the problem is a manufacturing process, begin to establish a stable process. Once the process is stable, definition of the potential cause will be clarified. On the other hand, if engineering design causes are identified, screening experiments may help identify the key variables which are affected by subsequent processes, and robust design actions may be appropriate.

Four or five potential causes to investigate should be identified. Identifying several potential causes forces the team to address multiple causes rather than search for a single cause. An implicit part of the problem analysis is investigating potential causes in parallel rather than in series.

Prevent Recurrence

A second concern in the behavior and strategy phase is to make sure that the problem once solved will not recur. The analysis begins with understanding what in the process allowed the problem to occur. A cause-and-effect diagram can be used to outline the reasons the problem occurred. By asking "because?," the cause-and-effect diagram could be constructed.

Another effective tool is a process flow diagram. The process flow of the manufacturing or engineering process or even a service can be effective in identifying where in the process the problem could have been prevented. Most of the time, to prevent recurrence of the problem, a change to the management system will be required. Managers must understand why their system allowed a problem to develop. The same system will allow future problems to occur.

Management systems, practices, and procedures need to be fully understood to be effective. Most of them are carry-overs from previous experiences and organizational structures. Some are outdated and need to be revised. Understanding the elements of a management system can be achieved by maintaining an up-to-date flow diagram of the system and process. Also, instructions should be easy to follow by those who are part of the system.

Management systems, practices, and procedures should provide management support for "never-ending improvement" in all areas and activities. The system should encourage individuals to participate freely in the problem solving process. It should help them understand more about their job and how each individual's effort affects the outcome of the final product on the customer satisfaction. The system should encourage everyone to learn something new, and it should recognize individual and team effort when these new skills are applied.

Changes in the management system may require documenting new standard procedures, streamlining to remove obsolete procedures, and revising previous standards. Any changes in the management system need to be communicated clearly to all customers.

To prevent recurrence, additional training is often required. Training may be needed in statistical tools, new engineering or manufacturing technologies or disciplines, better process, or project management. Some basic problem solving tools are

1. *Process flow diagram*. A process flow diagram (sometimes called mapping) is a graphic presentation of the flow and sources of variation in a process. In manufacturing, a process flow is a graphic presentation of the flow and sources of variation of machines, materials, methods, and operators from the start to the end of the manufacturing and/or assembly process. To graphically display the total process, some standard symbols are helpful in commonizing the process flow diagrams. While the symbols used will vary from one application to another, it should be noted that any process can be diagramed.
2. *Control charts*. The various types of control charts are graphic tools used to separate controlled and uncontrolled variation in a process. All such charts have the same two basic functions:

   - To establish whether or not a process is operating in a state of statistical control by identifying the presence of special causes of variation. This permits corrective actions to be taken.
   - To maintain the state of statistical control once it is achieved. This allows for periodic recalculation of the control limits which may, in turn, lead to reduced variability within the process being charted.