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Problem-solving skills utilized by graduating engineers from a baccalaureate program to solve problems

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PROBLEM-SOLVING SKILLS UTILIZED BY GRADUATING ENGINEERS FROM

A BACCALAURATEATE PROGRAM TO SOLVE PROBLEMS

A dissertation in partial satisfaction

of the requirements for the degree of

Doctor of Education in Organizational Leadership

by

James Welch

January, 2009

Diana B. Hiatt-Michael, Ed.D.–Dissertation Chairperson

This dissertation, written by

James F. Welch

under the guidance of a Faculty Committee and approved by its members, has been submitted to and accepted by the Graduate Faculty in partial fulfillment of the requirements for the degree of

DOCTOR OF EDUCATION

September 26, 2008

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DEDICATION

This dissertation is dedicated to my wife, Marion, who has given me the consistent support, love, and patience that were essential in the completion of this work. Additionally, I am dedicating this dissertation to my deceased father, James D. Welch, and my mother, Jeanette C. Welch, who gave me the inspiration and tools to accomplish academic and professional goals.

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Dr. Diana Hiatt-Michael, my chairperson, has provided me invaluable insight and guidance throughout the dissertation process. However, her sincere concern and unwavering motivation was extremely appreciated and necessary in completing this dissertation.

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Dr. Ken Santerilli provided extensive assistance throughout the dissertation process. This included arranging for the study at the university, as well as coding the data.

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VITA

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ABSTRACT

This study extends the knowledge of the problem-solving frameworks and skills used by

graduating engineers (GE). The frameworks are comprehensive systematic processes that

a GE uses to frame the problem. The problem-solving skills are mental and physical

mechanisms, such as heuristics and flow charts.

An in-depth qualitative study of 31 randomly selected graduating engineers from

a state university was employed to obtain firsthand data on how GEs solved a specific

problem scenario. The methodology of this study was an open running dialog between

the researcher and the GE while the GE solved the standardized problem scenario. A one-

sentence problem scenario was provided. The GE asked questions of the researcher

throughout the process. The researcher responded with an established set of answers. The

researcher timed and coded the GE's responses.

The running dialogue was coded utilizing the problem-solving frameworks and

skills for each of the 31 GEs. Time ranged from 1 minute and 10 seconds to 9 minutes

and 48 seconds. Of the GEs, 90% utilized 2 or 3 of the 4 types of frameworks in different

combinations. However, 1 student applied only 1 framework and 2 students utilized all 4

frameworks. The 5 GEs who most rapidly solved the problem used different

combinations of the frameworks. The evaluation step in any of the 4 frameworks was not

implemented by 48% of the GEs. The choice of frameworks did not appear to be related

to gender, age, or experience.

The analysis indicated that the GEs also used different arrangements of problem-

solving skills. The GEs employed all 5 categories of problem-solving skills: tools,

defining, goal-identification, heuristics, and reasoning. Of the GEs, 100% utilized the

skills termed tools, defining, and goal-identification. The heuristic problem-solving skills were used by 97% and the reasoning skills were used by 26% of the GEs.

All of the GEs required a wide range of problem-solving frameworks and skills in order to solve effectively the problem scenario. Thus, engineering educators should provide student engineers with a wide range of frameworks and skills of problem-solving in order to provide a strong basis for their future work.

Chapter 1:

Introduction

Background

As societies across the world have become more connected through transportation and communication, business, government, and social agencies' competition has increased for economic gains. During the previous century, a country's competitive edge was highly based upon the skills of engineers (Lenton, 2007; McCaffrey, 2005). Skilled engineers continue to be a part of a country's economic growth and power (Massie, 2008; Melbourne School of Engineering, 2008; Newman-Ford, Lloyd, & Thomas, 2007). Teaching engineers how to solve problems and having engineers build and troubleshoot the equipment of an industrialized society have always been intertwined and mutual activities. According to the National Academy of Sciences (Engineering Education and Practice in the United States, 1985), learning how to solve problems is and has been the key component of engineering programs.

Engineers solve problems in many ways by using reasoning, logic, and many other types of problem-solving skills (Pae, 2008; Pritchard & Baillie, 2006). Depending on the experience of the individual, their type of problem-solving skills will vary in complexity, scope, and adaptability (Asa & Gao, 2007; Pae, 2008). Additionally, the type of problem also impacts which and when problem-solving skills are used to solve a problem (Otieno, Azad, & Balamuralikrishna, 2006).

Within the engineering environment, the engineer is required to use an extensive set of problem-solving skills. Each engineering environment presents unique problems for each of the specific engineering specializations, such as civil engineering and nuclear engineering. However, surveys across many technical industries indicated that the use

and application of computers affected many engineering specializations (Evans-Pughe, 2006).

One potential complex problem encountered by Graduating Engineers (GE) from a baccalaureate program is solving why a computer network is not functioning (M. Conley, personal communication, March 5, 2008; R. Celic, personal communication, March 15, 2008). In this situation the GE is required to analyze the elements of the network, such as the type of network protocol (Oppenheimer & Bardwell, 2002), type of computers connected to the network, and other functions of the network.

Solving a computer network issue entails dissecting and categorizing many characteristics of a complex problem. These must include a large number of variables or many interrelationships among the variables (Frensch & Funke, 1995). In solving a computer network issue (problem) the GE must analyze the relationships between the computers and the network protocol, as well as the relationship between the network protocol and the type of data that is being transferred over the network. Each of these variables has multiple relationships with other variables of the network, which impact network performance and why the network does not function properly.

Solving this complex problem requires the GE to use routine and nonroutine problem-solving skills. Routine problem solving skills are of "known or prescribed procedures to solve problems"(Gilfeather & del Regato, 2004, p. 1). There are several routine problem-solving skills, one of which is called defining (Nielsen, 2006). The defining problem-solving skill requires the GE to define a specific segment of the problem or define the general parameters or "boundaries" (Lumsdaine, Lumsdaine, & Shellnutt, 1999, p. 181) of the entire problem.

When solving a network system problem the GE may use the routine, defining problem-solving skill. For example, the GE could define or isolate the reason for the network failure to the individual computers attached to the network.

Nonroutine problem-solving skills are "procedures or strategies that do not guarantee a solution to the problem but provide a highly probable method for discovering the solution" (Gilfeather & del Regato, 2004, p. 1). For a network system problem the GE could use the nonroutine skill called brainstorming. In this case the GE may brainstorm reasons why the computer may be causing the failure in the network.

Additionally, some GEs will use problem-solving skills in a specific sequential, problem-solving framework (Cochran, 2006). For example, in the Dartmouth/Thayer problem-solving framework, the GEs are taught specific steps, which include "check problem definition, brainstorm alternatives, redefine problem" (1998, p. 1).

In this problem-solving framework, the routine, definition problem-solving skill is repeated twice: once at the beginning and again in the third step. At the beginning of the Dartmouth/Thayer problem-solving framework, the GE formulates a problem definition. At the end of the problem-solving framework, the GE uses the problem definition skill again to redefine the problem. In the middle of this sequence is the nonroutine, brainstorming action.

In other situations the GE may use routine and nonroutine problem-solving skills in a nonsequential problem-solving framework. In this case, the GE could define the problem before brainstorming alternatives, or define the problem after brainstorming alternatives.

In another problem-solving framework the GEs may use different routine and nonroutine problem solving skills. Kremer (2001) describes a problem-solving framework where the nonroutine, brainstorming skill is not used, but is replaced with the nonroutine, mathematical modeling skill. The mathematical modeling skill is extensively documented in Kremer's problem-solving framework. According to Kremer, the routine, problem definition skill has a minimal role in this process.

In Kremer's (2001) model of problem solving the framework of routine and nonroutine skills starts off with reading the description of the problem. This is the routine, problem definition skill. Following the implementation of this skill, the GE sequentially implements three, nonroutine problem-solving skills: which mathematical theory applies, converting the problem into a mathematical model, and visualizing the solution. Unlike the Dartmouth problem-solving framework, Kremer's problem-solving framework only uses the routine, problem definition skill once at the beginning of the problem solving activity.

Statement of Problem

Teaching problem solving is a central part of the engineering curriculum (Heywood, 2005). However, GEs use many types of problem-solving skills, in several different frameworks, to solve complex problems (Kranov et al., 2002).

Because of this diversity in the problem-solving process, the field of engineering does not utilize a common measure of problem-solving skills at graduation. Therefore, there is limited knowledge or measure of the GE's level of application of problem-solving skills.

Although solving problems is a central part of the engineering curriculum, there is limited research in how routine and nonroutine problem-solving skills are used jointly to solve complex problems by the GE. Also, data does not support whether gender, age, experience, particular engineering courses, or engineering specialization affect the order, frequency, and type of problem-solving skills utilized by a GE.

Statement of Purpose

The purpose of this research is to assess the type of problem-solving skills and the framework of how these problem-solving skills are used by the GE to solve a complex problem. This study will address this purpose by direct observation and questioning of the GE by the researcher, after the GE has solved a hypothetical complex problem.

Research Questions

1. Which problem-solving frameworks were used to solve a given problem scenario?

2. Which was the most frequently used problem-solving skill?

3. What differences, if any, are there among GEs according to these demographic variables: gender, age, coursework, and years of experience?

4. Were there any elements of a problem-solving framework or skills that were not frequently used by the GEs in the given problem scenario?

Significance of Study

The research will present insights into the problem-solving frameworks and problem-solving skills utilized by GEs. This information will assist college instructors in defining teaching objectives and skill sets that help engineers analyze and solve problems. Concomitantly, the business sector will gain graduating engineers who have an

improved grasp of the many types of problem-solving frameworks and skills, so that they are prepared to address the wide diversity of complex problems in the engineering profession.

Instructors currently use several strategies for teaching problem-solving skills such as Problem-Based Learning (PBL); (Barger, Engel, Gilbert, Maughmer, & Osif, 2001). These teaching strategies are based on a limited view of what constitutes a problem-solving skill. Therefore, in order to make this teaching process more effective, the instructor needs to identify what skills current students utilize. The instructors might consider adding more approaches and tools to assist the student engineers. Also, the instructor must understand the relationship between the problem-solving skills so that the engineering student can choose between skills in case one skill is not available to the engineer or is not appropriate for a specific problem. This study clarifies these specific aspects of the problem-solving process.

Additionally, the engineering developers and managers in the business sector are requesting that the graduating engineers have a higher level of expertise in solving problems (Thomson, Austin, Root, & Thorpe, 2006; Watson, 2007). These requests include specific problem-solving frameworks and skills that are adaptable and can be applied to different types of engineering problems (Eskandari et al., 2007). Other requests include knowledge of problem-solving skills that provide the engineer the ability to think within an area of constraints, rather than thinking in an unlimited all-possibilities mode (Longuski, 2007). This study will reveal which problem-solving skills are employed by GEs entering the field.

Definition of Terms

These terms have a special meaning for this study and are defined as the following:

Boolean logic. A form of logic that is based on symbolic notation (Averbach & Chein, 1980; Boole, 2005). The symbolic notation represents true or false statements that can be combined, by using algebra, to yield logical solutions.

Complex problem. This occurs when any one of the following elements are part of the problem (Frensch & Funke, 1995): There is "no precise definition of the operators available (what can be done)"(p. 15). There is "no precise definition of the problem space"(p. 15; Jausovec, 2000). "A large number of interrelated components"(p. 14). "Information about the system or system states is incomplete"(p. 14).

Deductive reasoning. This describes logic with which the problem solver infers from a set of premises (Sternberg & Ben-Zeev, 2001). This inference yields a conclusion or solution.

Defining. This is a routine problem-solving skill (Gilfeather & del Regato, 2004) that sets the boundaries (Lumsdaine et al., 1999) and constraints of a segment or segments of the problem (Murphy, 2004). One example of the defining skill is isolating or framing (Gloeckler, 2007) the failure of a computer problem specifically to a faulty power supply rather than another component, such as a faulty keyboard. This problem-solving skill is specific to each problem.

Fallacious reasoning. This occurs when the problem solver uses logical schemes "wrongly, as calculated mechanisms of preventing appropriate critical questions from

arising at all"(Walton, 1995, p. 14). This type of action prevents the problem solver from thoroughly researching the problem segment or segments.

Goal-identification (Goal ID). This is a routine problem-solving skill (Gilfeather & del Regato, 2004) in which the problem solver identifies the segment or segments of the problem as a goal the problem solver wants to achieve (Kirkley, 2003; Laird, Rosenbloom, & Newell, 1986). These include identifying a problem-solving segment as the goal of finding a solution or the goal of finding the causes of the problem. These goals are generic and can be applied to any problem in any sequence of the problem-solving structure (Cochran, 2006).

Heuristics. This is a nonroutine problem-solving skill (Gilfeather & del Regato, 2004) based on the experience of the problem solver (Pappalardo, 2007). One type of heuristic allows the problem solver to organize information (Black, 2004b) so they see patterns or similarities (Black, 2004a) between a current problem and problems the problem solver resolved in the past . Other heuristics use probability (Jeffrey, 2002) and analogical thinking (Kokinov & Petrov, 2001) to assist the problem solver in finding causes and solutions to complex problems.

Inductive reasoning. This describes logic with which the problem solver uses a set of specific inferences about a segment or segments of a problem to generate a larger generalization (Thagard, 1999). For example, a problem solver can use induction to infer that the problem of failed circuit board in a computer is due to a larger problem such as using the computer for an inappropriate purpose (Johnson-Laird, 2006)

Nonroutine problem-solving skills. These are "procedures or strategies that do not guarantee a solution to the problem but provide a more highly probable method for

discovering the solution" (Gilfeather & del Regato, 2004, p. 1). These include heuristics (Pappalardo, 2007), reasoning (numbernut.com, 2008, glossary section, reasoning entry) and the tools (Jonassen, n.d.) problem-solving skills.

Problem solving. This is a process that requires a GE to use cognitive problem-solving skills such as reasoning and heuristics to search through the problem space (Newell & Simon, 1972). The problem space is "a set of knowledge states (the initial state, goal state, and various possible states)" (Novick & Bassok, 2005, p. 326). Therefore a problem solver moves through this space "from one knowledge state to another, and local information about the path one is taking through the space (e.g. the current knowledge state and how one got there)" (Novick & Bassok, p. 326).

Problem solving skill. This "Refers to a person's ability to perform various types of cognitive or behavioral activity effectively" (*wps.prenhall.com*, 2002, glossary section, skills entry).This is an acquired ability that assists the engineer in solving a problem. Therefore, the problem-solving skill is a conscious and cognitive thinking action that the engineering student can learn and use to facilitate solving complex problems.

Problem solving framework. This is a sequence (Cochran, 2006) of problem-solving skills (*wps.prenhall.com*, 2002, glossary section, skills entry) that are used by the problem solver to find a solution to the problem.

Reasoning. This is a "process that leads to a conclusion or inference using known facts or assumptions"(*numbernut.com*, 2008, glossary section, reasoning entry). Reasoning includes the problem-solving skills of inductive, deductive, Boolean, and fallacious logic.

Simple problem. This is a routine problem in which all the critical steps are known (Savransky, 2000) and has few variables. A simple problem also can be solved quickly (Gurevich, Gorev, & Barabash, 2004).

Routine problem-solving skill. This is the use of "known or prescribed procedures to solve problems"(Gilfeather & del Regato, 2004, p. 1) such as defining (Nielsen, 2006) the specific aspects of a problem cause or solution. Additionally, the process of identifying a problem-solving goal (Laird et al., 1986), such as evaluating the solution, is a routine problem-solving skill.

Tools. These are physical and nonphysical devices to support and guide the GE in the problem-solving process (Jonassen, n.d.). Tools are nonroutine, problem-solving skills (Gilfeather & del Regato, 2004). Some tools are physical, such as graphic organizers, rulers, flowcharts, and Venn diagrams. Additionally, physical tools can be mechanical equipment such as a voltmeter, lever, or a software diagnostic application. Other tools are non-physical such as brainstorming, questioning, statistical calculations, and mental simulations (Conklin, 2006).

Assumptions

This study's methodology is twofold: administer a self-assessment instrument and interview problem solvers. Each of these requires the researcher to make assumptions about the motivation level, concentration, and the honesty of the subject's response.

Motivation

The researcher assumes that the subject is motivated to solve the problem. This motivation causes the subject to attempt to solve the problem, regardless of the complexity or other aspects of the problem (Isen, 1997).

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Concentration

The ability to concentrate is part of the problem-solving process. The subject must concentrate on each problem scenario so he or she can ascertain an appropriate response. The researcher assumes the subject has this ability (Ruggiero, 2001).

Honesty

When the researcher interviews the engineering students, the researcher assumes the problem solver will respond honestly and accurately to the questions. It is also assumed that the subject will not give the researcher information that does not match his or her own beliefs.

<center>*Limitations*</center>

Limitations are the restrictions and means the researcher uses to gather and analyze the data (Bryant, 2004). In this study there are three restrictions: type of problem-solving skills, aptitude of subject, and the innate characteristics of the subject.

Type of Problem-Solving Skills

This study does not address collaborative, group problem-solving skills. These problem-solving skills include building consensus, negotiating conflict, and facilitating the communications between team members.

Experience of Subject

The researcher has limited this study to GEs. The GEs are Graduating Engineering students.

<center>*Timeline for Study*</center>

Figure 1 shows the timeline for this study. The timeline begins with the topic selection and includes the preliminary defense, IRB submittal, and other milestones.

<center>11</center>

12/14/06
Select Topic

2/20/08
Review Chaps.
1,2,3

2/26/08
Continued
Preliminary
Defense

3/15/08
Submit
IRB

4/29/2008
Start
Interviews

5/2/2008
Complete
Interviews

5/21/2008
Begin
Coding

6/12/2008
Complete Coding

8/19/2008
Complete
Analysis

9/26/2008
Final Orals

12/14/2006

12/18/2008
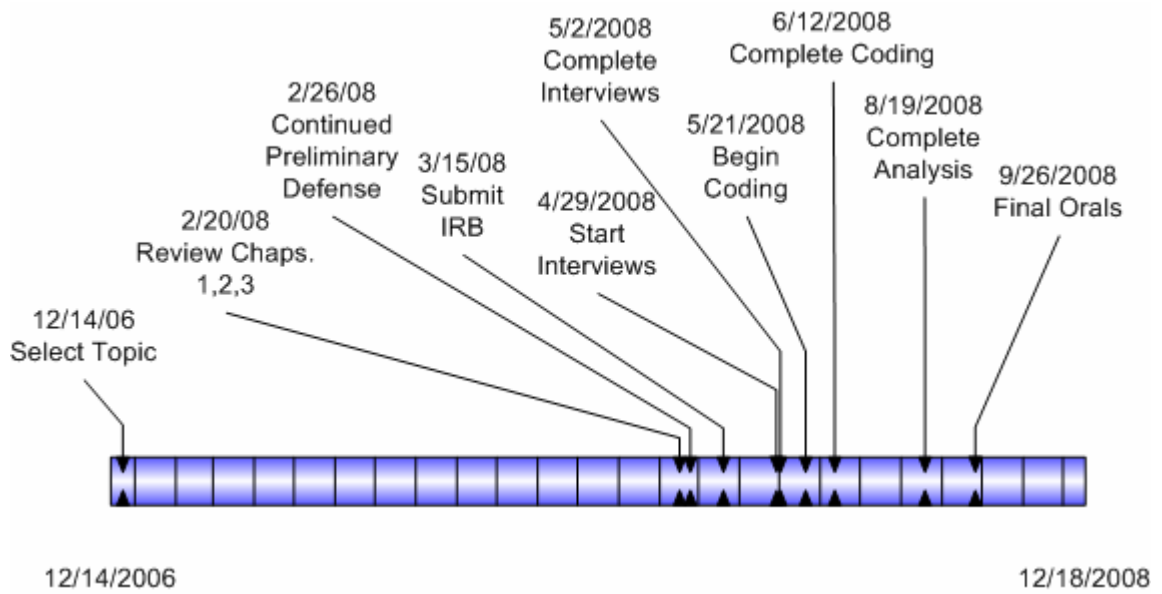
Figure 1. The timeline for each milestone of the dissertation process.

Chapter 2:

Literature Review

Teaching engineers how to solve problems and having engineers build and troubleshoot the equipment of an industrialized society have always been intertwined and mutual activities. According to the National Academy of Sciences *(Engineering Education and Practice in the United States*, 1985), learning how to solve problems is and has been the key component of engineering programs.

One trend in teaching engineers to solve problems in the early industrial society came from the behaviorism movement that was developed by the psychologist Skinner (Skinner, 1953). Behaviorism connects the behavior of the subject to a stimulus. In simple terms, the greater and more frequent the stimulus, the greater the chance the behavior of the subject will change.

Applied to teaching methodology, the engineer would practice the problem skill. The more the engineer practiced this skill, the greater the likelihood the engineer would know how to solve problems. This teaching methodology is still a commonly used method to instruct students (James, Harmon, & Bryant, 2007; Kremer, 2001). According to one study, an engineering student completes 3,000 problems and is described 1,000 problems by the professor during a 4-year degree program (Kranov et al., 2002).

With the increased complexity of a postindustrial society, the teaching profession has developed several new methodologies to teach problem solving to engineering students. One of these new methods is the case-based learning strategy. This teaching method originated at Harvard in 1870 (during the industrial revolution) and moved into the engineering curriculum at Stanford in the 1960s (Barrott, 2001).

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Case-based learning introduces the engineering student to a solved problem (Barger et al., 2001). The student then reviews the methodologies and solutions described in the case to understand the problem-solving process. Depending on the complexity of the problem, the engineering student gleans a variety of problem solving skills. As with other teaching methodologies, this method can be used with individual students or in the group setting.

Problem-based learning is similar to case-based learning; however, in this methodology there is no solution presented in the case (Barger et al., 2001). Instead, the task of answering the problem is typically given to a group of students. This team engages in a collaborative effort to find a solution to the problem. The benefit to this teaching methodology is twofold. First, each student sees how another student solves problems and thus gains insight into a new problem-solving skill. Second, the collaborative process is a strong learning tool that facilitates creative thinking based on a scaffolding of ideas in the team.

Inquiry-based learning is frequently used jointly with other problem-solving teaching methodologies. This process requires the instructor to have a questioning dialog with the student (Barger et al., 2001). The instructor poses a problem that hypothetically is based on a specific relationship between two parameters. For example, the instructor could state that a computer is not functioning and follow up by presenting the relationship between two parameters: the construction of a computer cable and the length of the cable from the computer to the power outlet. The student is required to use problem-solving skills such as reasoning to determine if the two parameters have any bearing on the

solution to the failed computer. Additionally, the student needs to support his or her

conclusion with scientific evidence.

Problem-Solving Frameworks

The previously mentioned teaching methods are learner centered. That means the

engineering student learns problem-solving skills as he or she responds to the case study,

inquiry, or problem. Alternatively, the instructor could give the student a list of problem-

solving skills that he or she would use to solve a problem. This method refers to the

problem-solving structure or framework of the problem (Cochran, 2006). A problem-

solving framework is a specific sequence of problem-solving skills that are followed by

the GE in a specific order.

In the 1960s, Dartmouth University began teaching the problem-solving cycle

structure to assist engineering students in solving problems (Muller, 1998). This cycle has

nine steps that lead the student to the solution of the problem. Each step may be one or

more problem-solving skills. The first several steps require the student to define and

redefine the problem. After this, the student looks for alternative solutions while

continuing to focus on the problem. This process continues until the problem is solved.

Another problem-solving framework is the Professional Decision Making (PDM)

process (Elger et al., 2001). This structure has similar beginning steps to the Dartmouth

model in which the problem solver must define the problem or situation. However, the

first step is an affirmation to the problem solver. According to the researchers of this

paper, the affirmation is a reinforcer to the problem solver to assist him or her in seeking

causes and solutions to a difficult problem. Some recommended affirmations are, "I think

I can solve this problem, I can do this, and I will work systematically and trust my process to guide me to a solution" (p. 2).

At the Vanderbilt-Northwestern-Texas-Harvard-MIT Engineering Research Center, a new hybrid problem-solving framework was developed that is based on the case, problem, and inquiry teaching methods (Pandy, Petrosino, Austin, & Barr, 2004). This problem-solving framework is called the STAR-Legacy cycle. The first step of the Legacy cycle is the challenges The challenges step uses the interaction between the instructor and student to develop a framework for the problem. Therefore, this part of the structure is learner centered. Another step is the research and revise step. This step could be implemented by a dialog with the instructor, independently by the student, or a combination of both methods.

Problem-Solving Skills

This section describes the problem-solving skills available to engineering students and other professionals who solve complex problems. The problem-solving skills are used within the problem-solving framework. These problem-solving skills are described in five sections: tools, defining, goals, heuristics, and reasoning.

Tools are nonroutine (Gilfeather & del Regato, 2004) problem-solving skills that are physical and nonphysical instruments. These instruments assist problem solvers in defining the problem, identifying the causes, and selecting specific solutions to problems. Physical tools are nonmechanical implements such as a graphic organizer, ruler, flowchart, and the Venn diagram. Additionally, there are mechanical and software tools such as a voltmeter, lever, and software diagnostic programs.

Nonphysical tools include a wide range of cognitive instruments and strategies (J. L. Adams, 1986) that are used to assist the problem solver. Examples of nonphysical tools include brainstorming, questioning, and mental mapping.

The next three skills are defining, goal identification, and heuristics. The defining skill is a routine skill (Gilfeather & del Regato, 2004) that describes the nature and parameters of the segment or segments of the problem. Goal identification is also a routine skill, which the problem solver uses to identify a specific segment or segments of the problem. Heuristics is a nonroutine skill that is based on the prior experience of the problem solver. One example is the ability to use an analogy. In this situation the GE connects two similar experiences so that the he or she is able to find a solution to the new problem that is based on a problem the GE has already solved.

Reasoning is also a nonroutine skill (Gilfeather & del Regato, 2004). This skill includes inductive, deductive, fallacious (Hamblin, 1970), and other types of logic. Inductive reasoning is logic that requires the problem solver to make inferences from specific or particular premises to a general outcome. Deductive operates from the general statement or premise to the specific or particular conclusion. Fallacious reasoning is logic that is based on invalid premises or inadequately constructed arguments.

Tools

Tools are physical and nonphysical instruments (Jonassen, n.d.) that assist the problem solver in finding the causes, defining the parameters, or ascertaining other aspects of the problem segments or segment. Therefore, in order for the problem solver to use these tools, he or she needs to understand the variety of the tools, how the tool is used, and when the tool is used. As with all problem-solving skills, there are situations

where one tool skill could solve the entire problem. There are two broad categories of tools: physical, nonphysical. Refer to Figure 2 for an illustration of each type of problem-solving tool.
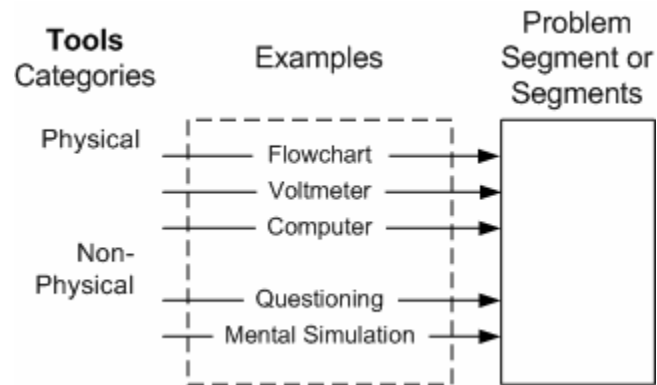
Figure 2. Examples of physical and non-physical problem-solving tools.

Some problem-solving tools are domain specific (J. L. Adams, 1986). This means the tools are used in a specific industry or discipline. Other problem-solving tools have a generic application. These tools can be used across industries and disciplines. For example, the flowchart problem-solving tool is used by many individuals from many different disciplines (Harrington, 1991).

The second element in defining problem-solving tools is the skill required to use them. Industry-specific problem-solving tools typically require on-the-job training to use them (J. L. Adams, 1986). However, the employee may learn how to use generic tools from an academic environment, individually at home, at the job, or combination of these different learning environments.

Physical. A large number of physical problem-solving tools are graphical templates that the problem solver uses to find causes and solutions to a problem. These graphical tools provide the problem solver with a way to visualize arguments and subtle

aspects of the relationship of multiple causes, multiple solutions, and other inter-relationships of the segments of the problem. Three examples of these tools are the Euler diagram, Venn diagram, and the flowchart (Goertz, 2006; Harrington, Hoffherr, & Reid Jr., 1999; Roberts & Sykes, 2005).

The flowchart uses a system of symbols that allows the problem solver to depict graphically the how a system process works. Harrington (1991) recommends the use of color on those aspects of the process to highlight areas of that might need improvement, correction, or perhaps even enhancement since they are working properly.

The BCG Matrix (generically called the growth-share matrix) is a graphic tool that illustrates market growth as compared to market share (Nutton, 2006/2007). This tool provides the engineering and marketing personnel with a visual perspective on when a product should be developed, enhanced, or retired.

One of the most sophisticated physical problem-solving tools is the computer. This tool has graphical and analytical characteristics that provide the problem solver with a wide range of problem-solving capabilities. The algorithms (Penrose, 1994) are instructions that determine how the computer and memory are used to manipulate data that is input by the user. The computer then outputs the data in a graphical, written, or verbal format. This data can be solutions to a computational problem, simulations of a problem, or a visual display of quantitative information.

Cheng and Simon (1997) designed a problem-solving software computer program (algorithm) and associated methodology called HUYGENS. This is a domain-specific graphical tool that is used in physics and other analytical disciplines. These researchers believe this diagrammatic tool is much more helpful than the traditional mathematical

approach. The mathematical approach requires the problem solver to reason by using abstract equations. Additionally, "The diagrammatic approach often requires less computation than the conventional approach "(p. 217)

The HUYGENS methodology has three major components: inputting data into the computer that contains the HUYGENS software program, executing the program, and viewing the diagrams. The data are variables associated with the experiment such as weight and volume of objects that are interacting and the relationship between these objects (Cheng & Simon, 1997).

The computer executes the software program with this input data to generate line drawings. These drawings show how the elements (weight, volume, and other variables) interact. The problem solver then views these diagrams and assesses the significance of this simulation (Cheng & Simon, 1997).

A physical tool that is designed specifically for the engineering discipline is the voltmeter. This device measures voltage, current, and other electrical quantities (A. J. Evans, 1994). The voltmeter can be used to provide data for other parts of the problem-solving process. For example, the problem solver can use the voltmeter to measure current when the tested equipment is operating at full power. This measurement would then be used, in conjunction with a schematic of the equipment, to assist the problem solver in defining the problem.

Nonphysical. Nonphysical problem-solving tools include many processes that require verbal and thinking skills (J. L. Adams, 1986). As with the physical problem solving tools, the non-physical tools require the problem solver to know when and how to use them during the problem solving process.

Using questioning is a powerful problem-solving tool that is frequently used in many disciplines to resolve problems. Denton (1999) created one such questioning tool that he calls the management-by-the-fundamental question. This tool requires the problem solver to articulate answers to several open-ended questions.

1. What is the reason for solving this problem?

2. Why am I solving this problem (reflection)?

3. How am I going to measure or assess the effectiveness of solving this problem?

Some questioning problem-solving skills are one-word adjectives that force the problem solver to make connections between the problem and a potential solution. Other questions are phrases that may guide the problem solver in completely new dimensions through the problem space (Osborn, 2001). The following set of questions were designed by Osborn to assist a problem solver in developing a product.

> Put to other uses (other uses if modified)?…Adapt (what else is like this, what other idea does this suggest, what could I copy)?…Modify (change meaning, color, form)?…Magnify (stronger, more time, greater frequency)?…Minify (what to subtract, omit, split up, understate)?…Rearrange?…Substitute?…Reverse?… Combine? (pp. 286–287)

The aforementioned questioning tools are described in many sources (Finlayson, 2001; Leeds, 1987; Mayer, 2000; Nadler, Chandon, & Dworetzky, 2003; Whitney, Cooperider, Trosten-Bloom, & Kaplin, 2002). Each volume uses questions to assist the problem solver in resolving certain aspects of the problem.

Nadler et al. (2003) classify questions into three categories with each category having specific subsections of questions. Table 1 lists the three categories of questions, along with descriptions of each category of question.

Table 1

Descriptions of Foundation, Action, and Organization Questions

Category	Description
Foundation	The foundation questions define the purpose and structure of the problem. This includes identifying the uniqueness of the problem, having a workable solution, and determining what is "purposeful information" (p. 29).
Action	Each action question has a framework that includes: "list alternatives, build details, and select the option" (p. 88). This framework can also be used in the Foundation and Organization questions. The second level of an action question focuses on four parts of a problem: "people, purposes, target, and results" (p. 87).
Organization	These sets of questions are structured to assist the problem solver in providing insight into how an organization can sustain the recently developed solutions.

Brainstorming is a problem-solving tool with which the problem solver spontaneously generates ideas about a specific issue (J. L. Adams, 1986; Osborn, 2001). The problem solver can use specific creative, cognitive skills, such as "forced association" (Miller, 1999, p. 175), to derive causes to a problem or perhaps different types of solutions that might resolve the problem. For example, the problem solver attempts to tie two concepts, such as the low power level of a circuit and the flickering of a computer screen, together. The problem solver brainstorms as many reasons to explain this relationship. The key part of using this problem-solving tool is that no judgment is made by the problem solver with regard to the practicality of any proposed answer. All data from a brainstorming session is available for future analysis.

Nonphysical problem-solving tools also include role model playing activities. De Bono (1985), who coined the phrase lateral thinking, developed a tool that uses lateral

thinking called Six Thinking Hats. This problem-solving tool can be used with individuals or group. With individuals, the problem solver symbolically or actually wears one hat of six colors. Each colored hat represents a specific form of thinking.

1. White Hat: An analytical style in which the problem is evaluated in terms of measurements, statistics, and calculations.

2. Red Hat: This style describes an emotional problem solver. He or she looks for problem solutions based on the feelings and other interpersonal aspects of the problem.

3. Black Hat: For every positive and constructive recommendation to solve a problem there are many negative reasons why that recommendation will not work. The black hat is the person who espouses that negativity.

4. Yellow Hat: The yellow hat problem solver is positive about the problem solving session. They use their skills to construct a solution to the problem by building upon multiple concepts brought up in the meeting and/or realized by the yellow hat problem solver.

5. Green Hat: This style represents a creative, out-of-the box thinker. The green hat problem solver spontaneously generates alternatives, solutions, and different perspectives of the problem.

6. Blue Hat: The blue hat is leader and organizer of the problem-solving process. He or she facilitates this entire process.

The problem solver writes responses about the problem issue using the type of thinking defined for that hat. The problem solver then places another hat on his or her head and continues the process of analyzing the problem (De Bono, 1985).

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Buzan (2005) designed a mind map graphical tool or type of mental simulation that assists the problem solver in searching for alternative solutions or other aspect of the problem-solving process. The mind map process requires the problem solver to draw spontaneously a tree with each branch and limb representing solutions to aspects of the problem.

Along the line of the mind mapping tool is the Imaginization process of organizational specialist Morgan (1997). In the book of that title, Morgan suggests using images to assist the problem solver in finding solutions to organizational problems, such as determining the role of a leader or finding an organization structure that is decentralized.

For the leadership problem, Morgan (1997) suggests visualizing the organization as set of strategic termites that must build and create an organization. The spider plant is used as an image that must be flattened. In this image, each tentacle of the plant could represent a division or unit of the organization.

A different set of nonphysical, problem-solving tools include mathematical and statistical processes such as computing regression analysis; measures of variability, variance, and standard deviation; and different types of correlations (Norusis, 2005). One of these mathematical tools is the Bayes theorem. This tool consists of a series of equations that are completed with variables supplied by the problem solver (Tabak, 2005). The problem solver then computes these equations to yield a value that represents a particular probability of a problem segment or segments. These elements include determining the cause or causes of the problem or perhaps a solution.

The Bayes theorem allows the problem solver to determine an answer to a

problem segment, such as causes or alternative solutions, by factoring in the current and

past conditions associated with that problem segment (Tabak, 2005). Most important, the

Bayes theorem reverses the logic process and provides the problem solver with a value

(probability) of the conditional relationship to the existing problem segment. Figure 3

illustrates how the Bayes theorem is used to explain why a computer locks up.
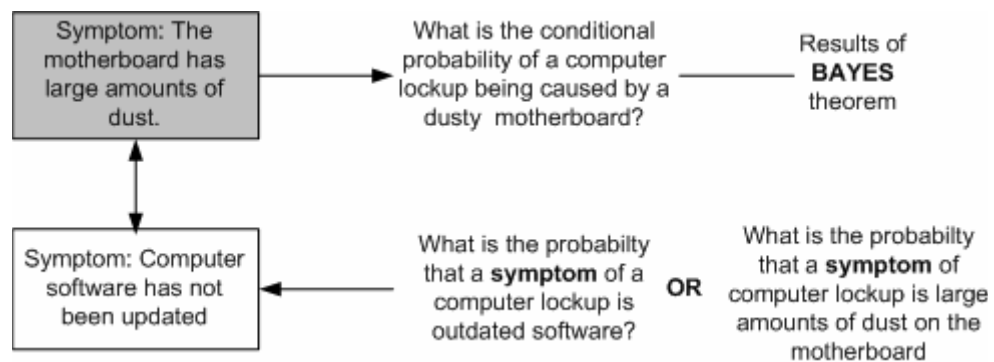
Figure 3. Using Bayesian probabilities to determine causes of computer lockup.

However, according to Tabak (2005), there is a potential downside to using this

tool . The Bayes theorem is computed on a conditional relationship between existing

parameters and the hidden solution. Tabak calls the problem solvers who use this

methodology Bayesians. This logic is not shared by other problem solvers, which Tabak

calls frequentalists. These problem solvers believe the probability of a particular problem

segment or element is based on the frequency of that element occurring.

Hybrid. There are three other tools that could be physical or nonphysical,

depending on how they are implemented. One of these is called working backward

(Rubinstein & Firstenberg, 1995). This tool could be used cognitively in a nonphysical

sense when the problem solver visualizes the faulty process and then works backward

from the symptom of the problem. In the process of working backward, the problem

solver may surface how the problem started or other elements of the problem. Figure 4

shows how the working backward tool could be used in a physical sense. In this case, a

spreadsheet is used to calculate a solution. However, by working backward from the

solution, the operator can detect potential problems in how the solution was derived.
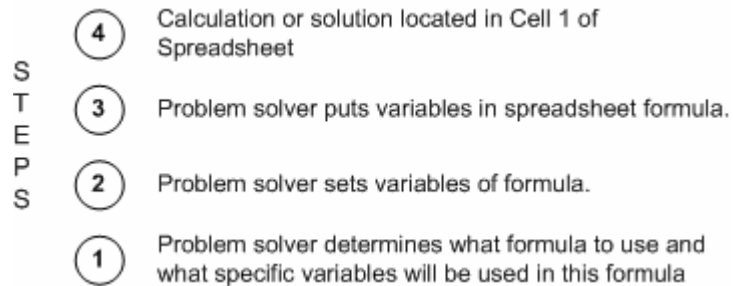
Figure 4. Working backward to determine an error in a solution.

The "stimulate the failure" (Agans, 2002, p. 43) is another problem-solving tool

that can used cognitively or physically. From the cognitive or nonphysical perspective,

the problem solver might speculate how he or she could obtain the same problem by

changing the existing parameters of the problem. For example, the problem solvers might

have diagnosed the reason for the lack of characters being displayed on the computer

monitor is a faulty keyboard cable. By using the stimulate failure skill, the problem solver

could speculate that a group of nonfunctioning key switches on the keyboard could also

cause the problem.

From a physical perspective, the problem solver would stimulate the computer

display failure by using a different technique. In the previous example, that would mean

creating a series of nonfunctioning key switches, with a functional cable, and then seeing

whether the characters are still not displayed on the computer monitor. According to

Agans, this is where the problem solver will "spray a hose on that leaky window"

(Agans, 2002, p. 43).

The third type of hybrid skill is called check, observe, and replace (Kuphaldt &

Divasto, 2002). This skill could be classified as physical if implemented with physical

tools or nonphysical if implemented by actions of the problem solver without the use of a

physical element.

The check, observe, and replace skill (Kuphaldt & Divasto, 2002) is used in three

ways. The check and observe method allows the problem solver to investigate an aspect

of the problem. For example, the problem solver might believe the problem with a faulty

keyboard is a loose connector between the keyboard and computer. In this case, the

problem solver might physically test the connection with a device (physical tool) or

simply look at the connection to assure continuity (nonphysical tool).

The replace skill (Kuphaldt & Divasto, 2002) is used similarly in attempting to

evaluate a potential problem. In the aforementioned example, the problem solver might

suspect that a connection is faulty, but cannot confirm this suspicion by observation or

physically checking the connection. Therefore, one way to validate the connection is to

replace the potentially faulty connector with a functional connector and then test the

system. If the keyboard works, then the connector was the problem and replacing it was

the solution.

Defining

Defining is a routine problem-solving skill (Gilfeather & del Regato, 2004) that

describes the nature, parameters, constraints of the segment, or segments of the problem.

The defining skill is specific to the problem (Pew & Mavor, 1998) such as framing

(Gloeckler, 2007) the cause of a computer failure to the power supply rather than the

keyboard.

As with the tools problem-solving skill, the defining skill may be used several times during the completion of a problem. Each time this skill is used, the GE might be following a specific problem-solving framework or the GE is randomly using the defining skill (Cochran, 2006). In the following example, the GE follows a problem-solving structure that consists of defining the problem, changing or fixing a component, testing a component, analyzing a component if it fails, and redefining the problem.

1. The engineering supervisor defined the problem. He or she told the GE that the reason for the computer failure was that the power supply was faulty.

2. The GE replaces and tests the computer. The computer fails.

3. The GE uses a problem-solving tool to analyze the problem, such as a voltmeter. The GE tests the input voltage and finds that the voltage is lower than the rating required by the power supply.

4. The GE uses the defining problem-solving skill to redefine the problem as the input power.

The defining skill can also be used to reframe the entire context of the problem. One example is illustrated in the following scenario.

1. The computer is displaying pictures on the monitor but not displaying characters on the monitor.

2. The GE suspects the problem is the keyboard and therefore defines the problem as the keyboard. The GE replaces the keyboard.

3. This action results in characters displayed on the monitor, but now the pictures are not displayed on the monitor.

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4. The problem solver now analyzes the system using a nonroutine problem-solving skill, such as questioning the computer operator. The GE determines that the operator changed the monitor display parameters and that was the reason the pictures were not displayed.

5. The GE uses the defining skill to define the problem as an employee training issue.

Goal Identification

Goal identification is a routine problem-solving skill (Gilfeather & del Regato, 2004) with which the problem solver identifies the segment or segments of the problem (Laird et al., 1986). These include high-level cognitive processes such as identifying the causes or solutions to the problem.

This routine skill (Gilfeather & del Regato, 2004) is closely identified with the defining routine skill. Both skills allow the GE to frame and isolate a segment or segments of the problem. However, the goal-identification skill identifies generic segments of the problem such as problem definition, causes, solutions, and other types of goals. However, the defining problem-solving skill defines specific characteristics of a problem. In one case, the GE could use the defining skill to define the solution as replacing the computer monitor. In another situation, the GE could use the defining skill to determine the problem definition, such as fixing a faulty computer.

The goal-identification skill is also closely associated with the problem-solving framework or structure (Cochran, 2006). Some GEs use a problem-solving framework that contains goals that are specifically identified. For example, a simple problem-solving framework could be: (a) Define the problem, (b) Search for the causes, (c) Select the

cause that impacts most people, (d) Analyze the cause, (e) List the solutions, (f) Select the best solution, and (g) Implement the solution.

Each of these steps in the problem-solving framework (Cochran, 2006) is a generic goal in the problem-solving process. In this example, the GE does not have to use the goal-identification skill if this is how he or she solves problems. The GE starts every problem with the define problem goal and proceeds down list of steps until the problem is solved. However, in other cases, the GE might not use a formal problem-solving framework. In these cases, the GE may or may not use the goal-identification problem solving skill.

One example of using the goal-identification problem-solving skill is documented in the Mathematics Framework for the California Public Schools (Curriculum development and supplemental materials commission, 2006). This document describes the problem-solving skills that students need to learn at each grade level through Grade 12. The difficulty of problem-solving skills increases with each grade level. This represents an educational philosophy in which there are certain problem-solving skills that only older students can learn.

Of the 14 problem-solving goals achieved by the seventh grade student, 6 are listed below (Curriculum development and supplemental materials commission, 2006):

1. Analyze problems by identifying relationships, distinguishing relevant information from irrelevant information, identifying missing information,sequencing and prioritizing information, and observing patterns.(Curriculum development and supplemental materials commission, 2006, p. 77)

2. Determine when and how to break a problem into simpler parts.

3. Use estimation to verify the reasonableness of calculated results.

4. Make and test conjectures using both inductive and deductive reasoning.

5. Apply strategies and results from simpler problems to more complex

   problems.

6. Use a variety of methods, such as words, numbers, symbols, charts, graphs,

   tables, diagrams, and models, to explain mathematical reasoning. (p. 77)

As can be seen, each goal identifies a specific problem-solving process. Unlike

the defining problem-solving skill, these processes are generic and can be used in any

discipline.

Some goals are identified in a specific sequential order (Steiner, 1996). In this

situation, the problem solver must complete all the goals, in a specific order, to arrive at a

solution to the problem. Figure 5 shows how four goals could be identified

nonsequentially and sequentially.
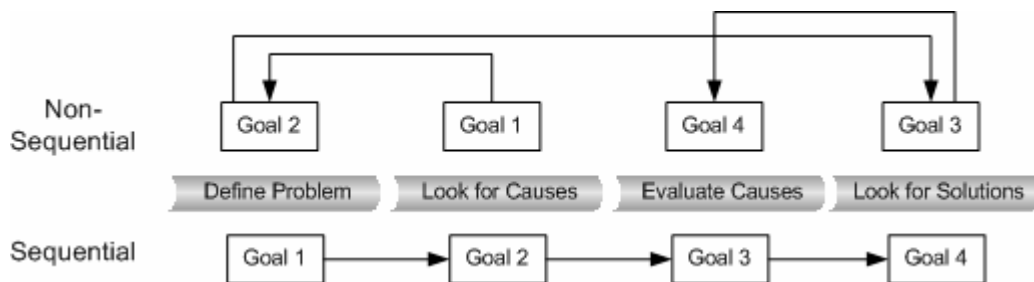
Figure 5. Four problem solving goals that are nonsequentially and sequentially identified.

The nonsequential goals process requires the problem solver to search for causes

before they define the problem. In the sequential-goals process (Steiner, 1996) the

problem solver starts with defining the problem (Zimmerman, 2006) and then looks for

causes to the problem. This illustration shows the significance of the define problem goal.

As can be seen, a problem solver might find causes to an incorrect problem if the define problem goal is not the first completed goal.

Sternberg uses a hybrid type of goal identification (Sternberg & Spear-Swerling, 1996). That means some of the goals are completed sequentially while others are recursive. Recursive is a repeated process: (a) Define the problem, (b) Select a process to solve the problem, (c) Determine how to represent the information, (d) Determine the steps in solving the problem, (e) Make a decision on what resources should be used to solve the problem, (f) Monitor the solution(s), and (g) Evaluate the solution(s).

Goals (a), (b), (e), (f), and (g) are sequential steps starting. However, goals (c) and (d) are recursive. Goal (c) occurs frequently throughout the problem-solving process because each problem-solving stage might require different ways to represent the information. For example, the representation of information in the evaluation step might be graphical while the definition of the problem in goal one might be verbal. The same recursive rationale is applicable to goal (e). In this case, the resources or problem-solving tools might be different for each step of the problem-solving process (Sternberg & Spear-Swerling, 1996).

Hayes presents six types of sequential goals (Hayes, 1989):

1. Finding the problem.

2. Representing the problem.

3. Planning the solution.

4. Carrying out the plan.

5. Evaluating the solution.

6. Consolidating gains. (p. 3)

Goals 1 and 2 are key features of using the goal-identification skill in this specific problem-solving structure. Hayes (1989) describes these goals as internal or external representation techniques. An internal technique is envisioning the problem in the mind so that one can see what variables apply to the definition of the problem. However, the problem might be complex and so this method is not always practical. In that case, Hayes recommends using an external representation to find and define the problem. This could involve using a problem solving tool, such as a flowchart, or other type of graphic that assists the problem solver in representing the problem.

The sequential designation of identifying problem-solving goals has limitations. Potter (2005) articulates one view in his analysis of strategic thinking skills. According to Potter, a problem solver who uses goals to find a solution is missing other potential, alternative solutions. This occurs because the use of sequential goal setting requires the problem solver to use vertical thinking. Vertical thinking is a rigid method that forces the problem solver down one path. Instead of this method, Potter recommends using eight strategic thinking skills when they are necessary, that is, nonsequentially. These eight goals represent another way a problem solver can use the goal-identification problem-solving skill. They include analysis, evaluation, deduction, induction, abstracting, grouping, synthesis, and persuasive expression.

The goal-identifying problem-solving skill also includes one of the fundamental and popular concepts of how to solve a problem. That concept is the scientific method. The scientific method technique has three main parts or steps: validation, reducibility, and causality (Medawar, 1982). The problem solver completes these generic goals in order to create a hypothesis for a new theory, solve a problem, or explain a phenomenon.

Validation (Kaner, Falk, & Nguyen, 1993) is the first step. The problem solver

validates the premises in the problem to determine if they are true. If the premises are

true, then the problem solver quantifies the amount of tolerance or variance in the

premises.

The reducibility step asks the problem solver to view the problem from different

perspectives. Medawar (1982) calls these perspectives "tiers" (1982, p. 83). For example,

in analyzing a specific illness in a patient, the physician may look at the illness from five

tiers.

Table 2 shows five, diagnostic tiers of an illness in a human. Adjacent to each tier

is a problem question that assists the physician in reducing the problem to a specific tier

or goal in the problem solving process.

Table 2

Using the Reducibility Step to Ascertain a Cause of an Illness

Tier/Goal	Problem Question
Community tier	Are their elements in the patient's environment that are causing the illness?
Family tier	Does the patient have close contact with immediate relatives?
Body tier	What is overall physiology of the patient?
Organ tier	Are there any specific organs associated with the illness?
Blood tier	What type of blood tests have been implemented during the last 2 days? What are the results of these tests?

In the third goal (body tier), the problem solver looks for connections,

relationships, or causes of the problem (Medawar, 1982). Alternatively this goal might

suggest that the problem is a result of the relationships between causes. Using the

aforementioned human illness problem as an example, it is possible that the relationship between the physical attributes of the organ tier and blood tier is what is causing the illness.

The Crosby Quality Education System (QES) is an all-inclusive problem-solving philosophy that contains a goal-identification skills process (Crosby, 1984). The QES also contains numerous problem-solving tools and heuristics. For this reason the QES and similar quality control philosophies are used by large companies when an overriding concern is for consistency in how and when employees solve problems.

The QES goal-identification skill requires the problem solver to use four generic absolutes for each problem: identify requirements, use prevention, understand zero defects, and calculate the price of nonconformance (*Quality education system for the individual*, 1988). These absolutes are the goals of the problem-solving structure that each QES engineer uses to solve problems.

The first goal asks the problem solver to identify the requirements of the problem (*Quality education system for the individual*, 1988). The next three steps are goals or aspects of the quality environment. They are implemented in any sequence that is relevant to the problem-solving process. The problem solver uses these goals to frame the problem and, therefore, they are very similar to the definition of problem goals used in other problem-solving structures (Sternberg & Spear-Swerling, 1996). Figure 6 illustrates how goals are used in the quality education. The Quality Education System uses four goals that provide the problem solver with a framework to solve the problem.

GOALS   Segment or Segments of the Problem

Identify Requirements

Use Prevention

Understand Zero Defects

Calculate Price of Non Conformance

Figure 6. Identifying goals in the quality education system to solve a problem.

Prevention is part of every solution (*Quality education system for the individual*, 1988). An effective solution includes a self-regulatory element that adjusts to different variances that occur during the new process. Zero defects represent another characteristic that the problem solver uses to frame the problem, specifically the solution aspect of the problem. The goal of every solution is to rectify the faulty process so there are zero defects. That means the problem solver is not trying for 96% correction, but is striving for a solution that has no defects.

A key goal-setting step is the calculation of nonconformance (Crosby, 1984). This requires the problem solver to measure the specific, faulty aspects of the problem. After this is accomplished, the problem solver has a measurable goal. For example, the price of nonconformance in a faulty design process is that the engineering technicians must rework the circuit boards 10 times to correct the poor soldering of the integrated chips to the printed circuit boards. This price of nonconformance is a measurable goal.

Heuristics

This nonroutine, cognitive skill is based on the experience of the problem solver. A heuristic allows the problem solver to organize information (Black, 2004b) so he or she

can quickly solve problems. During the early research in human problem solving, this organizational process was focused on the search and compare process. This process is illustrated in Figure 7.
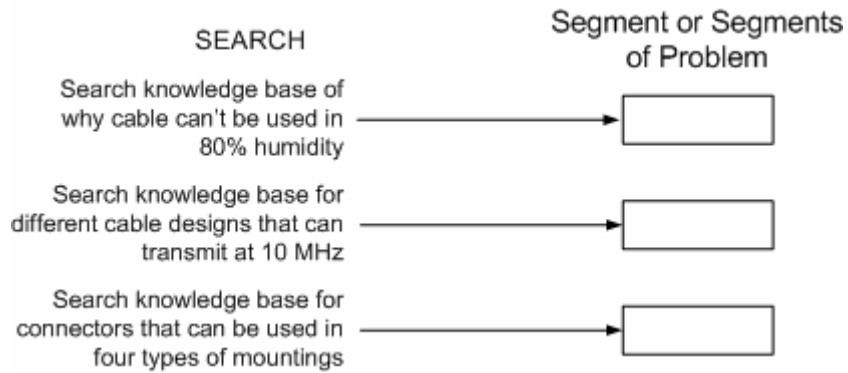
Figure 7. How some problem solvers search their experience by comparing.

In the left column are ways the problem solver is searching his or her experience, which is an accumulation of knowledge about different types of tasks (Sternberg & Ben-Zeev, 2001). By using the search and compare heuristic, the problem solver is able to retrieve and separate his or her experience into a specific segment or segments of the problem that are represented in the right column of Figure 7.

In this example, that is presented in Figure 7, these segments are the relationships between the computer cable and humidity, as well as the different types of cable designs. The early researchers believed that a competent problem solver could quickly solve a problem by improving how quickly he or she could search and compare his or her experience (de Groot, 1965).

One type of search is called the brute force search method of problem solving (Cusumano, 2005; Korf, 1988). Breadth-first is one type of brute force search. Figure 8 illustrates how three moves in chess equates to a two level search tree.
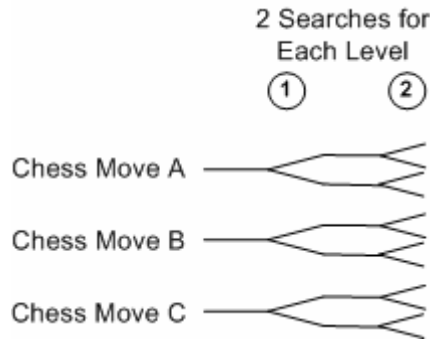
Figure 8. How three chess moves require two levels of searching counter moves.

In Figure 8, the chess player is evaluating moves A, B, and C. Each of these

moves branches into a series of counter moves that the problem solver assumes the other

chess player would make. Therefore, in order for the problem solver to determine what

move to make, he must search each frame (moves A, B, and C) to the capacity of his

memory. The problem solver then compares the results of searching A, B, and C to a set

of criteria for determining which move to make. For this reason, the search framing skill

is also called the "generate and test method" (Newell, 1990; Newell & Simon, 1972, p.

97). A breadth-first search for an engineering problem is shown in Figure 9. The engineer

must determine which cable to use by using this problem-solving skill to search two

levels of data for two cables.
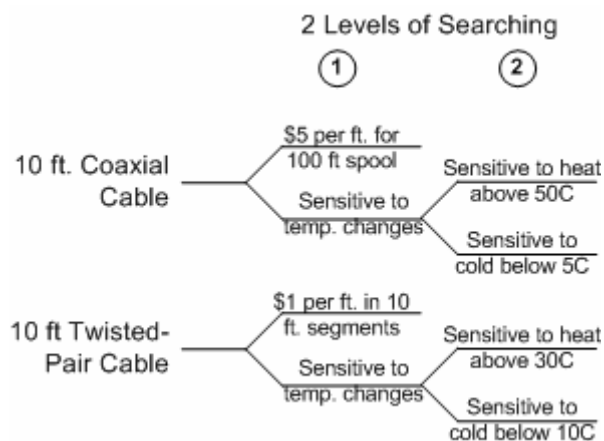
Figure 9. Two levels of breadth-first search for an engineering problem.

As mentioned, this problem-solving method (Newell, 1990) is extremely memory intensive. Therefore, early research in problem solving assumed that an electronic computer could search larger amounts of data more quickly than a human being and, therefore, would find the solution faster.

The early researchers of human problem solving decided to use this concept in matching chess grand masters against chess-playing computers (de Groot, 1965). Surprisingly, the brute force search method of an electronic computer, which could search thousands of variables a second, did not allow the computer to defeat the grandmasters. According to de Groot, this occurred because chess grandmasters used other types of problem-solving skills such as heuristics. According to Korf (1988), the computer cannot process the large number of searches fast enough with the necessary accuracy to be a viable problem-solving methodology.

These heuristic skills allowed the grandmaster to avoid exhaustive searches of potential moves so that a strategic decision is made in a reasonable period of time. Therefore, the study of heuristics became a key component of researching problem-solving processes. Since one part of being a competent problem solver is intelligence, one study on problem solving equates heuristics with the efficiency of an intelligent problem solver: "Intelligence is not a function of how hard the brain works but rather how efficiently it works" (Jausovec, 2000, p. 214).

One heuristic that a grandmaster uses is based on the concept of three parts of the chess game: opening moves, middle game, and the endgame. The middle game is the point at which the "game possibilities become trillions upon trillions, and every chess player confronts distinct chess molecules that they have never seen before and will never

see again" (Shenk, 2005, p. 104). Therefore, rather than use the brute search method, the chess player looks for tactical advantages such as controlling the middle segment of the board. The chess player is not looking for a solution to the problem, which in this case would be to find a sequence of moves to checkmate the computer. Instead, he or she is resegmenting the problem, which is how to control the middle space of the board.

Tversky groups intuitive and judgmental skills into a special type of heuristics called availability heuristics (Tversky, 1983). These heuristics define problem-solving skills that assists the problem solver in making decisions, estimating frequencies, and making many types of diagnostics (K. J. Gilhooly, 1996). Figure 10 illustrates how the availability heuristic is used to solve a segment or segments of a problem.
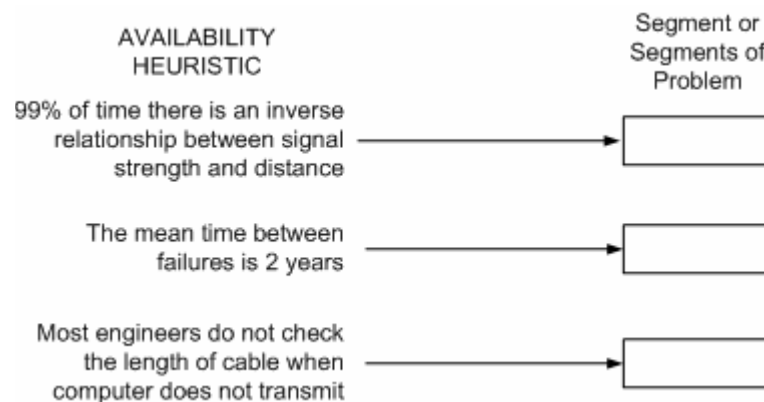
Figure 10. Using the availability heuristic for a failed computer connection.

In Figure 10, the problem solver uses the availability (Tversky, 1983) of specific data of several aspects of a computer that cannot transmit data. In the second element of this analysis, the problem solver notes that a specific computer electronic assembly has a Mean Time Between Failures (MTBF), (Duncan, Luftig, & Warren, 1995) of 2 years. This means this assembly typically does not fail within 2 years; however, this assembly could last longer. The problem solver might use this statistic to frame the computer

problem, that is, the engineer will not troubleshoot this assembly if it was installed within the 2-year period.

Another aspect of the availability heuristic is frequency matching of a problem-solving variable (Griffiths, Steyvers, & Firl, 2007). An engineer might have to determine the frequency of failures that occur when building and assembling a specific component on a circuit board. The problem solver uses the availability heuristic, based on his or her experience, to frame the solution of the problem.

Frequency matching describes a process in which the problem solver looks at elements of the problem from a numerical event standpoint (Griffiths et al., 2007; Wolford, Newman, Miller, & Wig, 2004). The problem solver makes a decision based on the event that occurs more frequently.

In the example shown in Figure 11, the last element describes how most engineers do not check the cable connections of a computer when there are transmission problems. This heuristic is based on frequency matching (Griffiths et al., 2007) by the problem solver. He has observed and experienced that most engineers do not frame a transmission problem in this way. He or she does not check the cable connections.

Availability heuristics are also referred to as rules of the thumb, an engineer's attitude, and safety precautions (Koen, 2003). Some of these are quite specific such as using a percentage of the stress qualities of a material to estimate the strength of that material. Another specific heuristic involves how to tap a screw efficiently by turning the screw approximately 1.5 turns.

The researcher calls another heuristic that is similar to the availability heuristic, the evidence-based heuristic. This heuristic problem-solving skill evolved out of the

medical profession in which a large amount of problem solving is based on clinical experience of the physician (Gambrill, 2005; McGovern, Summerskill, Valori, & Levi, 2001). From an engineering perspective, the competent engineer might be the problem solver who has a large amount of technical experience in a specific engineering discipline. Figure 11 shows three different ways an engineer may use the evidence-based heuristic to solve a segment or segments of a problem.
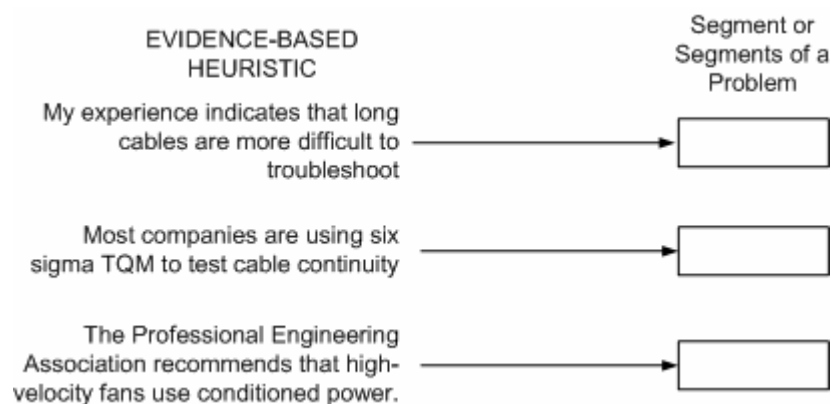
Figure 11. Three ways of using the evidence-based heuristic to solve a problem.

The heuristic process at the top portion of the left column of this example is based completely on the experience of the engineer (McGovern et al., 2001). The engineer uses his background in troubleshooting cables to segment immediately the problem as one based on the length of the cable.

The next two heuristic processes of this example rely on evidence from another source. The second process indicates to the engineer that most companies segment the cable problem as one that requires the use of six sigma TQM (Duncan et al., 1995) . The third process of this example, illustrates how the engineer may use recommendations by a professional organization as the method to segment or solve a problem.

According to Montgomery, the first heuristic process is called "clinical judgment" (Montgomery, 2006, p. 43) for physicians. Montgomery describes physicians as

clinicians whose judgment is of paramount importance. This could also be the reason engineers rely on this heuristic. For example, an engineer who is troubleshooting the failure of a National Security Agency computer would probably rely on his or her experience to frame the problem because of the magnitude of situation.

Alternatively, the other two evidence-based heuristics rely on evidence that might be more compelling because this rationale comes from a recognized industry source. Montgomery asserts that physicians should use these two heuristics as resources and supplement additional evidence (Montgomery, 2006). However, the physician uses his or her knowledge base and clinical judgment to perform the actual framing (diagnosis) and treatment plan.

Heuristics are also jointly used with other problem-solving skills to segment a problem. Arlin suggests the questioning problem-solving skill is the keystone to finding the best solution (Arlin, 1990). Arlin's logic is formulated on the larger issues of what is the problem and how is it framed. For example, a problem solver might find a satisfactory answer to a problem simply because he or she incorrectly framed the fundamental problem posed in the problem space. According to Arlin, apparently this is what Einstein avoided in his seminal discoveries. Einstein found asymmetry in the current views of physics and, therefore, reframed the questions he was asking. Asymmetry means that Einstein found inconsistencies in how physics explained certain phenomena that previously were accepted as a consistent view. Arlin calls this process "pushing the limits" (Arlin, 1990, p. 233). This action represents the proclivity of the problem solver to ask questions that might provide solutions that are outside the limits of acceptance.

In Figure 12, the problem solver separates the problem in segments from answers to questions of the previous on existing segments. According to Flesch, this heuristic is an example of clear thinking (Flesch, 1951).
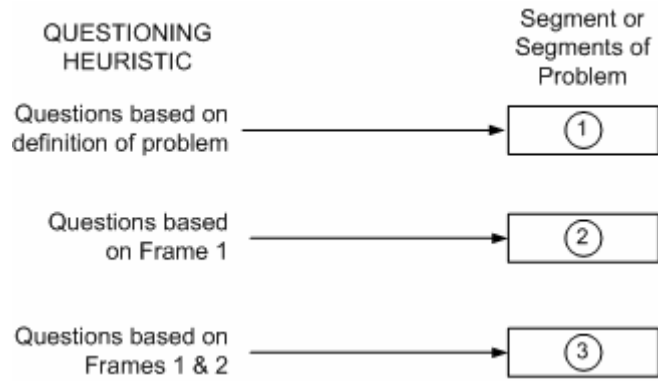
Figure 12. Using the questioning heuristic to segment a problem.

Figure 13 illustrates the questioning heuristic. In this example the problem solver uses clear thinking (Flesch, 1951) and asks questions that focus on the geographical location of cars that have failures. Perhaps the reason the problem solver uses these types of questions is that he or she believes failures are occurring because the supervisor of that region is not following the company's newly enacted preventative maintenance program.
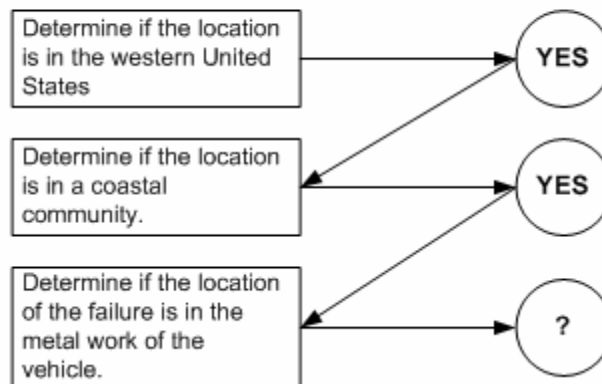
Figure 13. Using a heuristic questioning skill to solve a problem.

However, in the final question, the problem solver uses a different strategy in formulating the question. The problem solver is using clear thinking (Flesch, 1951) ascertaining what part of the vehicle has the failure. If the problem solver was continuing with the geographic questions, he or she would have used a different question that focused more specifically on the locality. For example, he or she could have asked a question that searched for the state or county that has vehicles with failures.

Perhaps the reason for the change in questions from geographical location to physical location on the car was that the failures occurred in coastal communities. The clear thinking (Flesch, 1951) of the problem solver may have allowed him or her to ascertatin that cars in coastal communities have an inordinately amount of metal failures because of the effects of salt air on the vehicles. The key concept in this example is that the problem solver uses questions about previous segments to formulate new questions to assist him or her in making new problem-solving segments.

Heuristics is also accomplished when the problem solver searches for structural matches between a previously solved problem and the current problem. If a match is found, the problem solver can apply the techniques he found beneficial in the older problem to the new problem. This pattern recognition problem-solving skill dramatically expedites the problem-solving process since the problem solver does not have to create new processes to find a solution to the problem (Hinsley, Hayes, & Simon, 1977). Figure 14 illustrates how the pattern match heuristic is used to solve a segment or segments of a problem. On the left side of the illustration are four light patterns of indicators on the Printed Circuit Board (PCB). The engineer observes the relationships of these patterns to ascertain which segment or segments of the problem may be causing the problem.
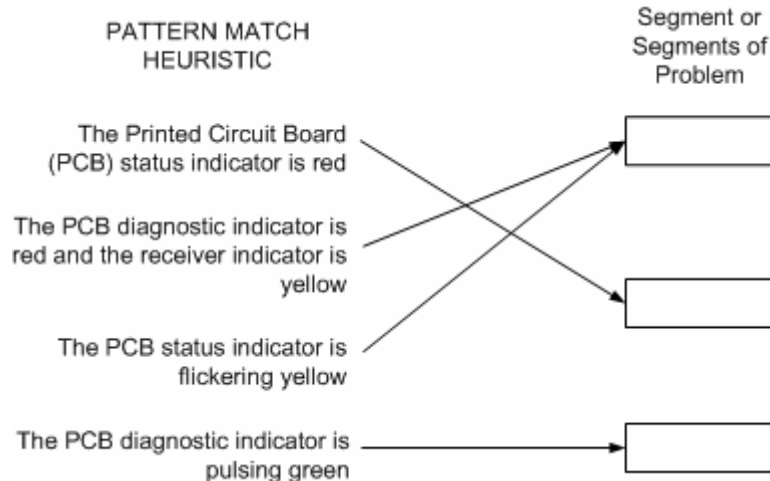
Figure 14. Using the pattern match heuristic to solve an engineering problem.

There are many studies that define this pattern matching process. Quilici and Mayer define two features of each problem that the problem solver uses in finding these patterns: surface and structure features (Quilici & Mayer, 1996). The Quilici and Mayer study focuses on statistical problems, but the concepts are easily adapted for engineering problems. The surface features represent the story line of the problem. These are high-level constructs and easily identified by novice problem solvers. The structural features represent the mathematical or basic logical elements of the problem.

Hinsley, Hayes, and Simon also implemented a study on how to segment mathematical problems by identifying mathematical features (Hinsley et al., 1977). In this study Hinsley et al. gave a series of algebra word problems to college students and asked them to group them in similar categories. The students effectively grouped them in categories ranging from scale conversion problems to ratio problems. These experiments also explored the issue of how much of the problem had to be read before a sorting process could occur. Interestingly, the results showed that many students only had to read the first few words before determining what category was appropriate for the problem.

The pattern-finding heuristic is similar to another framing problem-solving skill called analogical reasoning (Quilici & Mayer, 1996), or using the researcher's terminology, analogy heuristic. The example given in Figure 15 shows four sets of data that are separated into two separate segments. The problem solver uses structural similarities between the description of the first cable and the last cable to segment one part of this problem.
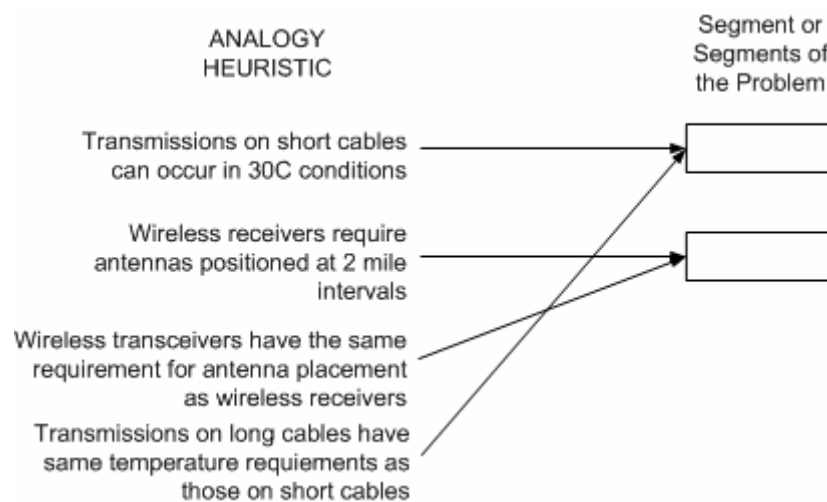
Figure 15. Using analogy heuristic for an engineering problem.

The first cable is short while the last cable is long. However, the problem solver is using the heuristic problem-solving skill (Quilici & Mayer, 1996) that states long and short cables have the same temperature characteristics. Therefore, both of these cables are put in the same problem segment. The next step in the problem solving process could be to look for other variables to determine which cable to use, focus on the other segment that involves wireless transceivers, or use another problem-solving skill to define further or resolve the problem.

The ability to make an unbiased decision or analogical comparison is a key principle of this heuristic. According to Kahneman and Tversky (1981), individuals

might use analogies to identical problems in different ways, depending upon individual preferences. One conclusion presented in Kahneman and Tversky's studies is that decision makers are risk averse. This means that if the problem is segmented so that a potential decision (solution) has a high risk factor, it is possible that the problem solver will not select that choice. This occurs because the problem is perceived as analogous to other highly risky decisions, which the problem solver wants to avoid.

Structure-mapping is another way to define the analogy heuristic (Gentner, 1989). Structure-mapping states that an "analogy is a mapping of knowledge from one domain (the base) into another (the target), which conveys that a system of relations that holds among the base objects also holds among target objects" (p. 201). The target objects represent the current problem. The solution to the problem is found in the transfer of relations from the base object or past problems.

One of the key aspects of structure mapping is that the base object (problem) does not have to come from the same discipline as the target object (current problem) (Gentner, 1989). For example, Gentner uses the phrases pure matching and pure carry-over matching to describe two types of the analogy heuristic. When the problem solver knows the domains of both objects, Gentner uses the phrase pure matching. Pure carry-over matching occurs when the problem solver is slightly familiar with the domain of the base object.

In both situations the element that is transferred is the analogy. How this analogy is used depends upon the knowledge of the user and numerous other factors. Gentner (1989) clarifies this process by comparing the transfer process to the growth of a plant (base object) and the development of a new idea (target object). When the problem solver

imports this analogy (a growing plant) he or she is typically not using it for new

knowledge since how the plant grows is not necessarily relevant to generating new ideas.

Instead the problem solver is framing the problem so as to "focus attention on certain

portions of existing knowledge" (p. 201). The problem solver uses information from the

target to match information from the base and vice versa. Kokinov and Petrov (2001)

added more ways to describe the mapping process of the base object to the target. Figure

16 illustrates the analogy heuristic that is based on the mapping effect.
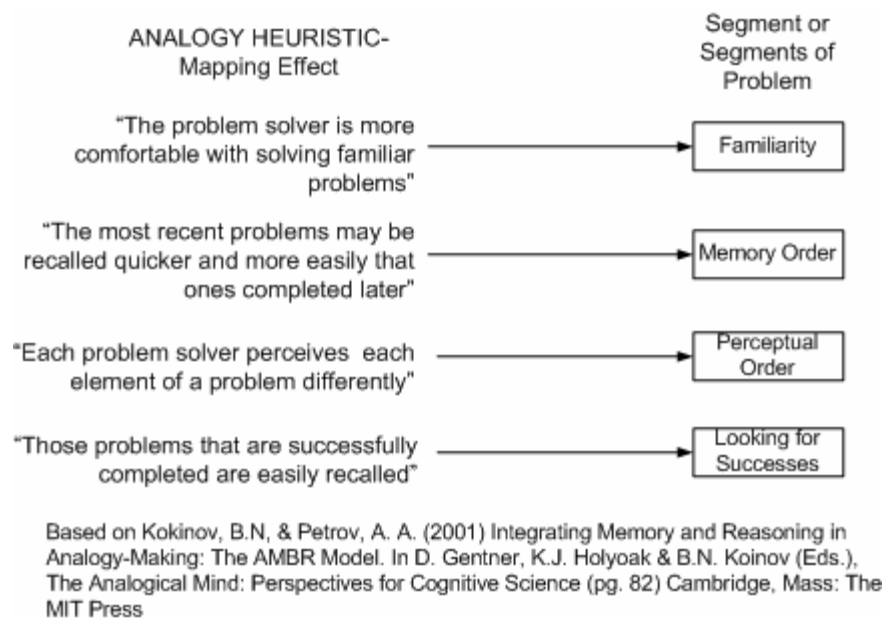
Figure 16. Several mapping effects that assist in solving a problem.

Hummel and Holyoak designed a computer program to test many of the

analogical effects listed in Figure 16 (Hummel & Holyoak, 2002). Additionally, this

program tested the concepts of close and far analogs. Close analogs are analogs that are

found in recently solved problems. Far analogs are analogs found in older, solved

problems or analogs found in earlier problems that are not structurally identical to those

in the target problem.

This computer program cued the students with a analog in a source problem (Hummel & Holyoak, 2002). That means the students viewed the source analog prior to viewing the target problem. These students chose the analog in the source problem as a match for their target problem, even though there were better close analogs and far analogs.

Additionally, the Hummel and Holyoak (2002) computer program confirmed that there is competition between analogical elements in the source problem and the target problem. Each source problem typically has competing analogical elements that might make a match difficult with analogs in the target problem. For example, the target problem might be determining how to segment the troubleshooting of a faulty computer keyboard. In this case, the engineer would use an analogy heuristic problem-solving skill with past, source problems to identify analogs to segment the target problem. Two examples of source analogs from source problems, along with competing analogs from target problems, are shown in Table 3.

Table 3

Example of Competing Analogs for Troubleshooting a Computer Keyboard

	Source Analogs	
Target Competing Analogs	Computer Keyboard A	Computer Keyboard B
Keys	Membrane and secured to circuit board.	Plastic and secured to separate mechanical switch.
Cable to Computer	5 feet with USB connection.	5 feet with RS232 connection

In this example, the analogs are the computer keys and the cable that connects the keyboard to the computer. Both of these factors are analogs (Hummel & Holyoak, 2002) that match in some way with the operation of the keyboard. Therefore, if the engineer is using the analogy heuristic, he must determine which competing analog is the best match with why he believes the keyboard is faulty. After this mapping is accomplished, the engineer then may use the appropriate source analogy to segment this aspect of the problem-solving process.

The engineer might decide that the keys or the cable are not the reasons for the faulty keyboard. When this occurs the engineer might (a) use a different mapping effect (listed in Figure 15), such as creating target analogs (Hummel & Holyoak, 2002) that he is familiar with; or (b) use parts of each competing analog (keys and cable) to segment the problem before looking for a match with a source analog.

Utility is a heuristic problem-solving skill used in many disciplines such as finance, psychology, and engineering. Utility is a measure of expected value (Chernoff & Moses, 1959; Giere, 1997) to the problem solver and is measured in units called utiles (McCaffery, Kahneman, & Spitzer, 2000). The larger the number of utiles, the greater the expected value to the problem solver. The problem solver uses the number of utiles to determine how to solve the problem. Each problem solver computes the utiles of the problem differently. Therefore, the way the problem solver segments the problem is different too. Figure 17 illustrates how the utility heuristic problem-solving skill is used in segmenting a cable purchasing decision.

UTILITY HEURISTIC-
Expected Value

Segment or
Segments of a
Problem

A Highly insulated cable costs $20 & lasts two years → Cost

B Moderately insulated cable costs $10 & lasts three years → Insulation

C Minimally insulated cable costs $15 & lasts five years → Durability
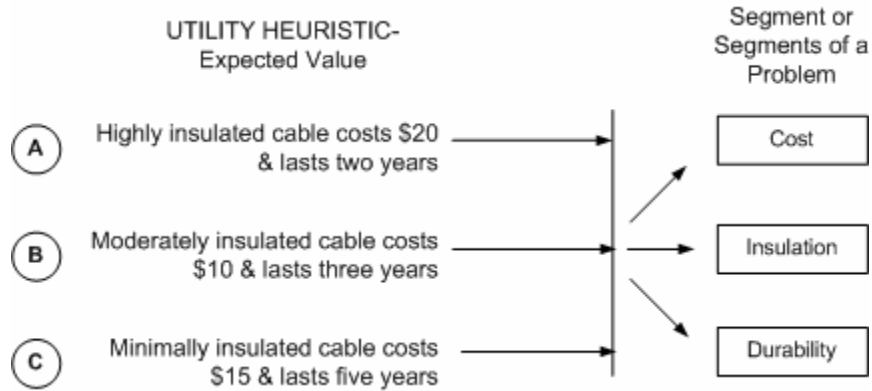
Figure 17. Using the utility heuristic to solve a segment or segments of a problem

In this example, the engineer weighs the value of three aspects of the cable in determining which cable to purchase: cost, insulation, and durability. Each of these values can be weighed equally or the engineer can give specific values, such as insulation, a greater weight (McCaffery et al., 2000). The process of assigning utiles to each value and then computing these values represents the utility problem-solving skill. After these values are tabulated, the engineer has effectively segmented the problem. Table 4 shows one way these values can be weighed.

Table 4

Assignment and Computation of Utiles for Each Cable

Cable	Cost	Insulation	Durability	Totals
A	10	2	2	14
B	7	10	7	24
C	2	7	10	19

In this example the engineer gave three levels for each value: 2 for lowest level, 7 for midrange, and 10 for the highest level. However, the difference between the lowest level and the midrange level was 5 points versus the difference between the midrange

52

level and highest level, which was only 3 points. This means the engineer segmented the problem so that a cable that received maximum number of high levels would be preferable to cable that received a strong set of midrange levels. Using this heuristic method for this example, the computation of expected value (McCaffery et al., 2000) or utility shows that cable B provides the best value for the engineer.

Another aspect of the utility heuristic is how the problem solver views the permanence of the segmenting process. For example, there are studies that show individuals segment a problem so that the decision yields a transitional benefit much more easily than a decision that has long-range and permanent change (McCaffery et al., 2000). For example, an engineer could use the utility heuristic to segment the problem at one stage of the problem-solving process for which the expected value is lower than would be anticipated. At a later date the engineer changes his expected value scale and analyzes the segments of the problem to yield a solution that is more permanent.

A different perspective of the heuristic problem-solving skill is illustrated in the documentary movie of crossword puzzle players called *Wordplay* (O'Malley, Creadon, & Walsh, 2006). These problem solvers (crossword puzzle players) vary in degree of skill from the recreational puzzler to competing in international contests to being the editor of the prestigious *New York Times* crossword puzzle. The movie interviews several of these individuals in an effort to give the viewer an understanding of the mysteries and joys of this type of problem solving.

In one movie clip, President William Jefferson Clinton says the tactic in solving crossword puzzles is to find that hook that allows you find other hooks and start linking the puzzle together (O'Malley et al., 2006). He goes on to say that this hook might be

found in the clues that are located at the center of the physical square of the puzzle. President Clinton used heuristics via pattern recognition to organize the information in the problem.

Apparently the hook or pattern is a relationship between the theme of the crossword puzzle and the spacing of the crossword cells. Achieving this realization assists President Clinton in rapidly completing the remainder of the crossword puzzle (O'Malley et al., 2006).

There are many other examples of domain-specific heuristics. Simon and Baylor (1979) describe a heuristic used in chess called combinations. This occurs when a chess player uses a combination of moves with which he loses (sacrifices) pieces to yield an advantage.

Seirawan and Silman (1995) also describe this domain-specific heuristic in their description of obtaining control of as much board space as possible. In this case, the chess player must continually set up moves with the subgoal of controlling the center of the chess board. These moves may or may not lead to the ultimate goal, which is the checkmate of the king.

Reasoning

The nonroutine, reasoning problem-solving skill category describes those skills a problem solver uses to formulate logically a conclusion or solution to a problem. By using reasoning, the problem solver translates the known knowledge of the problem into concepts that were previously unknown (Sullivan, 2005). This newly generated knowledge can be the solution to the problem or other aspects of the problem-solving process.

Deduction and induction. Deductive and Inductive reasoning are based on the

Aristotelian model of deductive logic (Aristotle, 1984). In this model, the problem solver

establishes a set of premises or facts about the problem. In deductive reasoning the

problem solver draws an inference from the premises to the conclusion. If the premises

are correct, then deductive reasoning mandates that the conclusion is valid and correct

(Holyoak & Morrison, 2005). Figure 18 illustrates deductive reasoning.

Problem: A Computer is not operating properily.

> If the computer is working it will be using a long power cable.
> The computer is working.

Conclusion: The computer is using a long cable.

Figure 18. An example of using deductive reasoning to infer a conclusion.

In inductive reasoning the problem solver views or observes a series of premises

or events. The problem solver then extrapolates a rule or generalization from these

observations (Dunbar & Fugelsang, 2005; Klauer & Phye, 2008). Figure 19 illustrates

inductive reasoning. The engineer generalizes that the high humidity is reason why the

brand a computer does not work.

Problem: A brand A, 1.2 GHz computer does not work when humidity is above 80%.

> A brand B,1.2 GHz computer does not work when humidity is above 80%.
> A brand C,1.2 GHz computer does not work when humidity is above 80%.
> A brand D,1.2 GHz computer does not work when humidity is above 80%.

Generalization: All 1.2 GHz computers do not work properly when humidity is above 80%.

Figure 19. An example of using inductive reasoning to generate a rule.

Fallacy. A fallacy is an error in using the reasoning (Porter, 2002) problem-

solving skill to generate a logical conclusion based on one or more premises . A

competent problem solver recognizes fallacious reasoning during the problem-solving

process as well as to avoid using fallacies to reach a logical conclusion about how to solve a problem.

There are many fallacies that have evolved since they became part of human interaction and problem solving during Aristotle's era. Fischer described more than 100 different fallacies that are divided into 12 categories (Fischer, 1970). Because of this vast amount of literature on fallacies, the researcher has decided not to describe all fallacious reasoning. Instead, the researcher has focused on four fallacies that have a direct and immediate application to the problem-solving process.

The denying the antecedent fallacy (Hamblin, 1970) is one of several formal fallacies that is based on the sentence syntax of the argument. The term argument is used in the philosophical literature that describes fallacious reasoning (Walton, 1995). An argument has the premise and conclusion structure that forms what the researcher is calling the problem structure.

The problem structures of formal fallacies have an antecedent component and consequent component. The antecedent is the first concept stated in the problem structure. The consequent is the following concept or conclusion (Warburton, 2000). Denying the antecedent is a problem statement that is fallacious because the antecedent is discounted or denied. This action seems logical because of the syntax of the premises and conclusion. However, this thought process leads to a solution that is weak or difficult to justify, or the solution may be completely incorrect (Warburton). Figure 20 illustrates the denying the antecedent fallacy.

Problem: A Computer is not operating properly.

> If the computer is working it will be using a long power cable.
> The computer is not working,

Conclusion: The computer is not working because
it does not have a long power cable.

Figure 20. Using the denying the antecedent fallacy to form a conclusion

The antecedent concept (Warburton, 2000) is the computer works with a long power cable. The second premise denies the antecedent and states this is the reason the computer is not working. In actuality there could be many other reasons why the computer is not working and therefore, the replacement of the cable may or may not solve the problem.

The slippery slope fallacy is a casual argument in which the premises lead to a conclusion that is typically false and certainly not a solid solution to the problem (Groarke, Tindale, & Fisher, 1997). Figure 21 illustrates the slippery slope fallacy.

Problem: What is the shortest length of an identically constructed cable
that can transmit a 50 MHz signal.

> A 10 ft cable transmits a 50 MHz signal.
> A 8 ft cable transmits a 50 MHz signal.
> A 5 ft cable transmits a 50 MHz signal.

Conclusion: A 3 in. cable will transmit a 50 MHz signal.

Figure 21. Using the slippery slope fallacy to form a conclusion

In this example the engineer must determine the shortest length of cable that can transmit a 50 MHz signal. The problem statement indicates that all experimentally-designed cables use the same construction, so the only variable is the length of the cable. The engineer uses this logic (Groarke et al., 1997) to conclude that an exceptionally small cable will also transmit the 50 MHz signal.

From a problem-solving perspective, this is incorrect logic because there may be special properties of the signal as well as the cable that might not appear until the 1-ft threshold is crossed. However, in the slippery slope logic, the problem solver infers that each premise is linked to the other premise because of their similarity. Therefore, the conclusion is another inference based on similarity of the premises. Because of this inference, the slippery slope fallacy has several other names such as the domino theory, the appeal to indirect consequences, Non Causa Pro Causa, and the fallacy of the beard (Curtis, 2007; Mesher, 1999; Walton, 1995).

The key aspect of learning to recognize this faulty logic is for the problem solver to realize the spacing or proportion between each step or premise (Curtis, 2007). Theoretically, the cable problem could be logically concluded with an answer of 4.8 ft. The difference between the valid premise of 5 ft and 4.8 ft is minimal. However the difference between 5 ft and 3 in. (7.62 cm) is considerable.

The cable length problem surfaced fallacious reasoning that can occur between premises. There is a group of fallacies with which the problem solver may use fallacious reasoning in reading and interpreting words within each premise. This group of fallacies are called fallacies of ambiguity (Rudinow & Barry, 1999). One of these fallacies is the fallacy of equivocation. Figure 22 illustrates the fallacy of equivocation.

Problem: Should the engineer mount the video board to the computer enclosure with four screws?

The video board is secured to the enclosure with four screws.

Conclusion: Use four screws to mount the video board to the computer enclosure.

Figure 22. Using the fallacy of equivocation to form a conclusion.

In this problem the researcher assumes there are no other problem-solving issues surrounding this problem such using the hasty generalization fallacy (Salmon, 1989). Therefore, the problem contains a direct, plainly stated, problem that requires a yes or no answer to mounting the board. This problem statement is coupled with one premise that appears to answer the problem. However, hidden within the premise is a slightly different description of the mounting process. In this case, the premise uses the phrase securing four screws. The fallacy of equivocation occurs when the problem solver accepts the equivocation of terms (Curtis, 2007).

In this example, a board that is mounted is attached using four screws. However, in order to secure the board it may be necessary to use the four screws and tighten them to a specific torque level. If the problem solver equates the mounting term with the securing term, then he or she is using fallacious reasoning (Porter, 2002).

In some cases the analysis of this type of reasoning is difficult. That is, did the problem solver actually use the fallacy of equivocation and that was the reason he did not solve the problem. This can occur because of the way the problem solver and the person giving the problem interrelate (Van Laar, 2001). For example, in this case the source of the problem is the supervisor of the department. This person has worked with the problem solver for years and both of these individuals know that the term mounting means to add four pounds of torque to each tightening of each screw.

Recurrence reasoning. Recurrence reasoning requires the problem solver to review each premise to search for validity, accuracy, and recurrence (Dantzig, 2005). Recurrence means the same premise is restated with the same meaning. If the premises

meet these criteria, then the problem solver can make a reasonable conclusion. Figure 23

shows recurrence reasoning.

Problem: A YT Computer is not operating properly and has a 5 ft cable

> The same YT computers being used in the same way at the XLAN company work properly with 10 ft cables.
>
> The same YT computers being used in the same way at the ABEX company work properly with 10 ft cables.
>
> The same YT computers being used in the same way at the CITRX company work properly with 10 ft cables.

Conclusion: The YT Computer is not operating properly because it is not using a 10 ft. cable.

Figure 23. Using recurrence reasoning to solve a cabling problem.

A subset of recurrence reasoning is called counterexample reasoning. This skill

requires the problem solver to generate a counterexample that explains why the

conclusion is not necessarily true even though it is based on true and accurate premises

(Finocchiaro, 2005). Figure 24 illustrates recurrence reasoning.

Problem: A software program crashes when the F1 key is pressed.

> Pressing the F1 key generates a signal that matches the escape sequence and the program crashes.
>
> When pressing the F1 key the operator accidentally touches the reset button which causes the program to crash.

Conclusion: Either premise explains why the software program crashes.

Figure 24. Using counterexample reasoning to create a new conclusion.

In this example, the engineer might look at the first premise and determine that

the reason for the software crashing is because of a faulty F1 key. However, the engineer

could use counterexample reasoning (Finocchiaro, 2005) and speculate that the reason for

the software crashing is because the operator pressed the reset button.

Mathematical reasoning. This reasoning is a type of nonfallacious reasoning that

reconciles analytical mathematical concepts with the ambiguity of complex problems

(Cianciolo, Matthew, Sternberg, & Wagner, 2006). The following example illustrates how mathematical reasoning is a way to accommodate ambiguity that leads to a powerful thought process in solving problems.

The formula x + 1 = 0 where x cannot be a negative integer appears to be an impossible problem. The only logical answer is that x must equal -1, but this is not allowed in the definition of the problem (Byers, 2007). However, at one time in the history of mathematics, this was an impossible problem even when the stated problem did not include the exclusion of negative numbers. This occurred because the ancient mathematicians had not yet discovered the concept of negative integers and there was no way to add a variable (x) to an integer to obtain 0.

In this early part of mathematical history, this problem was conceived as being an unsolvable problem (Byers, 2007). Unsolvable problems present the problem solver with the unknown, uncertainty, and the associated ambiguity that must be resolved to solve a problem. The result of these elements in many cases is that the problem solver terminates the problem-solving process.

One reasoning problem-solving skill that overcomes this problem termination process is recognizing the constraints of a problem (Duncan et al., 1995). In the x +1 problem, the problem solver viewed the constraints of the problem as confining the calculation to a positive number domain. This meant that the problem was not solvable. Instead the problem solver could have used reasoning to remove these constraints and view the possibility of using a number system that also had negative integers.

Boolean logic is another branch of the mathematical reasoning skill. This logic relies on a system of symbols and mathematical axioms to represent ideas, premises, and

other nonmathematical constructs (Bennett, 2004; Boole, 2005). One application of Boolean logic is the formulation of a truth table that provides the problem solver a graphical mechanism to determine if a new engineering process is viable. Figure 25 shows the use of a truth table in solving a problem.

Problem: The LCD light displays an bright red instead of an orange color.

Fact: Red LED and Yellow LED must function
A= Functional Red LED, B= Functional Yellow LED
T= LED functions, F= LED does not function
Rule: A + B= Truth

A	B		Obtain Orange Color ?
T	T	→	Yes
F	F	→	No
T	F	→	No
F	T	→	No
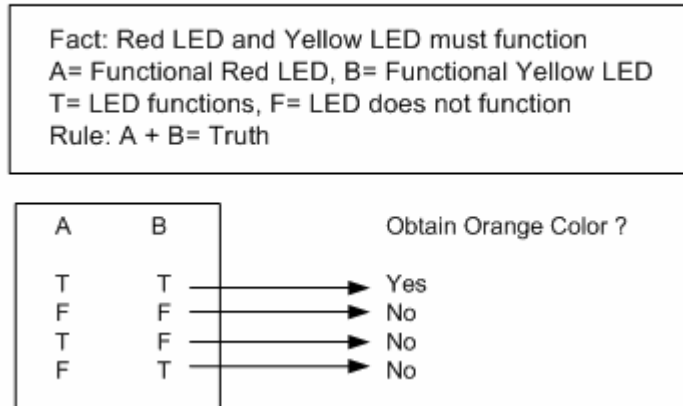
Figure 25. Using a truth table to determine why an LED fails.

This truth table uses the *and* function to match the A and B variables. The and function is the English equivalent of the + symbol. It means that both the A and B variables must exhibit a true or valid condition in order for the conclusion or solution to be valid (Salmon, 1989).

Only one of the four possibilities in this truth table provides this condition. That occurs when both LEDs are functional. All the other conditions have one or both variables exhibiting a false condition. This results in a bright red LED condition (Salmon, 1989).

Instruments and Protocols Used to Analyze Problem-Solving Frameworks and Skills

Solving problems involves a wide range of skills. These skills range from reasoning to determining what tools are necessary to solve a problem to the type of heuristic an engineering student employs when surveying a problem.

The researcher has divided the problem-solving instruments into those that use verbal protocols and those that use written protocols. The verbal protocols use the interview technique and the written protocols include numerous tests, surveys, and other types of quantitative instruments. Figure 26 illustrates these two categories of instruments.
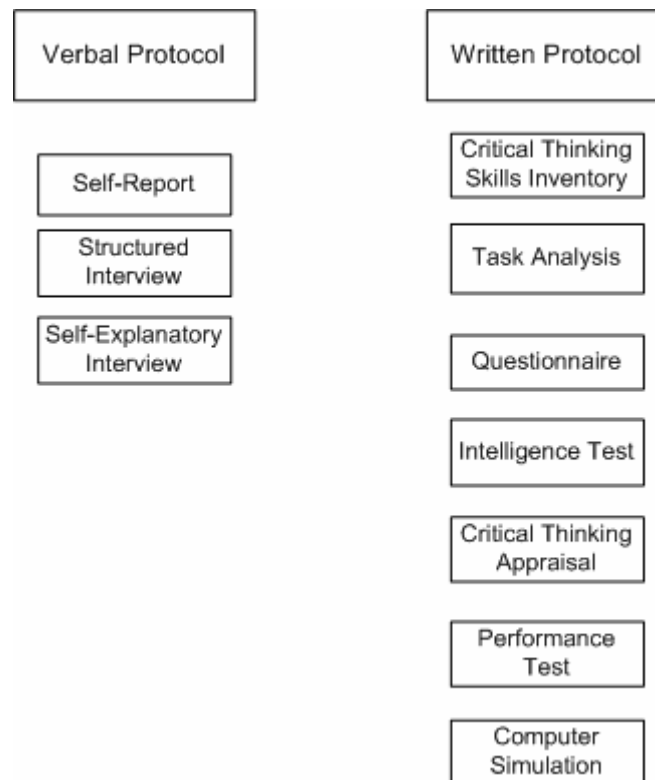
Figure 26. Problem-solving instruments based on verbal and written protocols.

These instruments are used to measure the metacognition of the problem solvers involved in this study. Metacognition is "any knowledge or cognitive process that refers to, monitors, or controls any aspect of cognition" (Moses & Baird, 1999, p. 533). This knowledge represents the problem solver's perspective of how he or she implements the problem-solving, cognitive process (Lenat et al., 1983).

Measuring metacognitive knowledge is extremely complicated because the problem-solving process is necessarily based on assumptions about human behavior. These include how the subject views his or her knowledge of the problem, as well as other biases such as "false-belief" (J. Evans, 1989, p. 93). Therefore, there is debate over the efficacy and validity of any of these instruments that the researcher uses in measuring this type of cognition.

Early Assessment Procedures of Problem-Solving Skills

One skill of an intelligent person is the ability to implement high-level cognitive activities such as problem solving (Davidson & Downing, 2000). An intelligent person is an individual who can solve complicated problems quickly and correctly. Therefore, the early analysis of human problem-solving skills was focused on the measuring the intelligence the problem solver.

Therefore, in order to assess an individual's problem-solving skills the researcher needed to implement intelligence tests. Spearman (1926) expands on this concept by outlining a two-factor theory of intelligence. His theory states that every human ability has two factors called *g* and *s*. These abilities include tasks that are measurable by tests. They may be high-level tasks such as composing music or low-level cognitive skills such as level of memory or the ability to discriminate opposites.

The g factor is unique for every individual and is part of every ability for that person (Spearman, 1926). The s factor is unique to each ability for that person. Additionally, the s factor is different for each ability for that person. Spearman calls the g factor a measurement of "mental energy" (1926, p. 98). This mental energy is the element

evaluated in many intelligence tests. Therefore, the intelligence tests are the first assessment instruments to test problem-solving skills.

The definition of intelligence changed in the 1980s with the development of the theory of multiple intelligences by Gardner (1999). According to Kornhaber, Fierros, and Veenema (2004), Gardner believed, "If general intelligence governs all problem solving, then young children should show roughly the same rate of intellectual development in mastering language skills, drawing, math, dance, or other areas" (Kornhaber, Fierros, & Veenema, p. 10).

This new definition of the relationship of problem solving to intelligence impacted the design of intelligence tests. Gardner's perspective defined intelligence as a problem-solving activity that occurred in multiple disciplines (Kaufman & Lichtenberger, 2006). According to Gardner (1999), there were multiple intelligences, with each intelligence having an "intellectual core" (Gardner, p. 37). This intellectual core forms the specific intelligence. For example, Gardner states that for linguistic intelligence the individual must have neural mechanisms that allow for "phonemic discriminations, command of syntax, sensitivity to the pragmatic uses of language, and acquisitions of word meanings" (Gardner, p. 37).

Because of this shift in the interpretation of intelligence and other influences mentioned earlier, many intelligence tests started including subtests that specifically measured problem-solving capabilities. In at least one case (Woodcock-Johnson Cognitive Abilities Assessment [WJ III COG]), additional intelligence factors were added to the redefined General Intellectual Ability (GIA);(Wasserman, 2003). The additions included the Visual Processing (*Gv*) and Fluid Reasoning (*Gf*) factors that are

specifically oriented to problem-solving abilities rather than the general intelligence scores. This meant that the assessment instruments could target specific problem-solving skills, such as reasoning, rather than a vague all-inclusive intelligence score.

Fluid reasoning incorporates several problem-solving skills, such as induction and sequential reasoning (Schrank, Flanagan, Woodcock, & Mascolo, 2002).The test questions that measure this factor include a variety of problem-solving skills: (a) Ability to draw conclusions from stated premises, (b) Organizing information in a math problem to reach a solution, (c) Ability to use inductive logic and categorical reasoning, and (d) Ability to use foresight to determine the appropriate solution.

Another example of the change in problem-solving subtests occurred in the Wechsler Adult Intelligence Scale-III (WAIS-III); (Pierangelo & Giuliani, 2006). There are now four factors, with each having a separate scale: "verbal-comprehension, perceptual-organization, working memory, and processing speed" (Wasserman, 2003, p. 429). Of particular interest and relevance to problem solving is how processing speed is measured. This scale is based on the measurement of a subskill called fluid reasoning (Homack & Reynolds, 2007; Wasserman, 2003) that is used in the previously described WJ III COG.

In the early 1900s, another early problem-solving assessment methodology began to develop. This methodology was initiated by Frederic Taylor (2005), an industrial psychologist who conducted studies of the workforce in the United States. These labor studies required the researcher to use many assessment tools: view the worker implementing the problem-solving task, scientifically analyze the motivation of the worker, review production statistics before and after changes to the task, and evaluate the

relationship between the worker's physiological capabilities and the tool(s) the worker uses.

The practitioners of this methodology analyzed each task as a problem that needed a solution (Taylor, 2005). That is, he or she developed a set of problem-solving skills the worker could use that would allow them to be more efficient. Since each task was different and unique, this analysis required a large amount of research into the dynamics of problem solving. These practitioners developed and assessed technical problem-solving skills, such as how to complete physically the task, and nontechnical problem-solving skills such as how to motivate a worker.

Taylor (2005) and other practitioners called this methodology the Theory of Scientific Management because the theory used scientific and engineering principles of human motion efficiencies, production statistics, and motivation techniques. The assessment model and resulting analysis of the best way to complete a task became incredibly complex. Taylor cites one study of cement work that consisted of more than 700 pages.

For the first half of the 19th century, task analysis was based on the observation of physical actions and behaviors of the blue collar problem-solving tasks (Schraagen, 2000). However, during the 1950s, the workforce changed in the U.S. and there was an increase in the number of white collar workers. The larger white collar workforce meant that there was an increased need to focus ways to improve its members' efficiencies. Since many white collar positions use cognitive skills such as decision making and problem solving, there was an increased need for the development of instruments that assess these skills.

A second trend in the early 1950s was the development of the computer. After the computer came into existence a new view of the human mind and problem solving was realized. That view was that the computer was like a human mind (Rothfeder, 1985).

As with the human mind, the computer assembled massive amounts of knowledge and then analyzed this knowledge through logical, problem-solving processes. These processes could be designed into a software set of instructions called an algorithm. Theoretically, if the algorithm was properly designed, it could simulate the problem-solving capability of a human. The match up of the computer and the mind has continued until the present and spawned the new discipline of Artificial Intelligence (AI; (Rothfeder, 1985).

These two trends of the development of the computer algorithms and the increase in the white collar workforce generated two new problem-solving assessments: computer confirmation and computer simulation. Computer confirmation describes a process in which the researcher develops a computer program that simulates the problem-solving process. That means the researcher designs a program with the rules and variables that allow the computer to solve problems. The General Problem Solver (GPS) program was one such program (Newell & Simon, 1972). As an assessment tool it provided the researcher a way to confirm different problem-solving methodologies by inputting the variables and reviewing the output of the computer program.

Computer simulation describes a software program that simulates a problem-solving event (Ericsson & Simon, 1993). The subject interacts with computer simulation by using problem-solving skills. After the completion of this interactive process, the software program generates reports on how the subject solved the problem. The

researcher then develops reports from embedded functions of this software program that assist the researcher in using the simulation as a problem-solving assessment instrument.

Also in the 1950s, another view of how problem solving is assessed came from the development of *Bloom's Taxonomy of Behavioral Objectives* (Bloom, 1956; McMillan, 2004). This taxonomy includes a list of cognitive processes that the student uses in the learning process such as analyzing, evaluating, and interpreting. According to McMillan, one method to evaluate these processes is to construct a specific questionnaire or test that addresses each of these reasoning skills. The researcher can then score the questionnaire to determine if the subject is able to use this specific reasoning skill.

Task Analysis and Self-Explanatory Interview

There are special types of task analysis methodologies that focus on the cognitive processes rather than on the analysis of physical and motivational behaviors used in the scientific methodology espoused by Taylor (2005). Several authors give a chronological evolution of cognitive task analysis that starts with the Critical Incident Analysis (CIT), Hierarchical Task Analysis (HTA), Cognitively Oriented Task Analysis (COTA), and ecological task analysis (Arnnett, 2000; Chipman, Schraagen, & Shalin, 2000; Flach, 2000).

The CIT and HTA use this analysis approach to understand and assess how human beings solve problems in high-risk industries such as military aviation and the operation of power-generation plants. These cognitive task analysis processes use instruments such as self-report questionnaires and the observation of the subject doing the complete task (DuBois & Shalin, 2000).

For example, DuBois and Shalin (2000) describe an assessment that used debriefing of a technician that was unable to fix a faulty computer system. Debriefing, in this case, is a process in which the problem solver explained how he solved the problem. This type of assessment is also called a self-explanatory interview. The computer technician explained that he was interrupted by officers as he was troubleshooting the system and this impacted his troubleshooting ability. According to one debriefing session, the technician described his behavior as "hesitant and unsure of how to proceed" (DuBois & Shalin, p. 41).

The debriefing with the technician revealed that he did not know how to tell the officers to stop interfering with his troubleshooting process (DuBois & Shalin, 2000). On the surface, this error in problem solving could have been assessed as inadequate troubleshooting knowledge or training of the technician. However, by using the self-explanatory approach, the failure in the cognitive problem-solving process was identified.

Kahney (1993) refers to this type of assessment as a verbal protocol, since the subject verbalizes responses that are coded and analyzed by the researcher. The researcher uses the phrase self-explanatory interview to describe this form of verbal protocol.

There are many types of self-explanatory interviews. Ericsson and Simon (1993) define these interviews by the type of coding and verbalization the subject uses to explain how he or she solved the problem. The subject verbalizes the steps he or she used without any comments about why or how he or she chose one path or another.

Another type of verbalization from the subject occurs when the researcher wants to pinpoint specific actions of the subject. For example, the researcher might ask the

subject to explain why he or she solved the problem one way or another. These types of questions by the researcher introduce mediating factors that cause the subject to process different portions of his or her memory regarding the problem-solving episode (Lochhead, 2001). The result is an corrupted version of what transpired during the problem-solving process.

Self-explanatory interviews are further defined by how they are administered: concurrent and retrospective verbal reports (Ericsson & Simon, 1993). Concurrent reports are called thinking aloud. In this case, the subject verbalizes what is transpiring in his or her mind as he or she works through the problem. Retrospective reporting occurs after the subject has completed the problem-solving session.

The self-report instrument might be the same as the self-explanatory interview. Typically the difference is that the self-report means the data received from the interview is used for analyzing the behavior of the subject. The purpose of this analysis is to match the specifications of the job with the problem-solving skill set of the subject (Dansereau, 1985).

The self-report assessment closely resembles the self-explanatory, since both assessments ask the subject to report what he or she has learned (1985). However, the self-report typically "assesses the students' perception of their own abilities, problems, etc." (Dansereau, p. 218). In this case it is similar an evaluative assessment and, therefore, is not the correct instrument for this study.

The self-explanatory interviews were adapted to other disciplines such as education. Jonassen (2004) developed a method titled teachback. This approach uses the same self-report technique described for the cognitive task analysis. The teachback

approach requires the student to explain (teachback) to the evaluator the reasons and rationale he or she used in solving a problem.

"Coding protocols" (Jonassen, 2004, p. 140) is similar to the teachback approach. In this case the subject writes the methodology and skills he or she used to solve the problem. An evaluator analyzes (codes) the processes into a set of problem-solving skills.

Whimbey and Lockhead (1999) enhance the coding protocols approach by allowing the subject to use whatever media or tools he or she needs to explain how he or she solved the problem. The subject's explanation might involve the drawing of diagrams, movements of the subject's hand on the diagrams, and/or any other process he or she used to ascertain the answer.

Jonassen (2004) also suggests a collaborative self-explanatory approach labeled "abstracted replays" (Jonassen, p. 140). This method does not distinguish between the evaluator and the problem solver. Both individuals solve a problem and then regroup to analyze how each of them solved the problem. Each individual describes the problem solving skills he or she used at each stage of the problem-solving process.

Another instrument that is similar to the self-explanatory interview is a work diary (Smith & Smith, 2005). This instrument requires the subject to complete a journal that describes how he or she solved problems during work hours. The diary then becomes a resource for the researcher. The diary can be used in conjunction with other instruments such as the self-explanatory verbal protocol.

Performance Test

A performance test measures what the subject does (Cronbach, 1960) on the day of the test. This is different from using a test that measures the ability of the subject to

solve problems. In an ability test the subject demonstrates he or she has the potential to solve a specific problem; however, it is unknown if the subject can demonstrate his or her problem-solving capability.

There are many types of performance tests that measure problem-solving skills. One of the most notable logic performance tests is the Law School Admission Test (LSAT) that is a requirement for entrance into many law schools. This is a scored test that is administered by the Law School Admission Council: "The LSAT helps law schools make sound admission decisions by providing a standard measure of acquired reading and verbal reasoning skills that law schools can use as one of several factors in assessing applicants" (Law School Admission Council, 2007, p. 1).

The logic portion of the LSAT requires the user to answer questions using a logic mind-set to solve a problem. In order to facilitate this process, there are many books that the prospective law student can purchase that give the problem-solving strategies for quickly and successfully solving these problems (Farthing, 2006; Killoran, 2007a, 2007b). The authors of the preparatory books suggest that the test taker frame the problem in various ways to assist him or her in finding the solution.

The Situational Judgment Test (SJT) is a performance test in which the subject is given a situation that relates to his or her workplace environment (Weekley & Ployhart, 2006). After this scenario is a list of several ways to resolve and respond to this situation. The subject uses problem-solving skills to select the type of response or course of action he or she would use in this hypothetical situation.

The SJTs may or may not be graded (Weekley & Ployhart, 2006). If they are graded, then the test has the meaning of an exam to the subject, since being graded

implies there are correct and incorrect answers. These types of SJTs are similar in purpose to the aforementioned LSAT for which there is one process and one answer to the hypothetical situation.

Inventories and Appraisals

Inventories are similar to the written task analyses developed by Taylor (2005) and described at the beginning of this section. The current inventories cover the full range of jobs and tasks. Some inventories are specific to solving problems, while others include all of the tasks required to complete a specific job.

Whimbey and Lockhead (1999) developed an inventory specifically for analytical skills called the Whimbey Analytical Skills Inventory (WASI). This instrument can be used in combination with a self-explanatory interview to ascertain the problem-solving level of a subject.

The WASI inventory (Whimbey & Lockhhead, 1999) is a conventional set of problem-solving questions that require the user to ascertain logically an answer by using one or multiple types of the problem-solving skills described in this study. This inventory has questions similar to those given in Table 5.

Table 5

An example of Questions Asked in a Problem-Solving Inventory

No.	Question	Answers
1	What are the next two letters in the sequence? B A C F E D __ __	GH, IG, HG, HI
2	A vehicle is traveling 60 miles per hour going South. What is the speed of a vehicle that travels 65 miles in 25 minutes?	65 mph, 130 mph, 120 mph, 156 mph

There are many other inventories available to the researcher. Most of these cover broad aspects of the job tasks, with some questions on problem-solving skills. Some of these inventories use the term questionnaire to describe the instrument. For example, the assessment tool called the Professional and Managerial Position Questionnaire includes "exercising judgment, processing of information and ideas, communication, and technical activities" (Smith & Smith, 2005, p. 13). Each of these processes is evaluated using questions specific to these processes.

The Watson-Glaser Critical Thinking Appraisal is a list of questions (items) that are divided into five categories of problem-solving processes: Inference, recognition of assumptions, deduction, interpretation, and evaluation of arguments (Crites, 1965; *Sample report of Watson-Glaser critical thinking proposal*, 2007). The subject is given questions from each of these categories, which require specific answers, to determine if he or she has these problem-solving skills.

Survey and Questionnaire

Many surveys ask the subject to recall past events to gather statistical information. Other surveys ask the subject to answer questions about past events or speculate on the outcome of future events. A third type of survey gives the subject a situation, which might be true or hypothetical. The respondent is then asked questions about this situation. The first survey type is called a sampling survey and the second two surveys are called survey questionnaires (Tourangeau, Rips, & Rasinski, 2000). Each of these survey types are used in analyzing problem-solving skills.

Surveys can be written, electronic (digital application over the Internet), or verbal. In each medium there are different areas of concern in designing, distributing, and

analyzing the survey (Sekaran, 2003). The sample survey is used to gather statistical data of problem solvers or problem-solving skills. For example, the survey could include questions about how many computer failure problems the subject has corrected in the last 20 days. Another line of questions might ask the subject whether he or she uses deductive or inductive logic in repairing computers.

The questionnaire surveys may use open-ended questions or specific questions oriented to a unique past event or hypothetical event. One set of questions might focus on one problem-solving skill and ask the subject what type of reasoning he or she employed to define the problem.

The survey questionnaires can also ask the subject about the ordering of events. Fowler (1995). For example, the evaluator might ask the subject to list the most productive problem-solving skills he or she used when troubleshooting the 3720 computer.

Both of these approaches focus on problem solving, which is a skill within the cognitive domain. According to Westgaard (1999), the survey, test, or questionnaire needs to use questions that are isolated to the cognitive, affective, or emotional domains. If the question uses multiple domains, then the response from the subject is diluted. Therefore, the design of the questions is extremely pivotal to the validity of the survey, test, or questionnaire.

Computer and Internet

Many questionnaires, performance tests, and inventories are available digitally for the computer user. These instruments may be accessed via an Internet connection, with the results sent electronically to the researcher. Alternatively, the instruments can be

written on a CD and then sent to the user for dedicated and remote use. The results of these tests are sent electronically or by mail to the researcher (Sekaran, 2003).

Each of these computer applications has advantages and disadvantages. One disadvantage is the potential lack of availability of the computer for the subjects. Also, the computer might be difficult to use by some subjects and this could impact the results (Sekaran, 2003).

On the positive side, the computer provides the perfect platform for administering cognitive-based problem-solving tests. This device can simulate numerous problem-solving tasks. Additionally, with the use of artificial intelligence, the computer program is able to respond to the subject's answers with other questions that define specific problem-solving skills. Most important, the computer gives the same set of instructions, with no interpretation, to each subject.

Current Trends in Teaching Engineering Problem-Solving Skills

One teaching methodology that is being practiced requires the instructor to teach the students different ways engineers view the problem-solving process (de Vries, Lund, & Baker, 2002; Downey et al., 2006). For example, one member of a problem-solving team might believe the way to define a problem is to talk with the people who are impacted by the problem. Another problem solver would define the problem by talking with the manager or the individual who created the problem.

This process is taught through the inquiry or case study method. The main thrust of this new methodology is that the engineering student understands that there are different cognitive levels of problem solving between competent engineers (Heywood, 2005).

This type of understanding of the fundamental problem-solving process is key to another engineering teaching methodology. In this methodology the student engineers are taught "multiple modes of reasoning" (Grasso & Martinelli, 2007, p. 2). This type of reasoning describes reasoning completed by disciplines outside the engineering discipline. However, because of the type of problem, the engineer needs to understand how these disciplines view the problem-solving process (Ericsson, 2006).For example, an engineer might troubleshoot a failed circuit board and recommend the solution to be the replacement of a low-tolerance integrated circuit. However, the finance department views the problem not as a replacement issue but as an item that can be depreciated with significant tax advantages. In this case, if the engineer would have understood the problem-solving methodology of the finance department, a quicker and better solution may have been generated.

Another trend in teaching problem solving is to use computers as an enhancement to the teaching process. As an enhancement, the instructor asks the student to use the mathematical processing capabilities of the computer to solve an equation or generate statistical data. In this case the formulation of the problem and other parts of the problem-solving process are still implemented by the student and facilitated by the instructor (Barker, 2004).

However, the computer with the correct software application is also being used as a design tool, which forces the student to go through (and learn) the entire problem-solving process independently of the instructor (Shaykhian & Shaykhian, 2007). This includes having the student define the variables of the problem, plan the steps between resolving each variable, and then specifically determine the outcome.

Summary

The research in this study has clarified several aspects of the problem-solving process. First, there are five problem-solving skill categories: tools, defining, goal idnetification, heuristics, and reasoning. The researcher found that these five main categories of the problem-solving skills were logically divided into two primary subcategories: routine and nonroutine. The routine problem-solving skills are grouped into two subcategories: defining and goal identification. The nonroutine skills are grouped into three subcategories: tools, heuristics, and reasoning.

The researcher found that these problem-solving skills were used in different combinations, within a model of the problem-solving process, that the researcher called a problem-solving framework. Additionally, the researcher found that there are many types of problem-solving frameworks being taught to GEs. Therefore, by studying and documenting what problem-solving skills and frameworks the GEs use, the curriculum can be adjusted so that the engineering students are aware of the full range of problem-solving processes.

The research in this study also indicated there are many conflicting protocols and methodologies for studying problem solving. This occurs because of the wide range of problem-solving skills and how solving problems is defined. One area of research recognizes this confusion and recommends a "fine-grained" (Simon, 1999, p. 675) technique that is called self-explanatory interview or thinking aloud. This is the protocol the researcher used in this study.

Chapter 3:

Methodology

The literature indicated five, primary categories of problem-solving skills: tools, defining, goal-identification, heuristics, and reasoning. The tools skill has two additional groupings: physical and nonphysical tools. Each problem solver uses each skill individually or sequentially with other skills to solve a problem. Figure 27 lists the two main categories and the five subcategories of problem-solving skills.
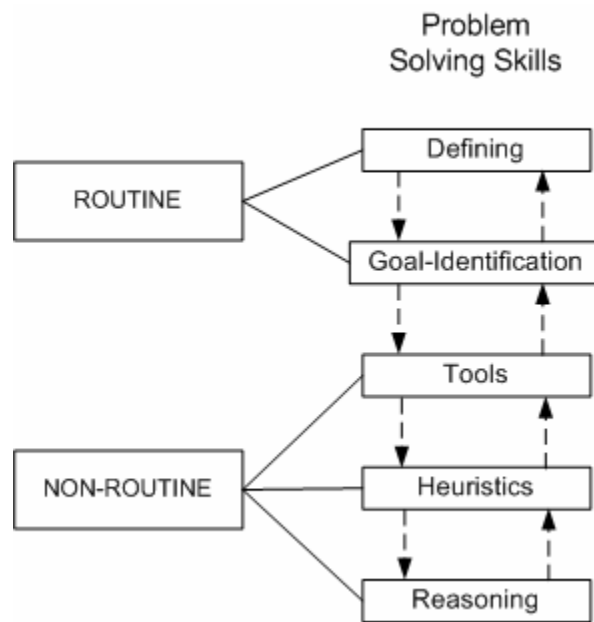
Figure 27. The routine and nonroutine problem-solving skills

The skills categories are connected to each other by dashed lines. The dashed lines between the problem-solving skill categories indicate that a solution or other problem element might be derived by using a combination of problem-solving skills.

Each of the problem-solving categories contains a large subset of skills that assist the engineering student in solving problems. Some of the skills are extremely complex and narrowly focused on a specific aspect of the engineering discipline. Other problem-solving skills are high level and can apply to engineering and other disciplines.

The tools category defines the skills to identify and use problem-solving tools such as brainstorming. The defining category defines the ability to determine the nature of the problem from a specific discipline perspective. Goal identification is used to identify high-level aspects of the problem-solving process such as when to work on the causes of the problem versus when to focus on the solutions. Heuristics and reasoning are low-level problem-solving skills that assist the problem solver in finding patterns or using Boolean logic to formulate relationships among the segments of the problem.

These problem-solving skills are generic and applicable to all disciplines. However, the focus of this study is specifically on the GE. Therefore, the research and methodology documented in this study are designed to provide more clarification of how engineering students solve complex problems. In order to implement this objective, the researcher used a descriptive qualitative research design utilizing 30 cases (Herbert & Beardsley, 2002; Stake, 1995).

This study uses two instruments: problem scenario and a self-explanatory interview. The problem scenario is a written document that describes a typical problem encountered by an engineer. This is followed by a nonintrusive interview in which the engineer describes how he or she solved the problem scenario.

Study Population and Sample

Obtaining Sample Population

This study focused on GEs enrolled in upper-division engineering coursework at a California State University. The total population is approximately 150 individuals.

81

The criteria for the sample are listed below:

1. GEs

2. Ability to speak and read English.

3. Engineering students who had taken problem-solving methods in different courses from different instructors.

Four additional characteristics are not specific to this study. They include gender, age, experience, and ethnic background.

To ensure that the sample was representative of the population, the researcher implemented the following sampling procedures. First, the California State University system administrator was given class lists of all GEs. The administrator then purposely selected 10 students using the three criteria. An additional 21 GEs were purposely selected by the administrator and the researcher. These GEs were selected from the graduate science fair that was administered on the California State University campus on May 2, 2008.

The system administrator arranged for the interviews of the 10 GEs who were selected from the class lists. The researcher arranged for the interviews of the additional 21 GEs. During the selection process, the GEs were notified that the research project would take up to 30 to 40 minutes and they will receive a memory stick for participating in this research.

The data collection portion of this study came from interviewing 31 college students completing a degree in engineering. These students were GEs enrolled in upper-division engineering coursework. Each student represented a different case and, therefore, the responses of the engineers are unique to their problem-solving style. This

diversity provided the researcher with a full range of problem-solving skills used by engineering students.

However, the researcher "instrumentally selected" (Stake, 1995, p. 4) graduating engineers, since this population has a similar set of problem-solving requirements. This homogeneous sampling feature (Wolff, 2002) allowed the researcher to decipher how different engineers use the same or different problem-solving skills to find a solution to an engineering problem.

There are many reasons the researcher selected this population. First, the researcher is familiar with the work and aptitude of the engineer. This allowed him to relate and interact closely with the GEs during the self-explanatory interview. Second, the engineering population is involved in discrete problem solving on their jobs. Every profession requires the use of problem-solving skills. However, for engineers the use of problem-solving skills is an occurrence that happens regularly and is many times the primary focus of their workload. For example, the engineer might be asked to troubleshoot a failure in a product or develop a new manufacturing process. These types of tasks force engineers to use a wide variety of problem-solving skills frequently throughout their work shift and work career.

Demographics

This study involved interviewing 31 participants. At the beginning of the interview session each participant was given a background document to complete (Appendix A). This background document contained five categories of demographic data: age, gender, experience, engineering major, and completed senior-level coursework. All 31 participants completed the background document.

The age category was divided into four ranges of ages: 20–25, 26–35, 35–45, and 46 and older. Each participant checked one box associated with a range of ages. Of the participants, 71% were between 20 and 25 years old and 23% were between 26 and 35 years old. The remaining 2 participants were 35 to 45 years old. There were no participants 46 years or older.

The gender category was represented on the background document by a male and female checkbox. Each participant checked the box associated with his or her gender. Of the participants, 94% were male and 2 participants were female.

The experience category was divided into three ranges: 1–5, 6–10, and 10 years or more. Each participant checked one box associated with the number of years he or she was employed in full-time engineering work. Participants who had less than 1 year of full-time experience checked the 1–5 years category. Of the participants, 97% checked the box with 1–5 years and 1 student had more than 10 years of full-time experience.

The fourth segment of the background document listed six engineering majors. At this university six engineering majors are taught within the Engineering department: (a) Civil Engineering, (b) Computer Science, (c) Construction Management, (d) Electrical Engineering, (e) Geomatics Engineering, and (f) Mechanical Engineering. Refer to Table 6 for the percentages of participants that are graduating in each engineering major.

Table 6

Percentages of Participants Graduating in Six Engineering Majors

Major	Percentage
Civil Engineering	19

(*table continues*)

Major	Percentage
Computer Science	13
Construction Management	16
Electrical Engineering	26
Geomatics Engineering	0
Mechanical Engineering	26
Total	100

Below each engineering major category was a list of senior-level classes required by the university to obtain an engineering degree. Each participant checked the boxes associated with the senior-level class that he or she completed or are completing. Some of these classes were the same for some of the engineering majors. However, there were no classes that were the same for all six engineering majors.

Similar classes were a Contemporary Conflicts of Morals class, required for all engineering majors except Construction Management. Additionally, the Senior Design I and II classes are required for Computer Science and Electrical Engineering majors.

The participants completed different percentages of their senior-level coursework. Refer to Table 7, which lists the percentages of completion for senior-level coursework.

Table 7

Percentages of Participants With Four Levels of Courses

	Percentage of Coursework Completed			
Participants	0–33%	34%–66%	67%–99%	100%
Civil Engineering	1	1	4	

(*table continues*)

	Percentage of Coursework Completed			
Computer Science			2	2
Construction Management		3	2	
Electrical Engineering	2	1	4	1
Geomatics Engineering				
Mechanical Engineering			2	6

The composite percentage of the coursework completed for all participants is displayed in Figure 28.
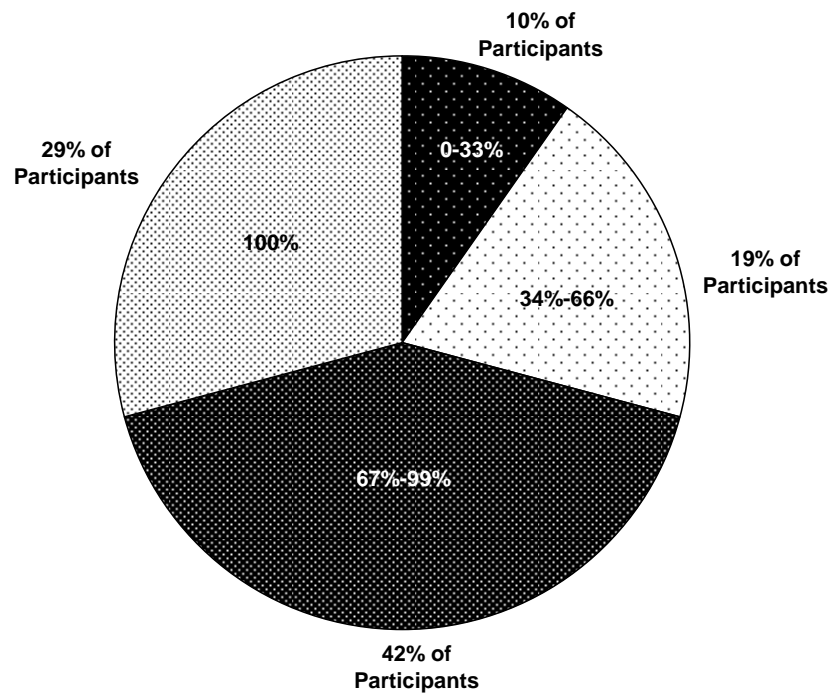
Figure 28. Percentage of participants completing percentages of course work.

Figure 28 shows that 29% of the participants completed all of their senior coursework and were graduating at the time of the interview. The smallest percentage of completed class work (0–33%) was completed by 10% of the participants and most of the

participants (42%) had completed between 67% and 99% of their senior course work.

The demographics of the sample are summarized in Table 8.

Table 8

Summary of Demographics For Sample of GE Population

Category	Findings
Age	A narrow range of ages
Gender	93% male
Experience	97% had the same level of experience
Engineering Majors	No participants represented in the Geometrics major. The most participants (by a small margin) were in the Electrical and Mechanical Engineering majors with some balance between the other majors.
Course Work	Wide range of different course work

Instrumentation

Rationale for Study's Design

The descriptive study is ideally suited for the analysis and clarification of problem-solving skills. The problem-solving skills are analyzed for each engineer (Merriam, 1998; Stake, 1995)and for the selected population of student engineers. An individual case is the process and problem-solving skills that an engineer uses to solve a problem. This methodology allowed the researcher to create a matrix of problem-solving skills for each engineer, as well as a composite matrix for the population of student engineers in this study.

These problem-solving skills represent the uniqueness of each engineer's approach to solving problems. Therefore, through the use of this analysis, the researcher

determined which problem-solving skills are used by the each student engineer (Stake, 1995). Additionally, the problem-solving skills of each case were categorized to determine similarities and differences between how engineers solve problems.

Problem Scenario Instrument

The researcher chose the problem scenario over performance tests, such as the logic portion of the LSAT, for two reasons. First, the LSAT did not provide a foundation for the second instrument in this study, which is the self-explanatory interview. The self-explanatory interview requires a problem scenario for the engineer to analyze and answer verbally. Second, the LSAT is a test that measures specific types of problem-solving skills, where using one skill is identified as the correct way and using another skill is identified as the incorrect way. This rationale does not match the purpose of this study, which is to increase the understanding of the problem-solving process.

The problem scenario is similar to the task skills inventories in capturing the problem-solving skills of the subject. However, these inventories are specific to a discipline; that is, the researcher reviews the job task and then completes an inventory of the problem-solving skills for a specific task within a specific discipline. Researching a job task to generate a skills inventory is time consuming and requires an extensive amount of analysis that is not within the time frame of this study.

The researcher did not choose intelligence tests to assess problem-solving skills because they assessed only reasoning problem-solving skills, such as induction. The researcher is measuring and analyzing all types of problem-solving skills. Additionally, these tests graded problem-solving skills, whereas this study is focused on how and what problem-solving skills are used by GEs.

Another instrument that could be used in place of the problem scenario is having the engineers write work diaries of their problem-solving skills (Smith & Smith, 2005). However, using this instrument is not a viable option because of several logistic requirements. The researcher does not have access to the subjects prior to the self-explanatory interview to explain to them how to create a work diary. Second, the researcher is not able to negotiate the addition of a workload for the GEs.

In summary, the problem scenario instrument is superior to the intelligence tests, work diaries, and other problem-solving assessment instruments described in this study. One benefit of this instrument includes the flexibility to write a problem that specifically is oriented to GEs. Another benefit is that it provides a good preparatory instrument for the all-inclusive self-explanatory interview.

Self-Explanatory Interview

The self-explanatory interview was chosen because it surfaces the problem-solving skills that the each engineer uses to solve problems. There is a vast amount of research on how self-explanations confirm the subject's knowledge of previous events (Chi, Lewis, Reimann, & Glaser, 1989; Mwangi & Sweller, 1998). Many of these studies use a worked-out example, similar to the problem scenario used in this study, as the target of the self-explanation. In this situation, the subject reads an example of a defined and solved problem. The subject reviews this example and formulates views on how it was solved that are based on the subject's academic knowledge of the discipline and various heuristic and problem-solving skills. In one study, the researcher asks the subject to read the first line of the example, "What are you thinking about?"(Chi et al., 1989, p. 159). This question elicits a response from the subject and the remainder of the

assessment continues until the subject has explained how he or she interpreted the solution to the problem.

The effectiveness of self-explanations in discovering a subject's knowledge is also supported by research on autobiographical memory (Nelson & Fivush, 2004). Autobiographical memory represents memory of biographical details such as past situations, emotions, and other personal events. Nelson and Fivush's protocol involves the researcher using "adult-guided interactions" (p. 502) to ascertain these types of memories.

Wilson believes the self-explanatory methodology has an additional benefit of making the problem-solving process visible to the respondent (Wilson, 2005). This means that the assessment process evolves to a learning process in which the respondent can improve and rethink his or her problem-solving skills.

The self-explanatory instrument was preferable to the self-report interview because the self-report title implies a grading process. The researcher believes that when a subject knows that he or she is graded, he or she may give responses that are untrue. In the test environment, the engineer might want to achieve a grade that equates with what the researcher wants to hear.

In summary, the self-explanatory instrument was used in this study because of the research behind the problem-solving assessment process. Multiple studies indicate the best method to elicit how a person solved a problem is to have him or her think aloud or explain to the researcher how he or she solved the problem (Chi et al., 1989; Mwangi & Sweller, 1998; Simon, 1999).

Administration of Protocol

The administration of this research had three phases: (a) Obtaining comments from the panel of experts, (b) administration of an offsite pretest, and (c) the administration of the formal interview: consent form, onsite pilot problem, problem scenario, and self-explanatory interview.

The researcher used six experts to validate the problem scenario and the researcher's response dialog. The problem scenario was one statement that defined the problem the GEs were required to solve. The researcher's response dialog was a list of responses used by the researcher during the self-explanatory interview. When a GE asked a question about the problem scenario, the researcher gave the response listed on the response dialog. For the questions that were asked, which were not included on the response form, the researcher responded with technical accuracy as it pertained to the focus of the problem scenario.

The validation of the problem scenario had two aspects: relevancy of the problem scenario to a senior graduating engineer, and the correct syntax. All experts agreed that the problem scenario was appropriate and relevant for the level of expertise exhibited by a senior graduating engineer.

Five members stated that the problem scenario statement had the proper syntax. One member made a suggestion on the structure of the statement. This suggestion was incorporated by the researcher.

All six members also validated the researcher's response dialog. All six members agreed that the responses were accurate, relevant, and appropriate for senior graduating engineers.

The panel of experts was located by a nonprobability, purposeful sample of engineers (Merriam, 1998). This means that the researcher specifically selected these experts for the purpose of providing expert views of the problem scenario and the researcher's response dialog.

The researcher located these experts through the convenience method and network sampling method (Merriam, 1998). The convenience method was based on contacts that the researcher made during more than 25 years of management within the engineering profession. These contacts were found through the network sampling methodology to locate additional experts in order to validate the problem scenario.

The researcher sent the problem scenario to the panel of experts. All experts returned the problem scenario form to the researcher with comments. The problem scenario form for the panel of experts is shown in Appendix B. The consent form for the panel of experts is shown in Appendix C. The offsite pretest was implemented at the researcher's house in a quiet office space with the door closed. The offsite interview included all aspects of the formal, onsite interview. This included the administration of the consent form, pilot test, problem scenario, and the self-explanatory interview.

The panel of experts validated the problem scenario and the researcher's response dialog. The purpose of the offsite pretest was to validate the administration of the formal onsite interview. The researcher used the convenience method and typical sampling methodology (Flick, 2005) to locate an experienced, nontechnical problem solver. The researcher used the nontechnical criteria for the participant to surface two specific areas: (a) To determine the maximum amount of time that should be allocated for the problem-solving session. The nontechnical person would probably take longer to solve the

problem scenario than the GE (b)To validate that the researcher's response dialog was clear and understandable. The nontechnical person would probably question the terminology used in the researcher's response dialog more frequently than the GE.

Both of these areas were clarified in the offsite pretest. The maximum time for an interview was raised from 30 to 40 minutes and several terms were clarified in the researcher's response dialog.

The administration of the formal interview involved three, separate phases: (a) Introduction and consent form, (b) Onsite pilot problem and interview, and (c) Problem scenario and self-explanatory interview.

Each of these phases occurred onsite at the school facility. The entire set of interviews occurred during 3 consecutive days. The interviews were conducted from 8 a.m. to 5:30 p.m. at different intervals, depending on the availability of the participants.

For the first 2 days, an office, located at the main engineering building, was used for the interviews. This office had one desk, two chairs, and a door that was closed for the interview. The 3rd day of interviews occurred in a small meeting room, adjacent to a large conference hall. This facility had two couches, one small coffee table, and a door that was closed for the interviews. On the 3rd day, 2 participants were interviewed in a patio area where there was limited foot traffic and sufficient privacy to conduct the interviews.

The researcher conducted five interviews on day one, six interviews on day two, and 20 interviews on day three. No interruptions occurred during these interview sessions.

The first phase of the interviews involved the researcher discussing the parameters of the research session and having the GE complete the consent form. The researcher sat across from the GE during the entire interview. Refer to Appendix D for a complete listing of the verbal protocol used to introduce the student to this research session. This appendix also describes the preliminary discussions involved in the delivery of the consent form and the introduction of the study to the GE. These parts of the methodology were not digitally recorded so as to "preserve the naturalness of the situation" (Flick, 2005, p. 167). Refer to Appendix E. for the consent form that was given to the GEs.

After the GEs were introduced to the research session and signed the consent forms, the researcher introduced the onsite pilot problem and interview. The purpose of this instrument was to familiarize the GE with the process of reading a problem scenario and then explaining to the researcher how he or she solved the problem. The onsite pilot problem and interview used the same administrative protocol as was used in the formal problem scenario and self-explanatory interview.

However, the onsite pilot problem and interview used a different type of problem scenario. The onsite problem described a nontechnical problem, whereas the problem scenario described a technical, engineering problem.

The onsite, nontechnical problem listed a pair of items in one column and four pairs of other items in an adjacent column. The GE was asked to select one of the four pairs that matched the single pair.

The researcher used this design so as not to suggest to the GE how to structure his or her problem-solving efforts when he or she was given the formal, self-explanatory

interview. The matching, onsite problem had no causes, problem definitions, or other aspects of the formal problem-solving process. The onsite problem had one correct solution. The focus of the onsite pilot interview was to have the GE verbally articulate his or her thought processes. The focus of the self-explanatory interview was to have the GE verbally articulate his or her problem-solving methodology by listing the causes, implementations, and other aspects of the problem-solving process.

The administration of the onsite pilot interview was not recorded. None of the GEs had difficulty understanding the problem, selecting one of the pairs, or explaining why they selected one of the pairs. A complete description of the verbal protocol is given in Appendix F. This appendix also includes the onsite problem.

The formal problem scenario is a single-page document with a written description of an engineering problem. This document was given to the GEs after they had completed the onsite pilot interview (see Appendix G). The researcher provided the GEs with a pen or pencil to write notes or other information to help them solve the problem. None of the students chose to use a writing instrument. Refer to Appendixes H and I for the verbal protocol used by the researcher in administering this instrument.

The problem scenario is an engineering problem that was complex enough to require a solid understanding of problem-solving skills. However, the problem scenario was not so complex as to hinder a response from the GE during the self-explanatory interview.

The researcher implemented this problem scenario design by writing a high-level engineering problem that has a wide range of causes and solutions that are not apparent during a cursory analysis. This design gave the GEs the opportunity to choose different

problem-solving skills to match the problem or to choose a skill that matched their problem-solving styles.

However, this design also meant that the GE could overanalyze the problem because the causes and solutions are not apparent and are vague. If this occurred, the problem solver could have become frustrated, called the problem unsolvable, and not been able to have a meaningful dialog with the researcher (Zeitz, 2007). There were no situations with which the GE became frustrated to the point of calling the problem unsolvable and terminating the self-explanatory interview.

Implementing the self-explanatory interview was the final phase of the methodology used in this study. This verbal instrument was used after the GE had read the problem scenario. The self-explanatory interview was recorded and the GE was given 30 to 40 minutes to describe the steps he or she used to solve the problem.

This interview was a unique type of interviewing in which the researcher is not interviewing and asking questions. Instead, the GE asked the researcher questions that helped him or her solve the problem.

The researcher responded to the questions using the researcher's response dialog. According to Merriam (1998), this type of interview is called the "research-related observation" (Merriam, p. 95). This type of observation required the interviewer to look at the entire context of the interview process. This included how the GEs articulated their responses—with or without hesitancy or with confidence.

One of the key aspects of this type of observation is not to have the researcher elicit a set of responses from the problem solver. This could possibly negate the original responses of the GE. However, according to Flick (2005), it is necessary to demonstrate

to the participant that the researcher is interested in the participant's responses and wants the participants to discuss openly and freely how he or she solved the problem. Flick says the researcher should "observe in a way that influences the flow of events as little as possible" (p. 137).

The researcher facilitated the self-explanatory interview by:

1. Showing interest in how the GE articulated causes and solutions to the problem. The researcher did this by nodding approvingly.

2. Giving verbal positive reinforcement and encouragement throughout the interview.

3. Assisting the hesitant GE by referring him or her to the methods he or she used in solving the onsite pilot interview.

At the conclusion of the self-explanatory interview, the researcher asked the GE if he or she had any comments about the process, debriefed the GE, and gave him or her a memory stick for participating in this research study. The debriefing involved informing the GEs of the elements of the problem-solving process, such as defining the cause, as well as giving them positive reinforcement about their problem-solving skills.

Delimitations

A delimiting factor in this study is a proximal variable (Fiedler, 1996). In this study, a proximal variable is a perception or other orientation of the participant during the administration of the self-explanatory interview. This includes what the subject perceives at the time of the explanation, such as the temperature of the room and where he or she is positioned in relation to the researcher. For example, if the subject believes the room is

extremely warm, it is possible that he or she will give an incorrect answer because he or she cannot think or solve problems when the environment is hot.

The researcher implemented several measures to delimit environmental, proximal variables. These included the use of properly ventilated meeting rooms where the participant was comfortable, along with a quiet environment that assured the participant's responses were heard by the researcher, without distractions.

<div align="center">Data Collection Procedures</div>

There were five phases of data collection that corresponded to the five aspects of the methodology used in this study: (a) panel of experts; (b) introduction, completing back ground form, and signing consent form; (c) offsite pretest; (d) onsite pilot interview; and (e) self-explanatory interview. The researcher describes each of these data collection phases in this section, in addition to how the resource materials were stored and how the rights of the participants were protected.

Storage of Resource Materials

After each phase of data collection, the research materials were stored in a secured area. This secured area was at the researcher's home, in a locked cabinet or backup hard drive. The researcher is the only person who has the key for this cabinet and the password for data on the hard drive. These research materials are secured for 5 years before being disposed. The paper items are shredded and the digital recordings are permanently erased.

Panel of Experts

The researcher sent the problem scenario, researcher's response dialog, and consent forms via e-mail, delivery by the postal service, or hand delivered by the

researcher. The delivery method was based on the requirements of each expert on the panel. All experts returned the problem scenario, researcher's response dialog with their comments, and the consent forms via e-mail, direct delivery to the researcher, or via the postal service.

Offsite Pretest

The offsite pretest was administered in the researcher's home in a secluded area. The researcher compiled his observations from the interview in a set of field notes. The researcher then discussed these notes with the participant. The researcher asked questions about the structure of the interview process, what problem solving strategies he or she used, and how he or she solved pivotal areas of the problem, such as defining the type of e-mail.

Introduction and Signing Consent Form

This phase and the next two phases occurred at the university in one of two conference rooms. The last two GEs were interviewed in a patio area that was quiet, with minimal foot traffic.

In this phase the researcher welcomed the GE, described the consent form, asked the GE to complete the background form and explained the logistics of the research session. Additionally, the researcher offered the GEs a memory stick for their participation in this study.

The researcher did not have enough memory sticks for the 31 participants. The last 2 participants interviewed were advised that they would not be receiving a memory stick. However, the researcher offered to send them memory sticks the next day. They

indicated that receiving a memory stick was a nice offer; however, they were happy to participate in the interview, and the researcher did not need to send them a memory stick.

Onsite Pilot Interview

The onsite pilot interview consisted of the administration of a short nontechnical problem scenario and a discussion about the problem-solving process with the researcher. There was no data collection because this was an onsite practice session for the GEs. Therefore, none of the responses given by the students was used in the analysis of how they solved this hypothetical problem.

Self-Explanatory Interview

The self-explanatory interview was recorded using a primary digital recorder and a backup digital recorder. The researcher also recorded field notes. The researcher gave the participants his business card that contained his e-mail address. The researcher told each participant that he would send them a copy of the transcripts if he or she sent him a request via e-mail.

Protection of Human Subjects

The protection of the human subjects is of utmost importance during this study. The researcher implemented the following procedures to assure the confidentiality, physical needs, and emotional needs of the subjects:

1. All tape recordings, field notes, and coded files are stored in the researcher's home premises in a locked filing cabinet for 5 years before disposal. The GEs will have the opportunity to review the digital recordings.

2. The panel of experts and participants will not receive compensation for this research project. The GEs will be offered a memory stick as an appreciation for their involvement in this study by the researcher.

3. The panel of experts and participants had the opportunity to sign consent forms that define confidentiality, ability to option out of study, and assistance from the researcher. None of the panel of experts or the GEs decided to option out.

In all cases the researcher followed the federal and professional standards for conducting research with human subjects. This included the compliance with the strict guidelines outlined by the Institutional Review Board.

Chapter 4:

Data Analysis and Findings

The purpose of this research was to assess the type of problem-solving skills and the framework of how these problem-solving skills were used by the GE to solve a hypothetical problem. This hypothetical problem was called the problem scenario.

The self-explanatory interview required the participant to read the problem scenario and have dialog with the researcher. This dialog was interactive between the researcher and the participant. The participant would ask the researcher about the problem in order to find the cause and, ultimately, the solution to the problem. The researcher responded with a consistent set of answers. These answers were based on the researcher's response dialog that was validated by the panel of experts.

In this chapter the researcher will describe how the data was analyzed by three coders. Additionally, the researcher will include the findings of the formal, self-explanatory interview. The five types of problem-solving skills will be used as the primary categories to organize these findings: problem definition, defining, goal identification, heuristics, and reasoning. Two additional categories will describe the problem-solving frameworks and behavior used by the 31 GEs.

Coding of Transcriptions

The core set of data for this research came from the digital recordings of the formal, self-explanatory interviews. The researcher recorded 4 hours and 14 minutes of dialog or 44,358 words. The mean number of words for each transcription was 1,430.

A professional transcriber transcribed these digital recordings into Microsoft Word documents. The Word documents were given to the researcher who duplicated two copies. The original Word document was coded by the researcher and the two copies

were coded by two doctoral researchers who possessed doctorates in education. These doctoral researchers used content analysis in their doctoral research.

The transcribed files contain the dialog of the self-explanatory interviews for each GE. The dialog is between the GE and the researcher. Because of different types of responses, the interview data needed to be reduced and summarized before the researcher could analyze the problem-solving methodology of each GE. The first step in completing this data-reduction process is to summarize and aggregate the data into categories (Creswell, 2007; Flick, 2005; Stake, 1995). This requires defining the categories.

In this study, the researcher defined and categorized five types of problem-solving skills. Therefore, these categories were used in the beginning, open coding phase (Flick, 2005). The use of these defined categories is based on the "correspondence" (Stake, 1995, p. 78) of different types of problem-solving skills: tools, defining, goal identification, heuristics, and reasoning. Therefore, by operationalizing these problem-solving skills categories as constructs, the coder was able to identify these categories by matching the segments of the transcribed text with the corresponding category.

The researcher and one of the doctoral researchers completed a full coding of the transcriptions. The researcher and the other doctoral researcher located three specific milestones in each transcription. The first milestone was the location in the interview where the participant identified the primary cause of the problem scenario. The second and third milestones were the locations where the participant identified the primary solution and implementation of the problem scenario.

The researcher trained the two doctoral researchers in the unique aspects of coding the transcripts from the self-explanatory interviews. This included giving the

researchers the transcriptions, coding sheet (Appendix J), and an example of a partially completed coding sheet that included the definitions of the problem-solving skill categories (Appendix K). The researcher explained how to use the coding sheet to code completely the transcriptions with one doctoral researcher. The researcher explained how to use the coding sheet to identify the three primary problem-solving milestones with the other researcher.

The coding sheet is a table with eight columns and 16 rows. The top row contains column titles or descriptions. The first column is labeled Steps and consists of a series of numbered steps. These steps designated the sequence of statements made by the researcher and the participant during the interview. One step represented one statement or statements verbalized by the researcher or the participant at one specific instance in time.

Each step is one row of the coding sheet. The steps are chronological. This means that the steps at the beginning of the coding sheet represent the beginning dialog of the self-explanatory interview. The steps at the end of the coding sheet represent the ending dialog of the interview.

The next five columns are used for the coding process. Each column represented one of the five problem-solving skills. Within these primary skill categories, the researcher identified subcategories of problem-solving skills listed in Table 9.

Table 9

Category and Subcategories of Problem-Solving Skills

Categories	Subcategories
Tools	Antiviral software, assistance, check/observe/replace, and questioning.

(*table continues*)

Categories	Subcategories
Defining	Unique to the GE. Some examples include Internet e-mail and monitor.
Goal- Identification	Problem definition, cause, solution, implementation, and evaluation.
Heuristic	Evidence-based, analogy, pattern match, and utility.
Reasoning	Deduction

These subcategories were used by the coders to identify what problem-solving skill the participant was using. If the coder could not match one of these subcategories with the participant's dialog, the coder would create a new subcategory. No new subcategories were identified for any of the 31 participants.

The coding process began by having the coder match the statement in the participant's dialog with one or more of the problem-solving subcategories. The coder recorded these subcategories in the cell of the table that matched the step (row or Y coordinate) and the problem-solving category (column or X coordinate). The researcher's dialog was not coded or included in the coding table. This dialog was used by the coder only as a reference point in the coding process.

For example, the doctoral researcher would first review the dialog of the participant to determine what category would be used for the code. Hypothetically, in this example, the doctoral researcher selected the goal identification (Goal ID) column as representative of the problem-solving skill that the participant is using. The doctoral researcher then identified the subcategory that the participant used. The doctoral researcher placed this term in the cell of the table that represented the time when the dialog occurred.

The other doctoral coder and the researcher reviewed each self-explanatory interview for three, specific goal identification problem-solving subcategories: primary cause, primary solution, and primary implementation. The primary cause, primary solution, and primary implementation are specific subcategories that the researcher designed into the problem scenario. Unlike other causes, solutions, and implementations that the participants identified, these goal subcategories were clues to solving the problem scenario. For that reason, the second doctoral researcher and the researcher specifically identified these during the coding process.

The primary cause was defined as the Internet e-mail system. The primary solution and implementation were combined in a single definition of identifying the Internet Service Provider (ISP).

Both researchers implemented this coding by identifying the paragraphs or statements in the self-explanatory interviews during which the participants verbalized the primary cause, primary solution, and primary implementation. The doctoral researcher numbered each participant's statement and then recorded the number of the statements that represented the primary cause, primary solution, and the primary implementation goals. These were sent to the researcher via e-mail.

Problem-Solving Frameworks

Each participant used a series of steps to solve the problem scenario. This series of steps form the problem-solving framework used by the participant. Most problem-solving frameworks have five steps: problem definition, cause, solution, implementation, and evaluation. Figure 29 graphically illustrates how these steps are used to solve a problem.
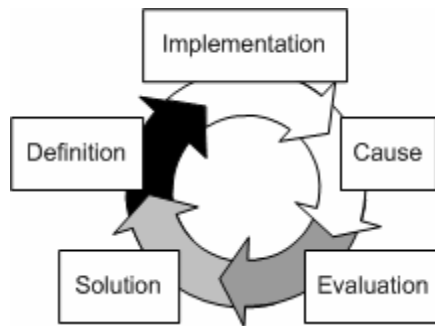
Figure 29. Using five steps of a problem-solving framework

The connecting arrows overlap and the steps can start at any point, illustrating two framework characteristics: the steps can be nonsequential, and can overlap.

Figure 30 shows four, problem-solving frameworks identified in this study. The problem definition step was not included in these frameworks since this step was not used by the participants. During the self-explanatory interview, the participants were given a written problem scenario. This problem scenario defined the problem the GEs were asked to solve. Therefore, the problem definition step was not used by the GEs.
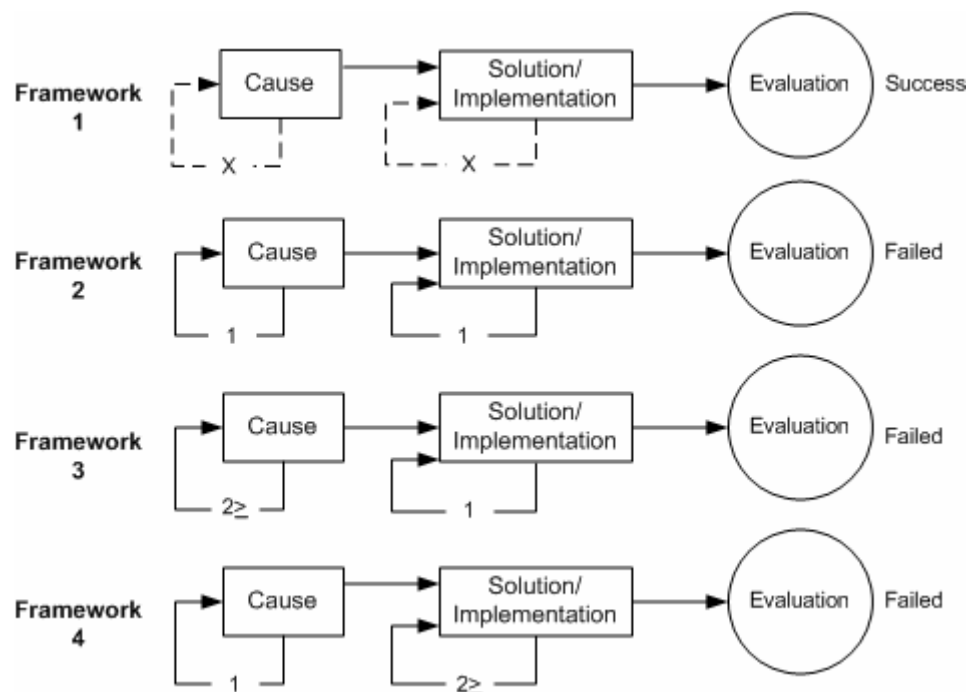
Figure 30. Four problem-solving frameworks that show cause to evaluation phases

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In framework 1, the problem solver might define several causes before moving to the next step. After the cause is defined, he or she might cycle or define numerous solutions and implementations before moving to the evaluation step. Defining the evaluation is the last step in this framework.

Framework 1 is the idealistic framework. The participant defines the cause to his or her satisfaction before searching for a solution or implementation plan. After the participant defines these steps, he or she might define the evaluation step. In this study, 52% of the participants stopped the problem-solving process after a solution and implementation were successfully defined. 48% of the participants did not employ the evaluation step.

In order to establish a structure for measuring how long it would take for a participant to solve a problem, the researcher put in place a standard set of responses he gave each participant during the self-explanatory interview. These standard set of responses were called the researcher's dialog responses and were validated by the panel of experts for relevancy and syntax.

The researcher's responses were designed to provide the participant with information on a specific or primary cause, primary implementation, and primary solution to the problem scenario. This arrangement provided the researcher and professional coders with markers or milestones for when the participant completed each of these problem-solving steps of a specific framework. Table 10 lists the generic and primary steps.

Table 10

Generic and Primary Steps of Research Study

Generic Steps	Primary Steps
Cause	Faulty Internet E-mail
Implementation	Phone call to ISP
Solution	ISP fixes problem
Evaluation	Up to participant

All of the participants used framework 1. This indicates that all participants at the end of the self-explanatory interview provided a cause, solution, and implementation to the problem scenario. However, 87% of all participants provided the primary cause, primary solution, and primary implementation to the problem, as defined by the researcher. The other 13% of the participants provided a solution and implementation to the problem scenario that was different than the ones defined by the researcher. These included deferring the solution and implementation to an outside source other than the ISP.

One participant used framework 1 exclusively to define correctly the primary cause, solution, and implementation. This participant completed the problem-solving process in 1 minute and 35 seconds.

The remaining three frameworks describe the problem-solving process that occurs when the participant did not successfully solve the problem by using framework 1. Each of these frameworks was used in different arrangements.

1. Using framework 2, 3, or 4 exclusively for the duration of the problem-solving process until implementing framework 1.

2. Using different frameworks, in different combinations, before implementing

   framework 1. For example, one participant used framework 2 once,

   framework 3 twice, and framework 4 once, before using framework 1 to solve

   successfully the problem scenario.

The second framework describes a participant who redefines the cause one time, before moving to the solution/implementation step. This means the participant is using problem-solving tools and heuristics to define the cause sufficiently to his or her satisfaction, before he or she defines a solution and implementation. However, in this case the solution and implementation are not successful. That means the solution and implementation was not the primary solution and implementation. This framework was used by 52% of the participants.

The third framework is the same as framework 2, except the redefining of causes occurs more frequently. In this case, the participant redefines the cause two or more times before defining a solution and implementation. This framework was used by 90% of the participants. Of these participants, 29% used this framework two or more times. This means that 29% of the participant's searched for two or more causes, two or more times during the problem-solving process.

In framework 4, the participant cycles through the solution/implementation steps only. This is a trial and error process in which the participant defines one solution and implementation plan after another. Eventually, the participant decides to employ another framework such as framework 2 or 3. Of the participants, 19% used this framework.

All of the participants, except for one GE used frameworks 2, 3, and 4 before using framework 1 to define the solution. Of the participants, 45% used both framework

2 and framework 3 before using framework 1. Two participants only used framework 2 before using framework 1 to solve the problem scenario and 45% of the participants exclusively used framework 3 before implementing framework 1 to solve the primary scenario.

The total time for completing the problem-solving exercise ranged from 1 minute and 10 seconds to 12 minutes and 39 seconds. The mean was 6 minutes and 17 seconds, and the median was 6 minutes and 5 seconds.

Finding a Cause and Solution

In this hypothetical problem or problem scenario the primary cause was defined as the Internet e-mail. This means the Internet e-mail was the primary reason for the failure of the employee's computer. This primary cause was correctly defined by 90% of the participants. Of the participants, 10% defined other causes, but none of these matched the primary cause of this research study.

The time for correctly defining the primary cause ranged from 37 seconds to 6 minutes and 44 seconds. The mean was 2 minutes and 22 seconds, and the median was 1 minute and 44 seconds.

The solution and implementation steps were jointly linked by 100% of the participants. Therefore, these participants defined the primary solution and then immediately defined the primary implementation in the same phrase or response.

The solution and implementation steps were summarized or conjoined in one action: contacting the ISP. The ISP was the organization that controlled the faulty Internet e-mail account used by the employee. In this problem scenario, the ISP was

upgrading the servers that provided the e-mail data to the company and the employee that had an issue with its Internet e-mail.

Because of this situation, the ISP was able to tell the GE that the upgrading of the server probably caused the intermittent problems with the employee's e-mail, and that the upgrading would be finished in 1 or 2 days. The upgrading of the servers represents the solution and the completion of this process represents the implementation.

This primary solution and implementation was correctly defined by 87% of the participants. Of the participants, 13% defined other solutions and implementations, but none of these matched the primary solution and implementation of this research study.

The time for defining the primary solution and implementation ranged from 1 minute and 35 seconds to 9 minutes and 48 seconds. The mean was 4 minutes and 50 seconds, and the median was 4 minutes and 31 seconds.

These mean and median times for defining the primary cause, primary solution, and primary implementation were dependent on the number of cycles that the participant implemented before he or she defined these primary steps. The cycles represent the processing of each step in the problem-solving framework used by each participant.

The Figure 31 scatter plot displays two variables in the participant's implementation of problem-solving frameworks. The number of times each participant used frameworks is displayed on the X axis. The period of time that the participant used these frameworks to search and find the causes, solutions, and implementations is displayed on the Y axis in seconds. The legend denotes that 1 GE used only one framework one time to solve the problem scenario. The other 97% of the participants used multiple frameworks multiple times to solve the problem scenario.
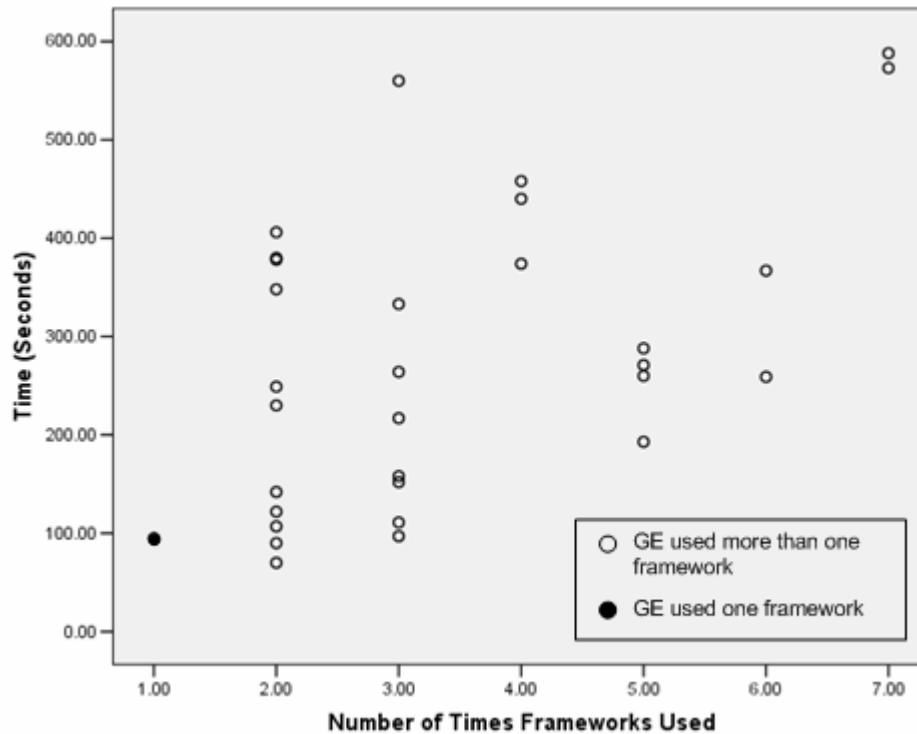
Figure 31. Frequency of GE use of frameworks by time to complete problem scenario.

The solid dark circle indicates the participant who only used one framework. The hollow circles indicate the participants who used more than one framework to solve the problem scenario. At far top right corner there are two GEs who used several different frameworks seven times to solve the problem scenario. The time to solve the problem appears to be concentrated in the 100- and 200-second range with several outliers at more than 500 seconds.

Participants' Behavior, Age, Experience

All of the participants completed the self-explanatory interview without requesting more time. Additionally, after the interview process was completed, 2 of the participants returned to the researcher to verbalize appreciation for being involved in this research study and to suggest other aspects to improving the problem-solving process

Of the participants, 29% were asked by the researcher about their level of stress and associated confidence during the problem-solving process. Of these participants, 89% expressed confidence in their ability to solve the problem with minimal stress.

> Well yeah, if you have confidence, you're able to get across the first, initial problem. There's a lot of initial things that people get caught up on, and a lot of this has to do with confidence (Respondent T02, personal communication, May 1, 2008).

> I wasn't too frustrated, the only frustrating part being, it's hypothetical. I'm more of a hands-on person. I've gone over to a neighbor's house and fixed her computer (Respondent F04, personal communication, May 2, 2008).

> Not really frustrated because I went through this a lot on the senior project design project (Respondent F06, personal communication, May 2, 2008).

Additionally, 61% of the participants needed assistance. In these cases, the participant was stuck and had difficulty moving to the next part of the problem-solving process. When this occurred the researcher asked a question that was designed to stimulate the use of problem-solving skills by the participant.

> So you have to figure out how to resolve that problem. What troubleshooting techniques would you do to narrow it down so that it is something you can find a solution for (Researcher, F19, personal communication, May 2, 2008)?

There were 2 participants who were between 35 and 45 years old. One of these participants had extensive experience while the other had limited experience. However, both participants appeared to use advanced problem-solving skills. These included extensive use of the heuristic problem-solving skill.

> Especially at a work station at a corporation. They usually either have no, or very limited hard drive so they don't have much memory space and if that gets full, so to its capacity, when you try to access a new Web site and it's trying to write it to the hard drive. Then the Internet Explorer starts having headaches and causes different things to happen (Respondent F04, personal communication, May 2, 2008).

The self-explanatory interview surfaced problem-solving skills in each of the five problem-solving skills categories: tools, defining, goal identification, heuristics, and logic. Within the tools, goal identification, heuristics, and logic categories there were additional subcategories of problem-solving skills that were identified by the researcher. The next sections describes the problem-solving skills identified from interviewing 31 GEs from the sample population of university students.Figure 32 lists the two main categories and the five subcategories of problem-solving skills.
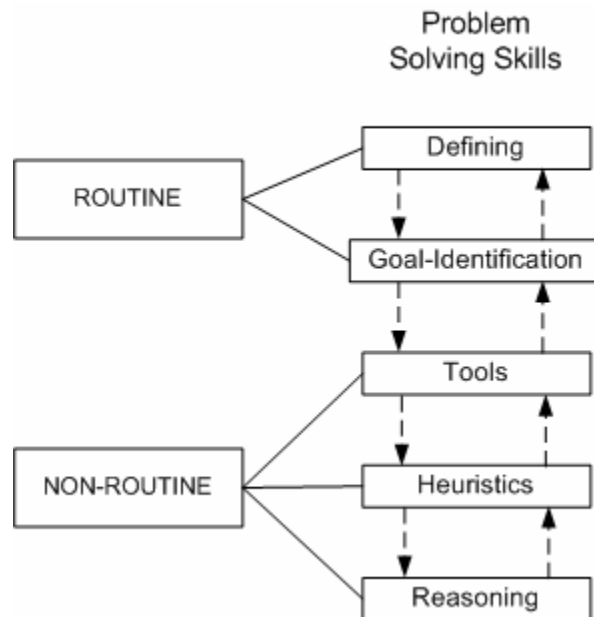
Figure 32. The routine and nonroutine problem solving skills

Tools

The tools category of problem-solving skills involves a wide variety of physical and nonphysical devices to support and guide the participant in the problem-solving process (Jonassen, n.d.). Tools are nonroutine problem-solving skills (Gilfeather & del Regato, 2004).

There was one physical device used by the participants in this study. That device was a software program that checked for viruses and other types of system problems on the computer.

The participants used many nonphysical tools. These included several types of questioning protocols and obtaining assistance from different sources.

One tool used by many participants in this study is a hybrid of physical and nonphysical elements. This tool is called the observe/check/replacement tool. The observe/check/replacement tool describes physical and nonphysical elements. For example, the user could observe a monitor, check the connections, and then replace the monitor with a new monitor using a cable extractor and screwdriver.

The most frequently used subcategory of tools was the nonphysical questioning tools. All of the participants asked questions to assist them in solving the problem scenario. The researcher identified two types of questions: foundation (Nadler et al., 2003) and frequency (Osborn, 2001) questions.

Questioning tool. Foundation questions are factual and were used by the participant to obtain answers about aspects or elements of the problem, such as the type of computer, or are any error messages being generated. Some examples include:

> When you're doing all the other applications, it doesn't flicker or freeze (Respondent F04, personal communication, May, 2, 2008)?

> Do you know much about the hardware, how old is it (Respondent F05, personal communication, May 2, 2008)?

> Okay, then I would ask them what was the last thing they did that may have caused this problem (Respondent W02, personal communication, April 30, 2008)?

All of the participants asked foundation questions. The researcher found that the foundation questions were grouped in themes. The seven most frequently asked

foundation question themes were: (a) What type of e-mail or account is the customer using?; (b) What's wrong with the computer?; (c) What type of attachments are included with the e-mail?; (d) What type of computer or hardware is being used?; (e) What is the status of other applications when processing e-mail?; (f) Do other computers have the same problem?; and (g) What was the last function the user was implementing before the problem occurred (i.e., the computer did not work).

These seven types of foundation questions are described in the following paragraphs. Each foundation question is stated and then a summary of the statistics is given for that question. Following these statistics are examples of the responses given by the respondents that illustrate the type of foundation question.

What type of e-mail or e-mail account is the coworker using? This was a factual question that provided a large scale perspective of the general region of the problem space. Asked by 42% of the participants. One participant asked this question twice (Respondent W02, personal communication, April 30, 2008).

OK. It's an Internet e-mail service. Which one in particular (Respondent F07, personal communication, May 2, 2008)?

What's wrong with the computer? This was a generic high-level question that was establishing the foundation or general focus of the problem. The participant wanted narrow the focus to a hardware issue, software issue, or another aspect of the operation of the computer. Asked by 94% of the participants. One participant asked this type of foundation question twice (Respondent W05, personal communication, April 30, 2008).

Well, first I'd ask the coworker what the particular problem is with the computer (Respondent F04, personal communication, May 2, 2008).

What type of attachments are included with the e-mail, or how were the attachments downloaded or manipulated in some way? This was a specific foundation question that narrowed the problem to aspects of the attachments sent with the e-mail. The participant wanted to understand if they were manipulated and this action could possibly cause viruses or other computer system problems. Asked by 35% of the participants. One participant asked this question three times (Respondent F13, personal communication, May 2, 2008).

> Meaning do you, are you into say downloading music, you have big files on your computer (Respondent F13, personal communication, May 2, 2008)?

What type of computer or hardware is being used? Another set of specific foundation questions with which the participant was investigating the hardware or structure of the computer that used the e-mail system. Asked by 35% of the participants. One participant asked this question three times (Respondent F13, personal communication, May 2, 2008) and a second participant asked this question twice (Respondent W04, personal communication, April 30, 2008).

> Are you using a CRT (Respondent W04, personal communication, April 30, 2008)?

What is the status of other applications when processing e-mail? In this type of questioning the participant is establishing the relationship between using other software applications while concurrently using e-mail. Asked by 32% of the participants.

> Um, so I'm thinking perhaps in the e-mail that you're looking at. Maybe you're opening up something that's running Active-X or something in the back ground that causes a flicker. And you don't realize that there's some other program (Respondent W04, personal communication, April 30, 2008)?

Do other computers have the same problem? This is a key type of foundation question since the participant is determining if problem with the coworker's machine is

unique or a symptom of company problem that affects all computers. Also, the

participant may be exploring potential, relationships that are occurring between the office

of the e-mail user and equipment outside this location. Asked by 19% of the participants.

One participant asked this question three times.

> (Can you still e-mail to people within the office (Respondent F09, personal
> communication, May 2, 2008)?

What was the last function the coworker was implementing before the problem

occurred (i.e., the computer did not work)? The focus of these types of foundation

questions was to determine what other, nonlocal elements, such as the user was surfing

the Internet, that are potentially part of the problem. Asked by 23% of the participants.

One participant asked this type of question twice.

> Did anybody else have the same complaint? OK, does it happen at the same time
> (Respondent T04, personal communication, April 30, 2008)?

> The second types of questions were frequency questions. These questions focused
> on amounts, quantity, specific times when a process occurred, or frequency of a
> process. Asked by 42% of the participants. Two participants asked this type of
> question twice.

> Now, do you do e-mail all day long or just do e-mail and then go back to your
> work (Respondent F04, personal communication, May 2, 2008)?

> Everything is working fine. And when did you notice this problem (Respondent
> F11, personal communication, May 2, 2008)?

> *Check/observe/replace problem-solving tool.* The check/observe/replace problem-

solving tool (Kuphaldt & Divasto, 2002) is a hybrid tool because it has physical and

nonphysical elements. In some cases this tool was used by the GE to check and observe

the operation of the computer. The GE did not replace a part that was suspected of

causing the problem. In other cases, the GE checked and observed the problem and

replaced the part to see if that action fixed the problem.

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Among the participants, 65% used this tool in different combinations of checking, observing, and replacing a part. One participant used this tool six times and a second participant used the check/observe/replace tool five times.

> Then I would go through to see what they say, when you respond back in a day. Check the other Internet services as well to see if they're doing the same thing. Because if they're doing the same thing, most likely it's your hardware or software on your computer (Respondent T03, personal communication, May 1, 2008).

> I would start looking at other computers (Respondent W03, personal communication, April 30, 2008).

> Well, if checking the e-mail is a problem, I would asks the coworker to try to forward all the e-mail to another one. In other words, to see if it's fine for now (Respondent W02, Personal communication, April 30, 2008).

> Well, first I would check to see if there was something wrong with the Internet connection. If it's a landline or if it's wireless. If it's a landline, I would check the physical connection to the back of the computer. If it's wireless, I would have to check the network processor (Respondent F19, personal communication, May 2, 2008).

The check/observe/replace tool was also used to test different components of the workspace. This type of application of the check/observe/replace tool was used by 58% of the participants. One participant used this application of the check/observe/replace tool four times.Another participant used this application twice

> Ok, all right. So I'd probably, if I were you, I'd probably switch my e-mail browser and see if it still, it doesn't sound like it's a hardware issue on your computer (Respondent F02, personal communication, May 2, 2008).

> Okay, so have you checked the file using a different kind of Internet browser like Firefox instead of IE (Respondent F11, personal communication, May 2, 2008)?

> Have you restarted your computer (Respondent F18, personal communication, May 2, 2008)?

> But I guess if we had some spare monitors, I would just swap it out and see if it happens again (Respondent W03, personal communication, April 30, 2008).

Antivirus, problem-solving tool. More than one third of the participants (35%) used an anti-virus program during their analysis of this computer problem. The antivirus program was used throughout the problem-solving process to determine if viruses were causing or contributing to the e-mail problem. However, in one case, the participant used the antivirus software after the e-mail problem was corrected (W04, personal communication, April 30, 2008). This was implemented as an evaluation tool to make sure the e-mail system was really functional after the ISP had fixed the e-mail server.

> Right, well I guess you can just run an antivirus (Respondent F09, personal communication, May 2, 2008).

> Probably recommend running a virus scan (Respondent F15, personal communication, May 2, 2008).

Using assistance problem-solving tool. All of the participants (100%) used one or two forms of assistance to gain information about the problem and/or to implement a strategy for solving the problem. These forms of assistance are divided into three categories: phoning the e-mail vendor, using a help file, or contacting a technical person.

Phoning the e-mail vendor was used frequently since the hypothetical solution to the problem was to contact the e-mail vendor. Used by 84% of the participants.

> Maybe ask them about the usage because if it is at 2 p.m., it seems like that would be a high traffic time (Respondent F06, personal communication, May 2, 2008).

A second form of assistance occurred when the GE determined the best tool was to search the Internet or an online help file for technical assistance. There are many software tools that facilitate the problem-solving process such as using an online help one tool that is part of many software applications. Used by 13% of the participants. One participant used this type of assistance twice.

First of all I would probably go to the Internet and get more information about it (Respondent F01, personal communication, May 2, 2008).

The third form of assistance occurred when the GE checked with technical personnel that were familiar with computer problems. This type of assistance describes contacting technical personnel within the company or some perhaps other individuals that have the expertise to solve the problem. Used by 19% of the participants.

I guess I would. I have a really close friend that knows a lot about computers. I probably would ask him first and tell him the symptoms (Respondent F12, personal communication, May 2, 2008).

Defining

Defining is a routine problem-solving skill (Gilfeather & del Regato, 2004) that sets the boundaries (Lumsdaine et al., 1999) and constraints of a segment or segments of the problem (Murphy, 2004). This can be implemented to isolate or frame (Gloeckler, 2007) a problem, such as determining that a faulty power supply rather than another component is the reason a computer printer does not print.

The defining skill can be used for each of the goals set in the goals identification problem-solving skill. That means the participant might use the defining problem-solving skill to define any of the goals: defining the problem definition, defining the cause of the problem, defining the solution of the problem, defining how the corrective action will be implemented, and defining the evaluation of the corrective action.

Defining the problem definition. The defining skill can be used to define and clarify the problem definition. In this research study the defining of the problem definition goal never occurred since the problem was defined in the problem statement that was given to the participant.

Defining the cause. This goal was defined by 100% of all participants. However, there was a wide range of definitions of the cause. These definitions fit in three large categories: low-level causes resulting from the type of computer or connections, high-level causes resulting from incompatibility or failure of software and browsers, and miscellaneous causes resulting from a software virus or specific computer settings.

One example of each of these causes is given in the following quotations. The first example was used by 39% of the participants, the second example was used by 100% of the participants, and the third example was used by 35% of the participants.

> I'm trying to think of what might be causing it. I'm wondering if it's the graphics card or if it's a loose cable (Respondent W04, personal communication, April 30, 2008)?

> Then I'd probably go to the computer, look at all of the installation and see the most recent ones. And may be uninstall the new ones to see if that would fix the problem (Respondent W02, personal communication, April 30, 2008).

> Did you run another program, like a virus checker. Seems like a virus (Respondent F11, personal communication, May 2, 2008).

Defining the implementation and solution goals. The definition of the implementation and solution might occur separately from the definition of the cause. In other cases the definition of the implementation and solution occur in one statement by the participant. In 100% of the participants, the definition of the implementation coincided with the definition of the solution. The first example shows how the definition of the cause is linked to the definitions of the implementation and solution. Of the participants, 97% added causes when defining implementation and solution.

The second example shows how the definitions of the implementation and solution are separate concepts. Of the participants, 35% defined implementation and solution jointly. Of this percentage, 91% also concurrently defined the cause,

implementation, and solution.

> Okay, if you recently updated drivers for any kind of hardware, it can conflict with the library dll files. Windows has dll problems, so if you overwrite them it will cause another error. So have you recently updated or installed any hardware (Respondent F05, personal communication, May 2, 2008)?

> Have you tried to reinstall, may be the video (Respondent F11, personal communication, May 2, 2008)?

These percentages of cause/implementation/solution responses do not include a

unique category of solutions. That category is called assistance. The participants in this

category solved the problem by requesting assistance from many different sources, such

as the ISP, a coworker, or completing a data search on one potential aspect of the

problem. All of the participants used this problem-solving tool to define jointly a cause,

implementation, and solution . The following example illustrates this type of problem-

solving skill.

> I would, honestly, just look in the Help file and try to troubleshoot the problem. They have a list of different things there (Respondent W01, personal communication, April 30, 2998).

Defining the evaluation goal. The evaluation goal occurs after a solution has been

implemented. Of the participants, 48% defined the evaluation goal. There were many

types of evaluations. Two examples are given below:

> Well, if they don't get it fixed in a timely manner, I guess I would look for someone else more reliable to provide our Internet than them. That would be pretty serious thing. So that means that should be happening on all computers (Respondent W03, personal communication, April 30, 2008).

> You mean like do I explain to them or do I tell them not to worry. If I was a technician, I would just sort of make an announcement saying it has been a couple of days of construction so the Internet, offline e-mail is not functioning (Respondent F11, personal communication, May 2, 2008).

Other aspects of the defining problem-solving skill. Another aspect of the defining

skill is determining the number of times each participant attempted to define the cause,

implementation, solution, or evaluation goal, without articulating a definition. This

process occurs when a problem solver is framing the goal, but does not have enough

information to define fully the goal. Of all participants, 84% used this technique before

they defined a specific goal. Of this population, 32% of participants used problem-

solving tools and heuristics five to six times during the problem-solving exercise.

Table 11 lists the number of nondefining actions in five categories: (a) 0, (b) 1-2,

(c) 3-4, (d) 5-6, and (e) 7-9. These categories were used in different frequencies by

different percentages of participants.

Table 11

Frequencies of Nondefining Problem-Solving Skills Used by Participants

Number of Nondefining Actions	Frequency	Percentage of Participants
0	5	16
1–2	6	20
3–4	5	16
5–6	10	32
7–9	5	16

Three examples are given below:

Have you received anything like e-mail from other people (Respondent F11,
personal communication, May 2, 2008)?

When you're doing all the other applications, it doesn't flicker or freeze
(Respondent F4, personal communication, May 2, 2008)?

OK, do you know much about the hardware. How old is it (Respondent F5, personal communication, May 2, 2008)?

Goal Identification

Goal identification is a routine problem-solving skill (Gilfeather & del Regato, 2004) in which the problem solver identifies the segment or segments of the problem as a goal the problem solver wants to achieve (Kirkley, 2003; Laird et al., 1986). These include identifying the five generic problem-solving goals: definition, cause or causes, solution, implementation, and evaluation. These goals can be applied to any problem in any sequence of the problem-solving structure (Cochran, 2006).

The definition of the problem was stated in the problem statement given to the participants before the explanatory interview occurred. All understood the problem definition and, therefore, there was no dialog pertaining to identifying this goal. The next goal in the problem-solving process is to determine the cause or causes of the problem. This was addressed by 100% of the participants. Table 12 lists the number of times the participants used problem-solving tools or heuristics to identify or ascertain the cause of the problem.

Table 12

Frequencies of Actions Used to Identify the Cause of the Problem by Participants

Number of Actions to Identify a Cause	Frequency	Percentage of Participants
2–5	7	22
6–9	12	39
10–15	12	39

An example of this type of problem-solving skill is given in the following

quotation:

> It's a functioning computer. So long as it's still functioning we can see what
> problems it is having. And to see what problems it's having, may be software or
> hardware related (T02, personal communication, May 1, 2008).

In this example the participant is exclusively looking for the cause of the

computer problem. He or she suspects that the cause might be in the software or

hardware; however, this is a broad statement and the participant is using the defining

problem-solving tool to pinpoint or frame the cause of the problem.

A subset of these frequencies is the number of times that the participant combines

the cause action with the implementation and solution actions. This means the participant

does not identify seeking a cause as a separate problem-solving skill. Instead the

participant combines a solution and implementation plan concurrently with seeking the

cause to the problem.

> Then I would try to turn it on, see if hitting some different keys would get it
> working (T01, personal communication, May 1, 2008).

Preceding this statement the participant did not identify a cause. Therefore, this

example represents a participant who believes that the solution of hitting various keys on

the computer keyboard will solve the unidentified cause.

Table 13 lists the number of times that the participants combined their actions in

identifying the cause, solution, and implementation goals. Within the two to four range of

responses, the two combined actions were used by 26% of the participants

Table 13

Frequencies of Actions Used to Identify a Combination of Goals by Participants

Number of Actions to Identify Concurrently the Cause, Solution, and Implementation	Frequency	Percentage of Participants
0–1	8	26
2–4	18	58
5–6	5	16

The corresponding part of this distribution is the number of actions that exclusively identify the implementation and solution goals. The researcher combined the implementation and solutions goals since 100% of all participants did not select the implementation goal separately from the solution goal. For all of the participants the implementation of a solution was combined with the solution.

> Despite the person's objections, I'd probably remove the Internet Explorer and reinstall (Respondent F04, personal communication, May 2, 2008).

Table 14 lists the number of actions used to identify solutions and implementations. These are grouped in three categories: a) 1-2, b) 3-4, and c) 5-6. These categories were used in different frequencies by different percentages of participants.

Table 14

Frequencies of Actions Used to Identify Solutions and Implementations by Participants

Number of Actions to Identify a Solution and Implementation	Frequency	Percentage of Participants
1–2	12	39

(*table continues*)

Number of Actions to Identify a Solution and Implementation	Frequency	Percentage of Participants
3–4	12	39
5–6	7	23

The number of causes versus the number of participants that defined those number of causes is shown in Figure 33. The causes are grouped into seven categories: (a) 3 causes, (b) 5 causes, (c) 7 causes, (d) 9 causes, (e) 11 causes, (f) 13 causes, and (g) 15 causes. Seven participants defined 9 causes and an additional seven participants defined 11 causes.
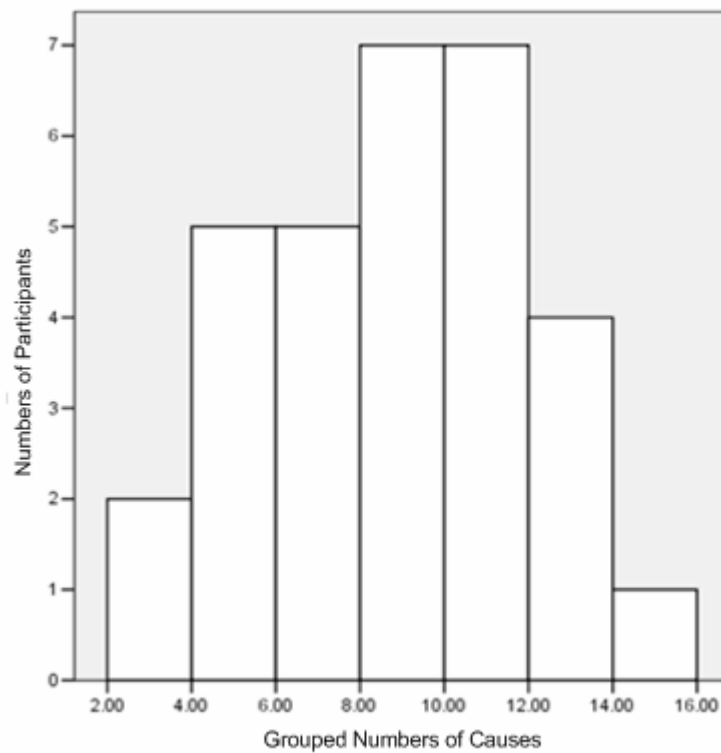
Figure 33.- Number of participants in defining seven groupings of causes

Figure 34 shows the number of participants that defined six groupings of solutions. For example, the number of participants identifying 3 solutions was 7.

The largest number of participants identified 2 solutions. The smallest number of participants identifying solutions was 2. There were 2 groupings of these participants. On one extreme 2 participants identified 2 solutions and on the other extreme, 2 participants identified 6 solutions.
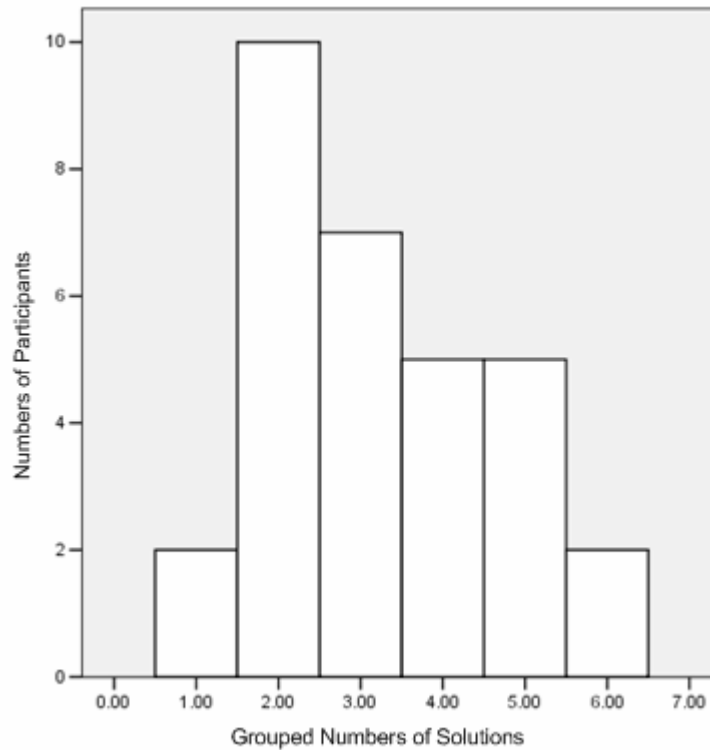
Figure 34. Number of participants in defining six groupings of solutions.

The fifth goal in the problem-solving process is evaluation.The evaluation goal occurs after a solution has been implemented. Of the participants, 48% defined the evaluation goal. However, most participants did not identify this goal. Instead, the participants ended the problem-solving exercise with the implementation of the solution. 19% of the GEs recommended two or more specific evaluation actions.

> I'd check to make sure that it worked properly, but other than that, maybe I would let my manager know that it's fixed (Respondent F14, personal communication, May 2, 2008).

Heuristics

Heuristics is a nonroutine problem-solving skill (Gilfeather & del Regato, 2004) based on the experience of the problem solver (Pappalardo, 2007). One type of heuristic allows the problem solver to organize information (Black, 2004b) so he or she sees patterns or similarities (Black, 2004a) between a current problem and problems the problem solver resolved in the past . Other heuristics use probability (Jeffrey, 2002) and analogical thinking (Kokinov & Petrov, 2001) to assist the problem solver in finding causes and solutions to complex problems.

Evidence-based heuristics. Evidence-based heuristics is a problem-solving skill based on the general level of experience of the participant (Gambrill, 2005; McGovern et al., 2001). The participant reviews his or her background of experiences and then determines a problem-solving tool to use or another problem-solving skill that is based on his or her experience of the problem or the problem space.

Of the participants (all except 1 participant), 97% used this heuristic in the self-explanatory, problem-solving exercise. Of these participants, 39% used the evidence-based heuristic three or more times.

> OK. The reception is not well. Where were you standing? Do you have problems getting a signal (Respondent T04, personal communication, May 1, 2008)?

> Especially at a work station at a corporation. Usually they either have no hard drive or a very limited hard drive. Therefore, they do not have much memory space and if that gets full there is no capacity. When you try to access a new Web site and it's trying to write it to the hard drive, the problems occur, such as the Internet Explorer starts having headaches and causes different things to happen (Respondent F04, personal communication, May 2, 2008).

In the first heuristic the participant is using his or her experience to articulate a foundation question about the signal. The participant knows from his or her experience

that the location of the receiver is pivotal to obtaining a clear signal. In the second example, the participant goes through a lengthy analysis using his or her experience to determine the cause of the e-mail failure.

Probability heuristic.Using the probability of a specific incident is a type of heuristic that the researcher calls a probability heuristic. This heuristic is part of the availability concept developed by Tversky (1983) in the explaining the decision-making process. The probability heuristic was used by 45% of the participants.

> You know, it is only happening intermittently, it isn't a connection problem. It isn't any kind of wires or things like that. So next we have to check for viruses (T02, personal communication, May 1, 2008).

> If you are not the only person who has that problem, then it could be a signal coming in. If something is coming in, it's not being distributed to all the people (Respondent T04, personal communication, May 1, 2008).

In both of these examples, there is the prominent theme of probability (or availability) of a number of events that are relevant to deciding what problem-solving tool or action to implement. In the first example there are an intermittent number of actions that constitute the pivotal factor. In the second example, the number of people experiencing the problem is a factor in suggesting a cause to the e-mail problem.

Analogy heuristic. The participant uses this heuristic when he or she bases his or her problem-solving actions on structural similarities between the current problem and problems he or she encountered in the past (Quilici & Mayer, 1996). After this match occurs, the participant can quickly duplicate the set of problem-solving actions used for the old problem and then use them for the current problem.

The analogy heuristic is based on generic or general structural similarities between current and old problems. The pattern match heuristic requires similar, specific

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structural markers to match two problems. The analogy heuristic was used by 32% of the participants.

> Yes. The cause will ultimately lead you to your solution. That's cause and effect. I mean, if you have a car with a popped tire, you're never going to go 50 miles per hour. What's the cause of your problem? It is the popped tire. So you automatically know your cause, and that is going to give you options on your solution. Your solution is to put your 50 miles per hour tire on you can only go at that speed (Respondent T03, personal communication, May 1, 2008).

This detailed example of an analogical heuristic demonstrates how the participant used a flat tire incident to assist him or her in solving the e-mail problem. The relationship of the cause and effect was pivotal to the types of questions and other problem-solving skills used by this participant.

> I would say that usually when you're looking at a computer system, it is usually the whole thing is not working right. So you are looking at it as a whole, or an individual component is not working. So, you know when I got it down to the e-mail that certainly helped narrow it down. I do not really know what was going on in my brain, but I just think of it in terms of a system working together (Respondent F01, personal communication, May 2, 2008).

In this example, the participant describes how he or she views the entire problem work space as a whole entity that has many components that must work together. This is analogous to comparing the problem with an automotive engine. When this occurs, the problem solver must understand how each part works together before he or she can determine which part (the problem) is failing.

Pattern match heuristic. The pattern match heuristic is similar to the analogous heuristic. Both of these heuristics are based on matching elements of old problems that were experienced by the participant, with similar elements in the current problem (Quilici & Mayer, 1996). However, the pattern match heuristic is more specific in comparing

these elements or markers in both problems. This heuristic was used by 26% of the participants.

> Like when I was going to send a file to my friends or something or to my father, I would upload, for example, a picture file, which is very large. The time it takes to send an e-mail with an attachment like that varies. However, it could take one to three minutes (W05, personal communication, April 30, 2005).

In this example the participant specifically matches the current e-mail problem with an e-mail transmission issue that occurred in his past. The participant used this heuristic to formulate foundation questions about the type of attachments used with the e-mail described in the hypothetical problem.

Utility heuristic. Utility is a measure of expected value to the participant (Chernoff & Moses, 1959). In the problem-solving domain this means the participant determines a plan of action that will yield the greatest value in the problem-solving process. In this problem-solving exercise, the value was directly related to the participant's effort in solving the problem. This heuristic was used by 23% of the participants.

> I need to have an understanding of the problem so when I contact the technician for repair, I can convey the problem. There is no reason to have a $75 an hour person, come out when it is a cord (T06, personal communication, May 1, 2008).

> Like sometimes there is a cookie or a bug or something like that. It is something you take care of yourself. So that is one of the first things I always check for.…It is an easy fix.…Yeah, it is usually like the more common things. The things that I can do on my own (F19, personal communication, May 2, 2008).

Both of these examples demonstrate how the participant used the utility heuristic to define how much effort they are going to use to solve the problem. These participants believed that they should solve as much of the problem as possible, before asking for assistance.

Reasoning

Reasoning is a "process that leads to a conclusion or inference using known facts or assumptions"(numbernut.com, 2008, glossary section, reasoning entry). Reasoning includes the problem-solving skills of inductive, deductive, Boolean, and fallacious logic. In this research the participants used deductive reasoning. Of the participants, 26% used deductive reasoning in defining causes, solutions, and implementations.

> I want to see you check your e-mail. OK. If you are checking your e-mail and it is a monitor problem and then we have a connection problem (T02, personal communication, May 1, 2008).

In this quote the participant is using deduction to determine the connection problem. The participant uses two premises (checking e-mail and monitor problem) to deduce or infer that the employee's computer has a problem with the connection.

Summary of Findings

The problem-solving findings of this study are categorized by the two primary dynamics of the problem-solving process: using problem-solving frameworks and problem-solving skills.

A problem solving framework is the systematic approach (Beasley, 2006) that the GE used to navigate through the problem process (Newell & Simon, 1972). For example, 52% of the GEs used one problem-solving framework that involves a five-step process: (a) The GE searches for a cause, two or multiple times, and selects the most probable cause; (b) After this phase the GE identifies a possible solution; (c) After identifying the solution, the GE defines an implementation plan; (d) The GE implements this plan; and (e) The last phase of this framework is when the GE evaluates the implementation plan to see if the problem has been resolved.

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Another type of framework uses a different number of searches. The GE immediately identifies one cause, rather that searching for causes multiple times and then selecting the most probable cause. After this phase the GE immediately selects one solution for that cause and implements that solution.

The second dynamic of the problem-solving process is the use of problem-solving skills. The researcher found that the GEs used five categories of problem-solving skills: tools, defining, goal-identification, heuristics, and reasoning. These problem-solving skills are the mechanisms that the GE used within the problem-solving frameworks to solve the problem scenario. For example, the GE might have used the deductive reasoning problem-solving skill to determine that the cause of the computer failure is a loose cable.

Problem-Solving Frameworks

All of the participants used framework 1. Framework 1 was a five-step process: (a) The GE searches for a cause, one or multiple times; (b) After this phase the GE identifies possible solutions. He or she then selects the most probable solution; (c) After identifying the solution, the GE defines an implementation plan; (d) The GE implements this plan; and (e) The last phase of this framework is when the GE evaluates the implementation plan to see if the problem has been resolved. Additionally, the GE might recommend modifications to the solution that would provide a better resolution to the problem. Using framework 1 results in a successful resolution to the problem scenario.

One GE used the above framework exclusively. Of the GEs, 97% used other frameworks before using framework 1 to solve successfully the problem scenario.

Additionally, 48% of the GEs did not evaluate the solution. Refer to Figure 30 for a description of all frameworks.

The second framework described a GE who searches for the cause one time before identifying a solution and implementation plan. Unlike framework 1, the analyzed data shows that this process does not yield a successful resolution to the problem. Therefore, the GEs who used framework 2 would have to repeat the problem-solving process. Framework 2 was used by 52% of the participants.

After framework 2 is completed, the GE has four options: use framework 1, use framework 2 again, use framework 3, or use framework 4. As the research indicates, all GEs, except 1would use one of the alternate frameworks.

The third framework is the same as framework 2, with the exception that casual searches occur more frequently (two or more times). In this case, the GE is identifying multiple causes. The GE then selects the most probable reason for the failure of the computer. This is followed by the identification of a solution and implementation plan. As with framework 2, the above solution and plan does not successfully solve the problem scenario.

The research shows that the results of using frameworks 1 and 2 are the same and the problem is not solved. The GE then either repeats using framework 2 or uses another framework. Framework 3 was used by 90% of the GEs.

In framework 4 the GE searches once for a cause and then searches two or more times for a solution and implementation plan. As with frameworks 2 and 3, the GE's solution does not solve the problem and he or she might repeat framework 4 or use

another framework. GEs that used this tactic are engaged in a trial and error process. Of the GEs, 19% used framework 4.

Another component of using the problem-solving frameworks was the amount of time the GE required to solve the problem scenario. There was a wide variance in the time that the GEs needed to define the primary cause and the primary solution and implementation. The primary cause and the primary solution were the elements of the problem that the researcher defined as the cause and solution to the problem.

This primary solution and implementation were correctly defined by 87% of the participants. Of the participants, 13% defined other solutions and implementations, but none of these matched the primary solution and implementation of this research study. The primary cause was correctly defined by 90% of the GEs. Of the GEs, 10% defined other causes, but none of these matched the primary cause of this research study.

The time for correctly defining the primary cause ranged from 37 seconds to 6 minutes and 44 seconds. The mean was 2 minutes and 22 seconds, and the median was 1 minute and 44 seconds.

The time for defining the primary solution and implementation plan ranged from 1 minute and 35 seconds to 9 minutes and 48 seconds. The mean was 4 minutes and 50 seconds, and the median was 4 minutes and 31 seconds. Refer to Figure 31 for a scattergram of the timing and frameworks used by the 31 GEs. This scattergram shows that the quickest time for solving the problem scenario was 70 seconds.

Problem-Solving Skills

The researcher identified six categories of problem- solving skills. These skills were divided into routine and nonroutine skills. The routine skills include defining and

goal-identification skills. The routine problem-solving skill is the use of "known or prescribed procedures to solve problems"(Gilfeather & del Regato, 2004, p. 1).

The nonroutine skills included tools, heuristics, and reasoning. These problem-solving skills are "procedures or strategies that do not guarantee a solution to the problem but provide a more highly probable method for discovering the solution" (Gilfeather & del Regato, 2004, p. 1).

The tools category of problem-solving skills involves a wide variety of physical and nonphysical devices to support and guide the participant in the problem-solving process (Jonassen, n.d.). Tools are nonroutine problem-solving skills (Gilfeather & del Regato, 2004).

One subcategory of tools was the questioning tools. The participants asked foundation (Nadler et al., 2003) and frequency (Osborn, 2001) questions during the self-explanatory interviewing process. The questioning tool was used by 100% of the GEs. The questioning tool was divided into two subcategories of questions: foundation and frequency questions.

Foundation questions were used by the GEs to obtain factual data about the problem scenario. All 31 GEs used foundation questions to assist them in ascertaining the cause or determining a solution to the problem scenario. Of the GEs, 55% asked between one and four foundation questions.

> When you're doing all the other applications, it doesn't flicker or freeze (Respondent F04, personal communication, May, 2, 2008)?

The second types of questions were frequency questions. These questions focused on amounts, quantity, specific times when a process occurred, or frequency of a process. Of the participants, 42% of the participants asked these types of questions.

Now, do you do e-mail all day long or just do e-mail and then go back to your work (F04, personal communication, May 2, 2008)?

Another problem-solving tool used by the GEs is called the check/observe/replace tool. The GE used this tool to intervene actively in the problem scenario to find the cause or solution to the problem. The GE would observe a part of the problem and replace a component to see if corrected the entire problem, or perhaps only a segment of the problem. Of the participants, 94% used this tool.

Well, if checking the e-mail is a problem, I would ask the coworker to try to forward all the e-mail to another one. In other words, to see if it's fine for now (Respondent W02, Personal communication, April 30, 2008).

A third tool used by the GEs was the implementation of an antivirus program. Many GEs believed that one of causes to the failed computer could have been a virus and, therefore, they used this tool to correct the problem. More than one third of the GEs (35%) used an antivirus program.

A fourth tool is called assistance and was used by all of the participants. The participants asked for assistance to solve the problem from a coworker, technical expert, or the ISP. Additionally, the participant might have used technical documentation to determine the cause or solution to the problem scenario.

I guess I would. I have a really close friend that knows a lot about computers. I probably would ask him first and tell him the symptoms (Respondent F12, personal communication, May 2, 2008).

Defining is a routine problem-solving skill (Gilfeather & del Regato, 2004) that sets the boundaries (Lumsdaine et al., 1999) and constraints of a segment or segments of the problem (Murphy, 2004).

In this research study the participants did not define the problem definition goal. The reason for this action was that the definition of the problem was stated in the problem scenario that was given to the participant prior to the self-explanatory interview.

The cause goal was defined by 100% of all participants.

> I'm trying to think of what might be causing it. I'm wondering if it's the graphics card or if it's a loose cable (Respondent W04, personal communication, April 30, 2008).

All of the participants concurrently defined the solution and implementation.

> Okay, if you recently updated drivers for any kind of hardware it can conflict with the library dll files. Windows has dll problems, so if you overwrite them, it will cause another error. So have you recently updated or installed any hardware (Respondent F05, personal communication, May 2, 2008)?

Goal identification is a routine problem-solving skill (Gilfeather & del Regato, 2004) in which the problem solver identifies the segment or segments of the problem as a goal the problem solver wants to achieve (Kirkley, 2003; Laird et al., 1986). The following example illustrates how the participant identified the cause goal.

> It's a functioning computer. So long as it's still functioning we can see what problems it is having. And to see what problems it's having, may be software or hardware related (Respondent T02, personal communication, May 1, 2008).

The corresponding part of this distribution is the number of actions that exclusively identify the solution and implementation goals. For all of the participants the implementation of a solution was combined with the solution.

> Despite the person's objections, I'd probably remove the Internet Explorer and reinstall (F04, personal communication, May 2, 2008).

The last goal the researcher identified in the self-explanatory interviews was evaluation. Of the participants, 48% identified the evaluation goal.

I'd check to make sure that it worked properly, but other than that, maybe I would let my manager know that it's fixed (Respondent F14, personal communication, May 2, 2008).

Heuristics is a nonroutine problem-solving skill (Gilfeather & del Regato, 2004) based on the experience of the problem solver (Pappalardo, 2007). The participants used evidence-based heuristics when they based their problem-solving decisions on their total experience in the field. Of the participants, 97% used this heuristic in the self-explanatory problem-solving exercise.

Especially at a work station at a corporation. Usually they either have no hard drive or a very limited hard drive. Therefore, they do not have much memory space and if that gets full there is no capacity. When you try to access a new Web site and it's trying to write it to the hard drive, the problems occur, such as the Internet Explorer starts having headaches and causes different things to happen (Respondent F04, personal communication, May 2, 2008).

The probability heuristic is based on the availability concept developed by Tversky (1983) in explaining the decision-making process. The probability heuristic was used by 45% of the participants.

You know, it is only happening intermittently, it isn't a connection problem. It isn't any kind of wires or things like that. So next we have to check for viruses (Respondent T02, personal communication, May 1, 2008).

The participant uses the analogy heuristic by comparing structural similarities between the current problem and problems he or she encountered in the past (Quilici & Mayer, 1996). The analogy heuristic was used by 32% of the participants.

Yes. The cause will ultimately lead you to your solution. That's cause and effect. I mean, if you have a car with a popped tire, you're never going to go 50 miles per hour. What's the cause of your problem? It is the popped tire. So you automatically know your cause, and that is going to give you options on your solution. Your solution is to put your 50 miles per hour tire on you can only go at that speed (Respondent T03, personal communication, May 1, 2008).

The pattern match heuristic is more specific than the analogy heuristic in comparing markers in both problems. This heuristic was used by 26% of the participants.

> Like when I was going to send a file to my friends or something or to my father, I would upload, for example, a picture file, which is very large. The time it takes to send an e-mail with an attachment like that varies. However, it could take one to three minutes (Respondent W05, personal communication, April 30, 2005).

Utility is a measure of expected value to the participant (Chernoff & Moses, 1959). The utility heuristic was used by 23% of the participants.

> I need to have an understanding of the problem so when I contact the technician for repair, I can convey the problem. There is no reason to have a $75 an hour person, come out when it is a cord (Respondent T06, personal communication, May 1, 2008).

Reasoning is a "process that leads to a conclusion or inference using known facts or assumptions" (numbernut.com, 2008, glossary section, reasoning entry). In this research, 26% of the participants used deductive reasoning.

> I want to see you check your e-mail. OK. If you are checking your e-mail and it is a monitor problem and then we have a connection problem (Respondent T02, personal communication, May 1, 2008).

Research Questions

Research Question 1

Which problem-solving frameworks were used to solve a given problem scenario? The researcher identified four different types of problem-solving frameworks. Framework 1was exclusively used by 1 GE. The remaining 97% of the GEs used a combination of frameworks 1, 2, 3, and 4. Refer to Figure 31, which shows the number of the frameworks (1, 2, 3, or 4) that the GEs used and the number of times those frameworks were used to solve the problem.

Research Question 2

Which was the most frequently used problem-solving skill? The routine problem-solving skills include defining and goal identification. The defining skill was used by all GEs. The goal-identification routine problem-solving skill is divided into five subcategories: problem definition, cause, solution, implementation, and evaluation. The cause, solution, and implementation were used by all GEs.

The nonroutine problem-solving skills includes tools, heuristics, and reasoning. Within the tools category are the questioning and assistance skills. These were used by all the GEs. Within the heuristics category are five types of heuristics. The most frequently used heuristic is the evidence-based heuristic that was used by 97% of the GEs. The reasoning problem-solving skill was used by 26% of the GEs.

Research Question 3

What difference, if any, is there among GEs according to these demographic variables: gender, age, coursework, and years of experience? There appeared to be no relationship between the use of specific problem-solving frameworks and the demographic variables. The GEs used a diverse set of problem-solving frameworks and solved the problem scenario in a wide range of times.

Refer to Figure 31, which shows the time that each GE used to solve the problem scenario. Additionally, this figure shows the number of times the GE used frameworks and if the GE used more than one framework to solve the problem scenario.

Research Question 4

Were any elements of a problem-solving framework or skills infrequently used by GEs in the problem-solving scenario? Of the participants, 48% used the evaluation goal.

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The nonroutine problem-solving skill includes tools, heuristics, and reasoning. Within the tools category there are two skills that were infrequently used: Check/observe/replace was used by 65% and an antivirus tool was used by 35% of the GEs. There were four heuristics that were infrequently used. These include probability heuristic, which was used by 45%; the analogy heuristic, which was used by 32%; the pattern-match heuristic, which was used by 26%; and the utility heuristic, which was used by 23% of the GEs. The reasoning category of nonroutine problem-solving skill included deductive reasoning. Of the GEs, 26% used this type of problem-solving skill.

Chapter 5:

Summary, Conclusions and Recommendations

Summary

Statement of Problem

Although problem solving is a central part of the engineering curriculum, there is limited research in how routine and nonroutine problem-solving skills are used jointly to solve complex problems by the GE. Also, data does not support whether gender, age, experience, particular engineering courses, or engineering specialization affects the order, frequency, and type of problem-solving skills utilized by a GE.

Statement of Purpose and Significance

The purpose of this research is to assess the type of problem-solving skills and the framework of how these problem-solving skills are used by the GE to solve a complex problem. This information will assist college instructors in defining teaching objectives and skill sets that help engineers analyze and solve problems. Concomitantly, the business sector will gain graduating engineers who have an improved grasp of the many types of problem-solving skills, so that they are prepared to address the wide diversity of complex problems in the engineering profession.

Methodology

Population. This study involved interviewing 31 participants. The researcher recorded five categories of demographic data for each participant: age, gender, experience, engineering major, and completed senior-level coursework. All 31 participants completed the background document. The following list gives a description of each demographic category.

1. Age: 71% of the participants were between 20 and 25 years old. Of the participants, 23%were between 26 and 35 years old. The remaining 2 participants were 35 to 45 years old. There were no participants 46 years or older.

2. Gender: 29 participants were male and 2 participants were female.

3. Experience: 97% of the participants had 1 to 5 years of experience. One student had more than 10 years of full-time engineering experience.

4. Engineering Major: 19% civil engineering, 13% computer science, 16% construction management, 26% electrical engineering, and 26% mechanical engineering.

5. Completed coursework: 29% completed all coursework, 42% completed between 67% and 99%, 19% completed between 34% and 66%, and 10% completed between 0% and 33%.

Data-collection procedures. There were five phases of data collection that corresponded to the five aspects of the methodology used in this study: (a) panel of experts; (b) introduction, completing back ground form, and signing consent form; (c) offsite pretest; (d) onsite pilot interview; and (e) self-explanatory interview. The following list gives a description of each data collection procedure.

1. Panel of experts: The researcher sent the problem scenario, researcher's response dialog, and consent forms via e-mail, delivery by the postal service, or hand delivered by the researcher. All experts returned the problem scenario, researcher's response dialog with their comments, and the consent forms via e-mail, direct delivery to the researcher, or the postal service.

2. Introduction: The GEs recorded demographic data on a background form and signed the consent form.

3. Offsite pretest: The researcher compiled his observations from the offsite pretest in a set of field notes.

4. Onsite pilot interview: There was no data collection because this was an onsite practice session for the GEs. Therefore, none of the responses, given by the students, were used in the analysis of how they solved the problem scenario.

5. Self-explanatory interview: The self-explanatory interview was recorded using a primary digital recorder and a backup digital recorder. The researcher also recorded field notes. The researcher gave the participants his business card that contained his e-mail address. The researcher told each participant that he would send them a copy of the transcripts if he or she sent him a request via e-mail.

Limitations

Each problem scenario has elements that determine the difficulty of finding a cause and solution. For this reason the time for the GE to solve the problem scenario might be longer or shorter than when are solving other types of problems. This study required the GE to solve the problem scenario within 30 to 40 minutes.

The findings in this study are based on a sample size of 31 GEs, who have a homogeneous mixture of some demographics, such as age, while other demographics are not sufficiently represented, such as gender. These aspects of the sample mean that the researcher has insufficient data to draw strong conclusions.

Findings

The problem-solving findings of this study are categorized by the two primary dynamics of the problem-solving process: using problem-solving frameworks and using problem-solving skills.

Problem-Solving Frameworks

All of the participants used framework 1. One GE exclusively used this framework to solve the problem scenario. The remaining 97% of the GEs used combinations of framework 1, 2, 3, and 4 to solve the problem scenario.

Refer to Figure 30 for a description of the four types of frameworks. Refer to Figure 31 for a scattergram of the time each GE used to solve the problem scenario. Additionally, this figure shows the number of times the GE used frameworks and if the GE used more than one framework to solve the problem scenario.

Problem-Solving Skills

All of the GEs used the routine problem-solving skills. The nonroutine problem-solving skills were used at different frequencies by the GEs.

The tools category of nonroutine problem-solving skills was used by 100% of the GEs. The heuristics category of nonroutine problem-solving skills was divided into five categories. The probability heuristic was used by 45% of the GEs, the analogy heuristic was used by 32% of the GEs, the pattern-match heuristic was used by 26% of the GEs, and the utility heuristic was used by 23% of the GEs. The most frequently used heuristic was the evidence-based heuristic that was used by 97% of the GEs.

The reasoning category of nonroutine, problem-solving skills defined deductive reasoning. OF the GEs, 26% used this type of problem-solving skill.

Conclusions

Conclusion 1

The GEs under study utilized different combinations of problem-solving frameworks. Research shows that many types of frameworks have been defined (Elger et al., 2001; Fogler & LeBlanc, 2008; Lumsdaine et al., 1999; Muller, 1998; Pandy et al., 2004; Poyla, 1985; Pretz, Naples, & Sternberg, 2003; VanGundy Jr., 1988) to describe the problem-solving process.

Most of these frameworks were defined by the authors to contain five steps: (a) problem definition, (b) cause, (c) solution, (d) implementation plan, and (e) evaluation. In step (a) the problem solver defines the problem to quantify the direction he or she will move. In step (b) the participant searches for a cause to the problem. The next three steps direct the problem-solver to search for a solution, design a plan to implement the solution, and then evaluate the solution and plan.

Many of these fore-mentioned authors emphasized the sequence of steps used to solve a problem. Fogler and LeBlanc (2008) defined a framework where the solution step (c) was followed by the implementation step (d), and concluded with the evaluation step (e).

The five, consecutive steps, defined by the authors, clearly emerged in the content analysis of the data from the GEs. However, the researcher, as well as his well-trained coders, determined that the GEs emphasized each step differently. This emphasis led the researcher to develop four frameworks that better fit the researched data.

These four frameworks contained four of the five steps that were used by the authors to define the problem-solving frameworks: causes, solution, planning, and

evaluation. This means that these four steps that were documented by the authors are represented in the four new frameworks used by the GEs. Each of this researcher's four frameworks did not include the problem definition step. This step was not included because the researcher defined the problem by giving the problem scenario to the GE during the self-explanatory interview. Therefore, the GEs did not need to define the problem.

The emphasis of a step was defined in the new framework as the number of times the GE used that specific step before proceeding to the next step of the framework. Refer to figure 30 and the subsequent text in Chapter 4 for an illustration of four, new frameworks.

Two of the four frameworks, identified by the researcher, emphasized the usage of the cause step. This was a result of the coding and analysis of the data. Framework numbers 2 and 3 described the cause step as one of the following: (a) users of framework 2 searched for causes one time, before searching for a solution, or (b) users of framework 3 searched for causes two or more times, before searching for a solution.

Framework 1 does not emphasize the cause, implementation, or other steps. Framework 4 emphasized the implementation step. In this framework, the GE used the implementation step two or more times before moving to the evaluation step. The solution step was not bypassed; instead, the professional coders and researcher found that the implementation and solution were often found to be conjoined.

According to Elger (2001) and Lumsdaine (1999), the implementation step is important and they emphasized this importance by extensively describing the barriers that interfere with problem-solving if this step is not used.

Framework 3 does not emphasize the implementation step, but instead emphasizes the searching for a cause. This framework was used by 90% of the GEs. Framework 4, that was used by 19% of the GEs, contains an implementation step used two or more times before the GE moves to the next step.

One possibility for the extensive searching of causes is that the GEs believed that finding a cause to the problem is more important than determining how to implement the solution. Refer to figure 31 for a chart of these framework usage patterns.

Another important aspect of the use of frameworks is the combinations the frameworks were used. 97% of the GEs used more than one framework, such as frameworks 1 and 2 or framework 1, 2, and 4. The reason for the mixing of different frameworks could be that the GE is attempting to find one problem-solving framework that is more effective than other frameworks.

The 40-minute time constraint of the research study may have affected the GE's usage of different frameworks. According to Glockner and Betsch (2008) when there are limits on the time to solve a problem and make a decision, the individual changes problem-solving strategies.

The 5 GEs who solved the problem the quickest used 10 combinations of the frameworks, while the 5 GEs who solved the problem the slowest used 23 combinations of the frameworks. This indicates that the quickest GEs used fewer frameworks and strategies than the GEs who took a longer period of time to solve the problem.

The reason for this difference in problem-solving completion rates could be that the combinations of frameworks the quick problem-solving GEs used were more efficient. Therefore he or she did not need to use additional frameworks. The

combinations of frameworks, that the slow problem-solving GEs used, were less effective, thus forcing the GE to use a larger number of frameworks.

Conclusion 2

The GEs under study utilized a wide range of problem-solving skills. The research of problem-solving skills shows that there were five categories of problem solving skills used: defining (Jonassen, 2004), goal-identification (Kirkley, 2003), tools (Jonassen, n.d.), heuristics (Pappalardo, 2007), and reasoning (Holyoak & Morrison, 2005) . Within these categories of problem-solving skills the GEs used a subset of skills.

The defining and goal-identification problem solving skills are routine (Gilfeather & del Regato, 2004) skills. These skills were used by 100% of the GEs. This probably occurred because these skills are routine, familiar and used in most problem-solving processes.

The tools category of skills included the subset known as the questioning tool (Nadler et al., 2003). The reason for the 100 percent usage of this tool is possibly a result of the design of the self-explanatory interview. This interview required the GE to ask different types of questions to determine the cause and other aspects of the problem.

Within the heuristics category, the most frequently used heuristic was the evidence-based heuristic (Pappalardo, 2007). This heuristic is a problem-solving skill where 97% of the GEs used their experience to formulate a cause, implementation, or solution to the problem. One reason for this high usage could be that this methodology is familiar and easy to use as well as being highly accessible.

The other heuristics, such as the analogy heuristic (Quilici & Mayer, 1996) is more complicated to implement. The analogy heuristic, used by 32% of the GEs, requires

matching an existing segment of the problem with a similar segment found in other problems. The complexity of this skill could be the reason that the analogy heuristic was used less frequently.

The reasoning skill category was used by 26% of the GEs. The small usage may be due to the concept that reasoning is part of the whole problem-solving process (Pesut & Herman, 1999) and is incorporated in other problem-solving skills.

Conclusion 3

The four problem-solving frameworks, as well as the five categories of problem-solving skills, facilitated the qualitative analysis of data. Each self-explanatory interview was professionally coded by two criteria: (a) type of frameworks and, (b) categories of problem-solving skills. This process allowed the researcher to define common themes that the GEs used when solving the problem scenario.

Conclusion 4

The GEs, under study, varied bimodally in their use of the evaluation step of the four problem-solving frameworks. The evaluation step is used when the GE evaluates or assesses the solution and implementation plan. When this occurs the GE analyzes the plan or solution and determines that these framework steps need improvement. The GE then makes recommendations to improve the plan or solution (Heywood, 2005).

Jonassen (2004) and Heywood (2005) state that the evaluation step is an important part of the problem-solving framework and is needed to assess the accuracy of the implementation plan. Additionally, Lumsdaine et al. (1999) specifically indicate that the evaluation step can be used to update the implementation plan immediately.

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Of the GEs, 48% evaluated the solution or implementation plan. However, 52% did not evaluate or expand on the solution to include preventative processes that would avoid another failure in the computer system of the coworker. These GEs viewed the problem as fixing a failed computer only.

> Then, I'd say according to what the boss is hoping for, a fully functional condition; there is nothing left to do (Respondent F09, personal communication, May 2, 2008).

One reason for this result could possibly be that these GEs were not aware of the evaluation step of the problem-solving framework Therefore, once the computer was fixed, they could return to their other responsibilities rather than implement safeguards that could avoid further computer failures.

Conclusion 5

The GEs under study did not appear to differ in problem-solving capability by gender or age. Shors (2006) indicated gender is a neutral issue in problem-solving until the individual reaches the teens. At that time the male gender is superior in problem solving. According to one study by Gihooly et. al (2007), there was no relationship between age and "abstract tests and cognitive functioning (p. 597)."

The problem-solving capabilities of different gendered GEs were similar. The female GEs used several types of problem-solving skills and frameworks as did their male counterparts. The problem-solving capabilities of the GEs, with different ages were also similar. GEs who were older, completed different coursework, and were more experienced, used many types of problem-solving skills and frameworks, as did younger, less-experienced GEs who completed different coursework.

Conclusion 6

No pattern was found in using the tools and heuristics problem-solving skills when determining the cause and solution to the problem. Adams and Wieman (2007) hypothesize that each problem-solver has a different set of problem-solving skills along with different levels of strengths in each of those skills.

There were five problem-solving tools and five heuristics used by the GEs in this study. None of the GEs used all of the tools and all of the heuristics. Each GE used various problem-solving tools and heuristics in different sequences. The reason for these unique sequences could be that the GEs only used those tools and heuristics that he or she was familiar with. Additionally, the GE may have used a specific tool or heuristic because he or she had successfully used this problem-solving skill before. Alternatively the GE may not have used this tool or heuristic because the GE was unsuccessful in solving the problem when he or she used this skill in the past.

Conclusion 7

The GEs under study did not use two, conventional, engineering tools: flowchart and Pareto diagram. Juran (1988) determined that the flowchart and Pareto diagram are important tools for the problem-solving process. Juran indicated that the flowchart is specifically useful when determining the implementation step of the problem-solving framework. In this case, the symbols of the flowchart would have provided a clear distinction as to who will implement the solution, who will assist in implementing the solution, and the type of equipment needed to implement the solution.

Juran (1988) also recommended the use of the Pareto diagram that could have assisted the GE in determining the implementation step. The GEs could have used the

Pareto diagram to set the priorities of the different parts of the implementation plan. This action could have provided the GEs a roadmap for interleaving each part of the plan so that the pivotal parts were positioned to yield the correct solution. Thus having a more efficient and shorter route to a solution.

One reason the GEs might not have used these tools is because they believed they were not relevant for this problem scenario. Alternatively, the GEs might not have used these tools because they had unsuccessfully used them in the past.

Recommendations

Recommendation 1

The following is a recommendation for teaching GEs how to use combinations of problem-solving frameworks. All problem solvers should use a mental framework or a systematic approach to solve problems. In this study the 5 GEs, who solved the problem the quickest, each used different combinations of these frameworks.

Because of this diversity in the use of problem-solving frameworks, the researcher is recommending the teaching of different problem-solving frameworks. With this knowledge the GE would be aware of the different frameworks before starting the problem-solving process. He or she could then select the problem-solving framework, or combination of frameworks, that would be appropriate for the problem.

Recommendation 2

The following is a recommendation for teaching the GEs about the wide range of problem-solving skills. The GEs should be exposed to five different heuristics to locate causes and solve the problem scenario. Each of these heuristics was fundamental in how the GE viewed the problem-solving process and impacted the time required to solve the

problem. For example, the analogy heuristic (Quilici & Mayer, 1996) required the GE to

search for an analogous problem that matched the current problem scenario. This search

could take the GE a short or long period of time.

For these reasons, the researcher is recommending that the engineering instructor

incorporate the training of problem-solving heuristics in the engineering curriculum. This

training could be included in the Problem-Based Learning (PBL); (Barger et al., 2001)

teaching methodology.

During the critique phase of the problem, the instructor would ask the GE which

heuristic he or she used and the rationale for the use of that heuristic. The instructor

would then add the time step to the discussion to surface the relationship of using this

heuristic to the how long the GE needed to solve the problem.

Recommendation 3

A recommendation for using the organizational guide of four frameworks of

problem-solving skills and five categories of problem-solving skills. The organizational

guide can be used for similar research studies that require organizing and categorizing

frameworks of problem-solving skills and categories of problem-solving skills.

Recommendation 4

The following are recommendations for teaching the use of evaluation in the

problem-solving process. The evaluation goal occurs at the end of the problem-solving

process, after the GE has successfully implemented the solution. At this point, the GE

evaluates the solution to determine if the solution continues to resolve the problem.

Additionally, the GE might add preventative processes to the solution to make sure the

solution adapts to additional problems or nuances to the primary problem that the GE did

not observe during the first analysis.

In the business environment the evaluation problem-solving goal is of utmost

importance. This occurs because the management team wants to have a solution to a

problem that works continuously after implemented, and does not require intervention at

a later date by the GE or another employee (Crosby, 1984).

Businesses can train the GEs to use this problem-solving skill by assessing him or

her in the ability to solve problems. This can be implemented by having an engineering

trainer administer a problem scenario, as was implemented by the researcher in this

study. Following this process, the engineering trainer would debrief the GE on how he or

she completed the problem. In particular, the engineering trainer would focus on the need

for the evaluation phase.

One of the GEs in this study implemented the following evaluation goals.

I would ask if the coworker was satisfied with the current state. With my
manager, if it is OK, I could stop there or recommend another provider as backup
(Respondent F05, personal communication, May 2, 2008).

Recommendation 5

There should be future research to determine the relationships of the GE's gender,

age, and completed coursework to problem-solving skills. Additionally, there should be

future research regarding the experience, the type of problem-solving frameworks and

problem-solving skills they use to solve a problem.

Recommendation 6

The following recommendations are for teaching GEs the relationship between

using different problem-solving tools and different heuristics, to determine the cause and

solution to the problem. The GEs should successfully used many tools and heuristics to solve the problem scenario. However, none of the GEs used all of the problem-solving tools and heuristics.

In order to provide a full complement of these two nonroutine categories of problem-solving skills, the researcher is recommending that within the engineering curriculum, the engineering instructor gives the GE problems with the requirement that they use specific tools and heuristics. This type of instruction will surface relationships between these problem-solving skills that would be informative and productive (what problem-solving skills work) to the GE problem solver.

Recommendation 7

There should be future research of GEs not using conventional problem-solving tools in different problem scenarios. This could be implemented in the business setting through the evaluation of Total Quality Management programs.

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APPENDIX A

Background

NAME:_____

AGE:

   □20–25   26–35   35–45   46-above

GENDER:

     Male   Female

EXPERIENCE (Full Time Engineering Workload)

     1–5 years   6–10 years   10 years or more

COMPLETED SENIOR-LEVEL COURSEWORK
(Core Classes for Senior Year)

Geomatics Engineering

     Satellite Geodesy   Physical Geology   Subdivision Design

     Senior Project   Contemporary Conflicts of Morals

Civil Engineering

     Reinforced Concrete Design   Project Design   Princip. of Electr. Circuits

     Senior Project   International Politics

Computer Science

     Computer Sys. Lab   Advan. Computer Archit.   Senior Design I

     Senior Design II   Contemporary Conflict of Morals

     International Politics Circuits

Electrical Engineering

     Physical Electronics   Senior Design I   Technical Area Design

     Senior Design II   Thermodynamics   Contemporary Conflict of Morals

Mechanical Engineering

    Heat and Mass Transfer   Design of Machine Elements

    Elements of Systems Design   Adv. Thermodynamics- Fluid Mechanics

    Contemporary Conflict of Morals ☐ Design Applications

Construction Management

    Adv Const Structures   Scheduling and Controls

    Construction Labor Laws Circuits   Mechanical Systems II

    Construction Mgmt.   Construction Soils and Foundation

    Construction Site Planning and Development   Heavy Construction

    Heavy Building

APPENDIX B

Panel of Experts Problem Scenario Response Form

Instructions for Evaluation of this Problem Scenario

Administration: This problem scenario will be given individually to graduating engineering students to assess their problem solving skills. The researcher will role play the other participants in this problem scenario according to the specifications of the problem that are outlined in the "Parameters."

The engineering student will not be given the "Parameters" since the purpose of this research is to determine how an engineering student solves a complex, vaguely stated problem. There is no correct solution to this problem scenario. Please review the problem scenario for:

1.   Punctuation and clarity.

2.   Relevancy. This problem should represent a situation that the engineering student would encounter as a newly graduated engineer. Additionally, the problem should contain a minimal amount of information, so as to challenge the engineer to use a variety of problem solving skills.

3.   Send your response via e-mail or postal.
        James Welch

4.   Sign **Consent Letter** and send by postal, or scan and send electronically.

Problem Scenario

A desktop computer is not working in the office of a co-worker. You are asked by your manager to repair the computer to a fully functional condition.

Comments:

_____

APPENDIX C

Consent Form for Panel of Experts

INFORMED CONSENT FOR PANEL OF EXPERTS IN RESEARCH ACTIVITIES

Participant: _____

Principal Investigator: James Welch

Title of Project: Problem Solving Skills Utlized by Graduating Engineers From a Baccalaurteate Program to Solve Problems

I _____ , agree to participate in the research study entitled "Problem Solving Skills Utlized by Graduating Engineers From a Baccalaurteate Program to Solve Problems" being conducted by James Welch, a doctoral student under the supervision of Dr. Diana Hiatt-Michael in organizational leadership at Pepperdine University, Graduate School of Education and Psychology. This research is being conducted in partial fulfillment of the requirements for a doctoral dissertation. I understand my participation in this study is strictly voluntary.

Purpose of the Study
The overall purpose of this research is to determine different ways graduating engineering students solve problems.

Procedures
My participation involves reviewing a problem scenario response form for relevancy and clarity. I realize that there is no one correct way to solve this problem scenario and that the purpose of this research is to understand the different types of problem solving skills used by graduating engineers.

Potential Benefits
I understand that the possible benefit to me from this review is knowledge of the different problem solving techniques that I use to solve problems.

Potential Risks and Discomforts
I understand that the problem scenario may be difficult to answer. I understand that if I feel uncomfortable during the review I may elect to decline to answer any question(s).

Confidentiality
I understand that the investigator(s) will take all reasonable measures to protect the confidentiality of my records and my identity will not be revealed in any publication that may result from this project. Towards this end, in lieu of utilizing my name, the primary investigator will apply a code to associate with any data collected from my participation. This will help to ensure confidentiality. Further, the confidentiality of my records will be maintained in accordance with applicable state and federal laws. The data gathered will be stored in a locked file cabinet to which only the primary investigator (James Welch) will have access. After five years, all data files will be destroyed.

Contact Information

I understand that the investigator is willing to answer any inquiries I may have concerning the research herein described. I understand that I may contact Dr. Hiatt-Michael at Pepperdine University if I have other questions or concerns about this research. If I have questions about my rights as a research participant, I understand that I can contact Dr. Stephanie Woo, PhD of the Institutional Research Board at Pepperdine University or via mail at Pepperdine University, Graduate School of Education and Psychology, 6100 Center Drive, Los Angeles, CA 90045.

I understand to my satisfaction the information regarding participation in the research project. All my questions have been answered to my satisfaction. I have received a copy of this informed consent form which I have read and understand. I hereby consent to participate in the research described above.

_____

Participant's Signature

_____

Date

_____

Witness

_____

Date

I have explained and defined in detail the research procedure in which the subject has consented to participate. Having explained this and answered any questions, I am cosigning this form and accepting this person's consent.

_____   _____

Principal Investigator   Date

APPENDIX D

Introduction and Consent Form Protocol

Researcher (Primary Investigator): Hi, thanks for coming here today. My name is Jim Welch and I am a doctoral student at Pepperdine University. I am researching how individuals solve problems, specifically what techniques he or she used to find a solution. I asked <name of instructor> to help me with this project by selecting 30 graduating engineering students that I could interview and that is why we are here today.

Researcher: This is a completely voluntary and confidential study. Your name and responses will not be published or distributed to anyone. Additionally you can leave this interview at any time without fear of penalty. The entire process will take up to 30-40 minutes. I have a background form that I would like you to complete and a consent form that lists the precautions of this study. The back ground form is a series of questions about demographic information. This informational is completely confidential. Can you complete this form now?

Researcher: The first part of the consent form explains who I am and the purpose of this study. This is followed by a description of what we will be doing here today. Briefly, this session is divided into three parts. In the first part I will give you a pilot problem for you to solve. This is followed by an explanation of how you solved the problem.

After this I will give you a formal problem that I would like you to solve. After you have read this problem I will ask you to explain how you solved the problem. This part of the session is the only segment that is tape recorded and provides the research material for my doctoral study. If you would like to review the tape recordings of this session, you can contact me at my e-mail address and I will send you the professionally transcribed tapes. All tapes and field notes are kept for five years in a secured, cabinet at my residence that I only have a key for. After five years the hardcopy is shredded and the electronic media is permanently erased.

Your name is coded to preserve your confidentiality.

This problem is not graded and most importantly there is no correct answer. The purpose of this exercise is to understand how you solved the problem. No results of this interview will be given to any academic institution or company.

Researcher: The rest of the consent form indicates that this session is completely voluntary and fully confidential. That means your name, the name of the school and any other identifying data is not published. This exercise is for research only. Additionally, you can voluntarily leave this exercise at any time without any concern for repercussions.

The bottom half of this form is for your signature. Do you have any questions about the purpose of this session or how the work session is implemented?

Can you sign the consent form now?

If at any time you wish to withdraw from this study, there will be no penalty or prejudice.

I really appreciate you taking time out of your busy schedule to participate in this study. Here is a memory stick to show my appreciation.

Consent Form for Participant

INFORMED CONSENT FOR PARTICIPATION IN RESEARCH ACTIVITIES

Participant: _____

Principal Investigator: James Welch

Title of Project: Problem Solving Skills Utlized by Graduating Engineers From a
Baccalaurteate Program to Solve Problems
I _____ , agree to
participate in the research study entitled "Problem Solving Skills Utlized by Graduating
Engineers From a Baccalaurteate Program to Solve Problems" being conducted by James
Welch, a doctoral student under the supervision of Dr. Diana Hiatt-Michael in
organizational leadership at Pepperdine University, Graduate School of Education and
Psychology. This research is being conducted in partial fulfillment of the requirements
for a doctoral dissertation. I understand my participation in this study is strictly voluntary.

Purpose of the Study
The overall purpose of this research is to determine different ways graduating
engineering students solve problems.

Procedures
My participation involves answering a problem scenario response form that will require
up to a 30-40 minute self-explanatory interview where I explain to the primary
investigator how I solved the problem. I realize that there is no one correct way to solve
this problem scenario and that the purpose of this research is to understand the different
types of problem solving skills used by graduating engineers.

I understand that the interview session will be digitally recorded. I also understand that
the audio files will be used for research purposes only. Further, I understand the files will
be stored as password protected files and the transcribed interview files will be stored in a
locked file cabinet and destroyed five years from the completion of the study. I will be
given the opportunity to review the digital recordings.

Potential Benefits
I understand that the possible benefit to me from this interview is knowledge of the
different problem solving techniques that I use to solve problems.

Potential Risks and Discomforts
I understand that the problem scenario may be difficult to answer. If I have difficulty
evaluating the response form the investigator will assist and guide me through the
problem solving process. Additionally, in all cases, my name is kept strictly confidential.
I understand that if I feel uncomfortable at any time during the interview, I may elect to

decline to answer any question(s) and/or end the interview session at my discretion at any time without penalty or loss of benefits to which I am otherwise entitled.

Payment for Participation
I understand that as a participant, I will a one gigabyte, flash memory stick. Further, I understand that even if I elect to end the interview session early or decline to answer any of the interview questions, I am still entitled to receive the memory stick.

Confidentiality
I understand that the investigator(s) will take all reasonable measures to protect the confidentiality of my records and my identity will not be revealed in any publication or institution that may result from this project. Towards this end, in lieu of utilizing my name, the primary investigator will apply a code to associate with any data collected from my participation. This will help to ensure confidentiality. Further, the confidentiality of my records will be maintained in accordance with applicable state and federal laws. The data gathered will be stored in a locked file cabinet to which only the primary investigator (James Welch) will have access. After five years, all data files will be destroyed.

Contact Information
I understand that the investigator is willing to answer any inquiries I may have concerning the research herein described. I understand that I may contact Dr. Hiatt-Michael at Pepperdine University if I have other questions or concerns about this research. If I have questions about my rights as a research participant, I understand that I can contact Dr. Stephanie Woo, PhD of the Institutional Research Board at Pepperdine University or via mail at Pepperdine University, Graduate School of Education and Psychology, 6100 Center Drive, Los Angeles, CA 90045.

I understand to my satisfaction the information regarding participation in the research project. All my questions have been answered to my satisfaction. I have received a copy of this informed consent form which I have read and understand. I hereby consent to participate in the research described above.

_____
Participant's Signature

_____
Date

_____
Witness

_____
Date

I have explained and defined in detail the research procedure in which the subject has consented to participate. Having explained this and answered any questions, I am

cosigning this form and accepting this person's consent.

Principal Investigator	Date

APPENDIX F

Onsite Pilot Interview Protocol

Researcher (Primary Investigator): Before I present you the formal problem scenario, I would like to have you try a dry run with a simple matching problem, so you can become familiar with how to express your problem solving methods.

Researcher: Can you read this problem and then select the answer?
Engineering Student: Reads and selects the pair from following onsite pilot problem.

Select the pair of items in the right column that matches the pair of items in the left column.

      Broccoli → Green as 1) Oranges→ Sweet

                          2) Cherries → Red

                          3) Radish → Red

                          4) Cabbage → Leaves

Researcher: OK, now comes the part of expressing how you solved this problem. Can you tell me how you solved this problem?

Give the engineering student time to verbalize a response. If he or she has difficulty, use the following dialog to guide him or her through the self-explanatory process.

Potential Dialog: In the left column, I noticed a vegetable and color of that vegetable. In the right column there were vegetables and fruits with different qualities. The qualities were colors, taste and physical characteristics. The best match was Radish → Red since that pair used the same scheme depicted in the left column. In the test case, broccoli was a vegetable that is green. The radish is a red vegetable, so that was a match. All of the others did not match up in both categories.

Researcher: OK, do you have any questions about how to describe a problem solving process? You should note that this problem had one correct answer. In the following problem scenario there is no one correct answer. However, you will use the same methods to express yourself for the problem scenario as you did for this matching problem.

APPENDIX G

Problem Scenario

A desktop computer is not working in the office of an employee. You are tasked with repairing the computer to a fully functional condition.

_____

_____

_____

_____

_____

_____

_____

APPENDIX H

Problem Scenario and Self-Explanatory Interview Protocol

Researcher (Primary Investigator): OK, we are ready to go. The first part of this process is for you to read the problem scenario. This is followed by an interview where you describe what you would do to solve this problem. Very similar to what you did with the pilot problem scenario, except in this case, there are no answers to choose from. Instead you will describe the process you would implement to solve the problem.

Researcher: Here is the problem scenario response form. You need to read the scenario and then decide on a method or methods to solve the problem. It is extremely important to note that there is not one correct response or responses to solve this problem.

Researcher: There is space at the bottom of the page for you to write notes or diagrams to assist you in solving this problem. If the GE asks about the time frame to solve the problem, the researcher states he or she has 20 minutes.

Researcher: Do you have any questions about how to complete this problem scenario response form?

Engineering Student: Reads problem scenario.

Researcher: Great, can you now explain to me how you solved this problem?

Researcher: That concludes this work session. Thanks for your participation.

APPENDIX I

Parameters of Problem Scenario

1. Manager: The manager, who asked the engineer to fix the faulty computer, only knows that an employee says their computer is not working.

2. Computer User: The computer user is seeing a flickering of the screen when he or she uses email.

3. Computer User: This is an intermittent operation that has been occurring for the last two days.

4. Computer User: The flickering lasts about two minutes at which time the email system does not work- cannot receive or send emails. The email system appears frozen.

5. Information Technologist (IT): The user is using an Internet email system not a company email system.

6. Computer User: During the flickering time all other systems work on the computer. This includes other s/w applications that use the company LAN.

7. (IT): The Internet email system uses the company LAN to access the Internet provider.

8. Computer User: There are other computer users that are voicing the same issues with their email system. However, this important detail will not surface unless the graduating engineer asks the employee this question, that is, do you know of any other employees that are having this issue with their email system?

9. (e-mail provider): The email provider says their email server has been up and down for the last two days so they suspect this may be the cause of the flickering screens and frozen system when using email. The email provider says they have corrected the issues with the email server and suggest waiting a couple of days to see if the employee's email system functions properly. <This realization is essentially the solution to the problem. However, some participants may continue problem solving to confirm that there are not other reasons for this computer failure. Additionally, the graduating engineer may provide a follow-up plan to this solution, such as informing the manager so he or she can alert the IT Department about this company-wide problem.>

APPENDIX J

Coding Sheet

STEP	TOOLS: Physical/Non-Physical instruments that assist GE in DEFINING	DEFINING: Defining specific boundaries of problem- which component is causing, when problem should be completed, etc.	GOALS: ID:Identifying generic, problem solving targets-causes, solution, definition, etc.	HEURISTICS: Shortcut answers, based on personal experience that use probability, etc. Used to assist GE in DEFINING	REASON: Logically (Inductively or deductively) constructing a response. Used to assist GE in DEFINING.	Other Category such as confience or assistance	COMMENT
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							

APPENDIX K

Sample Coding Sheet

STEP	TOOLS: Physical/Non-Physical instruments that assist GE in DEFINING	DEFINING: Defining specific boundaries of problem- which component is causing, when problem should be completed, etc.	GOALS: ID:Identifying generic, problem solving targets-causes, solution, definition, etc.	HEURISTICS: Shortcut answers, based on personal experience that use probability, etc. Used to assist GE in DEFINING	REASON: Logically (Inductively or deductively) constructing a response. Used to assist GE in DEFINING.	Other Category such as confidence or assistance	COMMENT
1.	QUESTION	NETWORK	CAUSE	EXPERIENCE			
2.	ANTI-VIRAL	CONTACT ISP				ASSIST	
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							