AN ABSTRACT OF THE DISSERTATION OF

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Title: How Refrigeration, Heating, Ventilation, and Air Conditioning Service Technicians Learn From Troubleshooting

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The purpose of this study was to understand how refrigeration, heating, ventilation, and air conditioning (RHVAC) service technicians (techs) learned from troubleshooting. This understanding resulted in instructional and curricular strategies designed to help community colleges prepare vocational students to learn more effectively from informal workplace learning. RHVAC techs were studied because they increasingly learn their trade skills through a combination of formal schooling and informal workplace learning, though many still learn their trade almost

exclusively in the workplace. Even those with formal training require considerable workplace experience to become fully competent. Troubleshooting is a major job function for RHVAC service techs, and troubleshooting is widely acknowledged as an excellent learning opportunity. The critical incident technique was used to interview 10 recent graduates of a community college RHVAC training program about what and how they learned from troubleshooting.

A majority of the techs reported that they received little continuing education or structured on-the-job training, and relied on informal learning to acquire new skills. They learned from others (in person and via cellular phone networks), by reflection during and after troubleshooting, by using manuals, and by writing in log books or completing work orders. They learned cause and effect relationships resembling symptom-cause troubleshooting charts which they held in memory for use in subsequent troubleshooting. They also improved their use of electrical schematics and electrical test equipment. Pride of workmanship was a significant motivator for learning.

Suggestions for community colleges included: integrating informal workplace learning strategies into technical training, preparing students to learn using cell phone networks, modeling and promoting pride of workmanship, counseling students to consider potential formal and informal learning opportunities available from employers when seeking employment, teaching root cause analysis as a learning strategy, promoting learning from technical manuals, having students keep daily logbooks as a learning strategy, and emphasizing reading electrical schematics and using electrical test instruments in training for electrical troubleshooting. A troubleshooting process that incorporates informal learning in the workplace was detailed.

How Refrigeration, Heating, Ventilation, and Air Conditioning Service Technicians Learn From Troubleshooting

by
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APPROVED:

Major Professor, representing Education

Dean of the College of Education

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Denis F. H. Green, Author

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Preface

In 1988 a student asked me a question I could not answer. I was a vocational instructor teaching refrigeration, heating, ventilating, and air conditioning (RHVAC), electrical troubleshooting, and mechanical maintenance skills to adults who wanted to become industrial mechanics. I had come to understand that my students needed to learn many critical skills on the job to be successful in their careers, but mentioning this in class made my students noticeably uncomfortable. Their discomfort puzzled me until one student finally blurted out in frustration, “I know how to learn in school, but how do I learn on the job?”

I could not answer the question. This dissertation is part of my ongoing quest to answer that long ago question.

“I know how to learn in school, but how do I learn on the job?”

HOW REFRIGERATION, HEATING, VENTILATION, AND AIR CONDITIONING SERVICE TECHNICIANS LEARN FROM TROUBLESHOOTING

CHAPTER ONE: INTRODUCTION

Refrigeration, heating, ventilation, and air conditioning (RHVAC) service technicians (techs) increasingly learn their trade skills through a combination of formal schooling and informal workplace learning, though many still learn their trade almost exclusively in the workplace. Even those with formal training require considerable workplace experience to become fully competent. In addition, troubleshooting is a major job function for RHVAC service techs (Bureau of Labor Statistics, 2003a, 2003b, 2004), and troubleshooting is acknowledged as an excellent opportunity for learning (Brockman, 2004). Given the importance of troubleshooting to RHVAC techs and its potency as a learning opportunity, a descriptive, qualitative study was conducted to explore how 10 recent graduates of a community college RHVAC training program learned informally from troubleshooting technical problems they encountered on the job.

This chapter is organized under the following headings: RHVAC service techs’ knowledge and skills, research background, problem statement and research questions, significance of the study, definitions of terms, and summary.

RHVAC Service Techs’ Knowledge and Skills

The importance of troubleshooting to RHVAC service techs was described in a task analysis of their work created for the Standard Occupational Classification System (SOC). The SOC compiled detailed descriptions for two RHVAC occupations, one of which focuses on service techs: Heating and Air Conditioning Mechanics 49-9021.01. The report ranked the skills needed for this occupation based on surveys of employers.

Troubleshooting was ranked first, repairing was ranked second, active learning (on the job) was ranked eighth, and using effective learning strategies was ranked twelfth out of 35 skills (Bureau of Labor Statistics, 2003a). To gain these skills,

> Employees in these occupations usually need one or two years of training involving both on-the-job experience and informal training with experienced workers... (and) training

> in vocational schools, related on-the-job experience, or an associate’s degree. (Bureau of Labor Statistics, 2003b, p. 4)

RHVAC techs usually specialize in installation or service work. Service techs specialize in troubleshooting and maintaining heating and cooling equipment rather than installing new equipment. A formal description of RHVAC service tech work was found in the *Occupational Outlook Handbook 2004-05 Edition* under the job classification: Heating, Air-Conditioning, and Refrigeration Mechanics and Installers (Bureau of Labor Statistics, 2004).

> Heating, air-conditioning, and refrigeration systems consist of many mechanical, electrical, and electronic components, such as motors, compressors, pumps, fans, ducts, pipes, thermostats, and switches.... Technicians must be able to maintain, diagnose, and correct problems throughout the entire system. To do this, they adjust system controls to recommended settings and test the performance of the entire system using special tools and test equipment.
>
> Technicians often specialize in either installation or maintenance and repair, although they are trained to do both. Some specialize in one type of equipment - for example, oil burners, solar panels, or commercial refrigerators. Technicians may work for large or small contracting companies or directly for a manufacturer or wholesaler. Those working for smaller operations tend to do both installation and

> servicing, and work with heating, cooling, and refrigeration equipment. Service contracts which involve heating, air-conditioning, and refrigeration work for particular customers on a regular basis are becoming more common. (Bureau of Labor Statistics, 2004, p. 1-2)
>
> Heating, air-conditioning, and refrigeration mechanics and installers held about 249,000 jobs in 2002; almost half worked for cooling and heating contractors. The remainder was employed in a variety of industries throughout the country, reflecting a widespread dependence on climate-control systems. Some worked for fuel oil dealers, refrigeration and air-conditioning service and repair shops, schools, and stores that sell heating and air-conditioning systems. Local governments, the Federal Government, hospitals, office buildings, and other organizations that operate large air-conditioning, refrigeration, or heating systems employed others. About 15 percent of mechanics and installers were self-employed.
>
> Because of the increasing sophistication of heating, air-conditioning, and refrigeration systems, employers prefer to hire those with technical school or apprenticeship training. Many mechanics and installers, however, still learn the trade informally on the job. (Bureau of Labor Statistics, 2004 p. 3)

RHVAC technicians are skilled workers whose job prospects “are expected to grow faster than the average for all occupations through the year 2012” (Bureau of Labor Statistics, 2004, p. 5). In 2001, the hourly wage in Oregon ranged from $13.35 to $21.04 (Haynes, 2001).

In 2004, the Bureau of Labor Statistics generated wage information based on national research.

> Median hourly earnings of heating, air-conditioning, and refrigeration mechanics and installers were $16.78 in 2002. The middle 50 percent earned between $12.95 and $21.37 an hour. The lowest 10 percent earned less than $10.34, and the top 10 percent earned more than $26.20. (Bureau of Labor Statistics, 2004, p. 5)

In summary, the RHVAC service trade rewards effective troubleshooters with middle-class, family-wage jobs. On-the-job learning is an important activity, and the need for skilled RHVAC techs is increasing due to rapid technological advances, especially those relating to energy efficiency and environmental concerns.

Research Background

The research into informal learning is replete with estimates of the prevalence of informal workplace learning. For example, from May to October, 1995, the United States Bureau of Labor Statistics estimated that 70% of all workplace learning was informal (Frazis, Gittleman, Horrigan, & Joyce, 1998). In this study of firms with more than 50 employees, each employee spent 31 hours during the study timeframe in informal training and learning, compared to 11 hours for formal training. Seventy percent of the employees received formal training while 96% were involved in informal learning. The cost of employer-provided formal training during this time frame was estimated at $13 billion for employee time spent in training, while the time spent in informal learning cost employers an estimated $24 billion (Frazis et al., 1998).

Marsick and Watkins (1990) estimated that 83% of workplace learning was informal or incidental (learning occurring as a byproduct of other workplace activities). To produce this estimate, they studied managers, professionals, and other white collar workers but did not study blue collar technicians. A large study of a variety of workers (Education Development Center, Inc., 1998) concluded that “informal learning is the fundamental way that workers develop competence, and acquire new skills and information” (p. 9). Many types of workers were included in the study, but the results were generalized, not reported in relation to specific types of workers. The study concluded that problem solving during the execution of one’s job was an excellent learning opportunity, but it did not identify different types of problem solving like technical troubleshooting. In another large scale study, Livingston (2001) estimated that two-thirds of Canadian workers or those about to enter the workforce “averaged about six hours a week in informal learning related to their current or prospective future employment” (p. 9). Industrial and service workers averaged 17 hours per week in informal learning, the same amount as corporate executives but more than managers and professional workers.

These research findings provided estimates of the general prevalence of informal workplace learning, but the study of how workers learn in specific occupations is often found in doctoral dissertations. For example, Maben-Crouch (1997) studied human resource personnel, Rossi (1995) studied nurses’ informal learning, and Wientraub (1998) studied sales personnel. Brockman (2004) studied the workplace learning of machine operators, the only recent study of blue collar workers.

Because of the preponderance of research into white collar work, Maben-Crouch (1997) called for research into other types of work, “But what about some technically-oriented professions? Would learning within work be as evident in these professions? What of blue-collar workers, or pink collar workers, those doing secretarial work” (p.150)? In addition, Willis (2000) suggested that the workplace learning of front-line workers should be studied, and Livingston (2001) suggested that most research on informal learning had revealed little about the learning strategies used by workers. Given this need for additional research, it was decided to study the learning of RHVAC service technicians and to focus on learning from troubleshooting because of its importance to these workers.

Problem Statement and Research Questions

The purpose of this study was to understand the informal learning of RHVAC service techs in order to answer this driving question: How can community colleges prepare technical students to learn more effectively in the workplace? It was assumed that the bulk of this workplace learning would be informal and that troubleshooting was an effective learning opportunity, so four research questions were generated to guide data collection and analysis.

1. How did the RHVAC service techs’ working conditions and the cognitive context of their jobs shape their learning?

The cognitive context is any aspect of the techs’ work that impacted their learning. To preserve their anonymity and to prevent harm to the techs, working conditions were described in general terms, and some questions were avoided. For example, the techs were not asked about the level of employer support for continuing education.

2. What learning strategies did the techs use to learn from troubleshooting?

The focus was on informal workplace learning, not formal learning, and not on troubleshooting methods.

3. What did the techs learn from troubleshooting?

General information was solicited, not specific technical processes or skills. For example they were not asked about the use of specific electrical test equipment, but were asked about the importance of general electrical troubleshooting skills.

4. When did the techs' learning occur, during troubleshooting, or as a result of later reflection?

The troubleshooting problem was deemed to be over when the repair had been made and the cause of the problem was confirmed.

Significance of the Study

Since learning on the job is so important to RHVAC techs, one would expect that popular RHVAC textbooks (Althouse, Turnquest, & Bracciano, 2003; Whitman, Johnson, & Tomczyck, 2005) and RHVAC training videos (Carrier Corporation, 1992; Johnson, 2000) would present information about workplace learning. This was not the case; only one video series mentioned the need for lifelong learning, and then only in passing (Johnson, 2000).

Since troubleshooting is a potentially excellent learning opportunity, one would expect that these same RHVAC texts and video series would present detailed troubleshooting methodologies that incorporate informal learning strategies. Again, this was not the case, and, while both video series presented a general troubleshooting method, neither mentioned learning from troubleshooting. This study is based on the premise that how these techs learned informally from troubleshooting would suggest learning and teaching strategies useful to instructors preparing technical students to learn more efficiently in the workplace.

Given the prevalence and importance of informal workplace learning, and, factoring in the tremendous cost of working hours spent in informal learning (Frazis et al., 1998), improving the effectiveness of workplace learners would have enormous, positive economic implications. The importance of effective learning to employers is supported by the inclusion of the skill of “Knowing how to learn” in the workplace as a prominent skill listed in the influential Secretary’s Commission of Achieving Necessary Skills (SCANS) report (1991). In addition, Willis (2000) suggested that the ability and willingness to learn might become a prerequisite for employment, since even well-educated new hires usually face a steep learning curve to become productive. Since much workplace learning is likely to be informal, community college graduates of technical training programs should enter the workforce prepared to learn in the varied situations they will encounter at work, thus helping them to succeed in the workplace.

Definitions of Terms

Formal and Informal Learning:

> Formal learning is typically institutionally sponsored, classroom-based, and highly structured. Informal learning, a category that includes incidental learning, may occur in institutions, but is not typically classroom-based or highly structured, and control of learning rests primarily in the hands of the learner. (Marsick & Watkins, 1990, p. 12)

> It (informal learning) provides a simple contrast to formal learning or training that suggest greater flexibility or freedom for learners. It recognizes the social significance of learning from other people, but implies greater scope for individual

> agency than socialization. It draws attention to the learning that takes place in the spaces surrounding activities and events with a more overt formal purpose, and takes place in a much wider variety of settings than formal education or training. It can also be considered as a complementary partner to learning from experience, which is usually construed more in terms of personal than interpersonal learning. (Eraut, 2004, p. 247)

> Informal learning is any activity involving the pursuit of understanding, knowledge or skill which occurs outside the curricula of educational institutions, or the courses or workshops offered by educational or social agencies. The basic terms of informal learning (e.g., objectives, content, means and processes of acquisition, duration, evaluation of outcomes, applications) are determined by the individuals and groups that choose to engage in it. Informal learning is undertaken on one's own, either individually or collectively, without externally imposed criteria or the presence of an institutionally authorized instructor. (Livingston, 2000, p. 2)

The differences between formal and informal learning can be envisioned as points along a continuum as illustrated in Figure 1-1. Some situations might be clearly formal or informal, while others might not be so easily defined, and some might integrate formal and informal learning. For example, a worker might attend a formal semiformal training program on how to operate a new computer program, then actually informally learn to use the program by applying what was learned while preparing a business report in the workplace.

Figure 1-1

Formal – Informal Learning Continuum

FORMAL	SEMIFORMAL	INFORMAL
Structured	Variable structure	Less structured
Testing	Optional testing	No testing
Teachers	Presenters	No teachers
Curriculum	Outline	No curriculum
Schools	Museums, clubs, structured on the job training	Any setting

0....1.....2.....4.....5.....6.....7.....8.....9....10

Informal Workplace Learning:

“Informal workplace learning is learning in which the learning process is not determined by the organization” (Education Development Center Inc., 1998, p. 9).

Marsick, Volpe, and Watkins (1999) described informal workplace learning in the following passage,

> It is integrated with daily routines. It is triggered by an internal or external jolt. It is not highly conscious. It is haphazard and influenced by chance. It is an inductive process of reflection and action. It is linked to the learning of others. (p. 5)

Constructivist Learning:

"In this process, the learner actively constructs information via problem solving or creative thinking" (Education Development Center Inc., 1998, p. 32).

"The essential core of constructivism is that learners actively construct their own knowledge and meaning from their experience" (Doolittle & Camp, 1999, p. 5).

Incidental Learning:

"...learning that occurs as a byproduct of another activity, such as a task or social interaction" (Education Development Center Inc., 1998, p. 33).

Workplace Learning Strategies:

"Selecting and using training/instructional methods and procedures appropriate for the situation when learning or teaching new things" (Bureau of Labor Statistics, 2003a, p. 4).

Reflection:

"Reflection is defined as the process of actively thinking about a problem, either in the midst of the problem or afterwards, to produce learning" (Maben-Crouch, 1997, p. 132).

"Reflection is an activity in which people recapture their experience, think about it, mull it over and evaluate it" (Brockman, 2004, p. 119).

Troubleshooting:

"Determining the causes of operating errors and deciding what to do about it" (Bureau of Labor Statistics, 2003a, p. 5).

> Troubleshooting is the systematic elimination of various parts of a system, circuit, or process to locate a malfunctioning part. The ability to troubleshoot effectively is a skill that combines technical expertise and logical and creative thought processes. The ability to troubleshoot is improved through experience with troubleshooting and the evaluation of the causes and solutions of problems. (Green & Gosse, 2000, p. 323)

Summary

Successful RHVAC service techs must be able to troubleshoot effectively and learn on the job. Troubleshooting is an excellent learning opportunity as well as being a major activity for service techs, but popular RHVAC texts and video series do not link learning and troubleshooting. Informal learning is widely practiced in many workplaces and has significant economic impact for employers. RHVAC techs are a type of blue collar worker not frequently studied by informal workplace learning researchers. Therefore, it was decided to conduct a descriptive, qualitative study to understand how 10 RHVAC graduates of a community college RHVAC training program learned informally from troubleshooting technical problems they encountered on the job. The driving question that guided this study was: How can community college instructors of technical programs prepare their students to learn more effectively in the workplace?

CHAPTER TWO: REVIEW OF LITERATURE

This literature review identifies and discusses research and technical writing that proved helpful in understanding the workplace learning of the RHVAC service techs interviewed for this study. The importance of informal learning and troubleshooting to RHVAC techs, and the lack of research into the informal learning of blue collar workers provided a foundation for the study. This chapter is organized around the study's four research questions.

Question One: How did the techs' working conditions and the cognitive context of their jobs shape their learning?

The cognitive context encompasses the numerous variables and attributes that impact and influence a learner in a defined situation. The defined situation in this study was troubleshooting RHVAC equipment in the workplace, outside of school. Learning outside of school creates a learning context that fosters different opportunities for, and modes of learning than does studying in school. What then are some of the difference between learning in and out of school?

Learning In and Out of School

In 1987, Lauren Resnick published a frequently cited article, *Learning In and Out of School*, in which she postulated four critical differences between learning in and out of school: (1) individual cognition in school versus shared cognition out of school, (2) pure mentation in school versus tool manipulation out of school, (3) symbol manipulation in school versus contextualized reasoning outside of school, and (4) generalized learning in school versus situation specific competencies outside of school.

Concerning shared cognition, Resnick argued that knowledge is distributed throughout a learning situation and resides in the participants, the tools available, and the artifacts of the situation. Tools shape learning, and they incorporate the knowledge and skills of those who invented and built the tools. This allows a worker to use a tool without the necessity of understanding how the tool works. For example, a digital, electrical testing meter automatically executes complicated mathematical calculations that provide precise measurements of electrical values. The meter user must analyze the results, especially when troubleshooting, but the mathematics has been accomplished by the test equipment. Troubleshooters can still learn from using the meter, but they learn about analyzing electrical circuits, not the mathematics of electrical laws.

Resnick wrote this about contextual reasoning, “Mental activities make sense in terms of their results in a specific circumstance; actions are grounded in the logic of immediate situations” (p. 15). As a result, people develop situation specific competencies that might work well in that situation but might not transfer to other situations.

While Resnick described four differences between learning in and out of school, Wagner (1992) differentiated between learning in and out of school in regards to the types of problems found in each context. Academic problems occur in school; practical problems occur outside of school and can result in the development of practical intelligence. Table 2-1 presents Wagner's distinctions between academic and practical problems. Wagner sees academic problems as being structured by the controlled, formal learning situation which limits the types of variables allowed. Practical problems, which take place in unregulated situations, have a more turbulent structure because they are influenced by numerous variables.

Table 2-1

Characteristics of Academic and Practical Problems

Academic Problems	Practical Problems
Well-documented	Ill-defined
Formulated by others	Unformulated
Complete information provided	Incomplete information provided
One or at most several methods for obtaining the solution	Multiple methods for obtaining the solution
Disembedded from ordinary experience	Grounded in ordinary experience
Single correct solution	No one correct solution

Source: Wagner, (1992), p. 110-111

Sternberg (Sternberg, Forsythe, & Hedlund, 2000; Sternberg & Grigorenko, 2002) built on this understanding of practical problems to postulate a triarchic model of human intelligence that blends analytical thinking, creative thinking driven by experience, and the possibilities of the context in which the thinking is taking place. It is the opportune blending of analytical, creative, and practical thinking that leads to successful thinking in the workplace, and much of this practical knowledge and skill is developed through informal learning in the workplace.

An often cited study of informal workplace learning was completed in 1998 by the Education Development Center, Inc. (EDC). The EDC studied informal workplace learning in three large (> 1000 employees) and four small (< 1000 employees) companies using a variety of quantitative and qualitative methods. The study included a comparison between formal and informal learning in a table which is reproduced in Table 2-2.

Table 2-2

Comparison Between Formal and Informal Learning

Formal Learning	Informal Learning
Variable relevance to worker needs	Extremely relevant to worker needs
Communicated information is constant across learners	Communicated information is variable across learners
Variable gap between current and target knowledge	Small gap between current and target knowledge
Instructional	Constructivist
Variable temporal gap to application	Immediately applicable
Represents core “organizationally beneficial” knowledge	Core and other knowledge
Scheduled	Arises spontaneously
Occurs in a setting other than that where the knowledge is used	Occurs in the setting where the knowledge is used
Has specific outcomes	With/without specified outcomes
With a “trainer” who is accountable for results	With/without reported results

Source: Education Development Center, (1998), p. 177

The differences in controlling contextual variables are evident. For example, formal learning is scheduled while informal learning arises spontaneously as the need for new learning is realized. The variability of outcomes is controlled by the curriculum specifications, and success is determined by a trainer who is accountable for the students' achieving the specified outcomes. Outcomes are usually less defined in the workplace and there is no teacher to evaluate and report results. Students receive a specific grade in formal education; workplace learners receive the unrecorded equivalent of the nebulous satisfactory or unsatisfactory grade based on how well the task was completed.

Of the comparisons between formal and informal learning, the assertion that informal workplace learning is constructivist while formal learning is instructional is a critical distinction. The constructivist notion of the personal creation of knowledge within the social context of learning (Brown, Collins, & Duguid, 1989; Doolittle & Camp, 1999) proved a key to understanding the techs' learning.

A key factor in the differences between learning in and out of school when training troubleshooters is the ability to control variables; variables are relatively controlled in school, but not out of school. The RHVAC program from which the techs' graduated presented them with problems of limited complexity. The variables were constrained by limited resources, limited time for learning, and the need to assign grades based on observable standards.

For example, joining copper pipe through brazing with welding torches is an important skill for RHVAC techs. In school the techs practiced brazing using relatively inexpensive pipe and fittings, under good lighting conditions, and using vices to support the pipe during brazing. In the workplace, RHVAC techs must occasionally install expensive valves that are sensitive to overheating, and do so in a dark, confined space that includes many variables not replicable in a lab setting, such as an irate customer.

In essence, schools teach by filtering, simplifying, and structuring experience so that it can be understood and learned by students. Hence the good lighting and supports for the piping when teaching brazing. In the workplace though, experience is unfiltered, complex, and unstructured by some accrediting authority. Therefore workers are often learning from their direct experience of the context and variables of the situation, experiential learning.

Experiential Learning

David Kolb’s (Kolb, 1984; Malinen, 2000) conception of learning from experience is summarized by his four stage cycle of learning that begins with a concrete experience, which is then subject to reflection. After reflection, the experience is conceptualized in relation to other experiences and is used during active experimentation that, in turn, influences other experiences. Kolb’s model is simplistic (Beard & Wilson, 2002) but illustrative in that it links reflection and experimentation (doing) as part of the learning process. In reality, an experience seldom occurs in isolation but as one of many in an ongoing parade of experiences. An individual experience is influential because of its unique characteristics, but even everyday experiences shape an individual by their steady accumulation, until he or she is seldom able to recall what specific incidents shaped a belief or caused certain behaviors (Eraut, 2004).

This is likely what John Dewey had in mind when he expressed the principle of *continuity* regarding learning from experience.

> The principle of continuity means that every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after. (Dewey, 1963, p. 27)

Dewey’s second important principle of learning from experience, *interaction*, is described as the interaction between an individual and his or her environment. Dewey envisions learning as a vibrant, practical application of the scientific method in which people invent then test hypotheses in everyday life (Morris, 1970).

In contrast to Kolb’s four-step learning model, Jarvis (1987) envisioned a nine-step, experiential learning process with the learner embedded within a social situation. A person could experience a situation that might leave him or her little changed and that resulted in little or no learning. When learning did occur from a particular experience, the process would involve both non reflective and reflective mental practices. The Jarvis model includes memorization, practice, evaluation, reasoning, and reflecting. These reflective practices can include problem solving and experimentation.

In addition to the rational processes involved in learning from experience, Boud, Keogh, and Walker (1996) highlighted the role of emotions and personal feelings during learning. Learning from experience involves thinking about the experience and dealing with any emotions evoked by the experience, then using the experience as a basis for future learning. Learners relate the new experience to what they already know or believe and must decide on the validity of the resulting knowledge, and then incorporate it into their knowledge structures. This occurs while being influenced, often unconsciously, by feelings and emotions engendered by the new experience, as well as the ongoing flow of additional experiences.

Brockman (2004) in her study of machine operators suggested that learning from experience took the form of a negotiation.

> ...this study suggests that workers do not learn from experience in a sequential, cyclical way. This provides evidence that learning from experience seems more a process of negotiation in which thinking, reflecting, experiencing and action are different aspects of the same process. It is through negotiation with oneself and in collaboration with others that may actually form the basis of learning. (p. 141)

The salient characteristics of experiential learning that relate to this study are (1) the importance of experience to learning, (2) the importance of reflection (intellectual and emotional) to learning, the continuous influence of accumulated experiences and, (3) the interactive dynamic between the learner and his or her environment. This interaction between the learner and his or her situation is discussed in the literature on situated learning.

Situated Learning

Situated learning theory focuses on the assumption that learning is context-dependent.

> The activity in which knowledge is developed and deployed, it is now argued, is not separable from or ancillary to learning and cognition. Nor is it neutral. Rather, it is an integral part of what is learned. Situation might be said to co-produce knowledge through activity. (Brown, Collins, & Duguid, 1989, p. 33)

This situating of learning includes not only the immediate situation, but the history, belief systems, and social structures that impact the learners' understanding of the situation (Bredo, 1994; Lave & Wenger, 1991). Lemke (1997) uses the language of living systems to describe the multidimensional interaction between learners and the situated "socioecology" in which they are acting.

Though situated cognition stresses the social nature of learning, this does not necessarily mean that all learning is group learning. The social nature of situated learning is not limited to the "head count" when learning occurs. It relates to the social structures and norms found in a situation.

> Activities embrace the norms of social groups.... Saying that activities are social means that norms constrain how we dress and talk, what constitutes being “on task”, what constitutes an interruption etc.... Saying that activities are social has nothing to do per whether the activity is done alone or with other people.... Action is situated because it is constrained by a person’s understanding of his or her “place” in a social process. (Clancy, 1995, p. 2)

Regardless of the number of learners interacting in a particular learning opportunity, situated learning is, by definition, somewhat narrow, perhaps even parochial because of the limiting influence of situation. The question is, to what extent is knowledge or skill learned in one situation applicable to another situation? This localized aspect of knowledge creation has led situated learning theorists to question the transferability of knowledge and skills (Lave & Wenger, 1991). It is postulated that a skill learned in one situation would transfer best to similar situations but little or not at all to markedly different situations.

Another prominent feature of situated learning is the concept of communities of practice which is related to the social nature of learning (Wenger, 1998). Becoming a member of a community of practice determines, amongst other things, what and how one would learn in specific situations. Learning enables the person to participate effectively in the social structures through which he or she moves (Bredo, 1994), and this includes the social structure of a particular workplace. In regards to workplace learning, the workplace community sets the standards and curriculum for its members.

For most RHVAC techs, success as a troubleshooter is a major prerequisite for membership in the RHVAC service technician community of practice. Formal certifications are seen as indicators of competence not guarantees of skill. It is proven expertise that entitles one to be called a “good troubleshooter”, and that appellation comes from one’s peers and employers, not from a certification.

Understanding the importance of the social aspect of learning is necessary to understanding the learning of workers like RHVAC techs who often work independently, especially when troubleshooting. While working alone these types of workers are aware of the standards for success created by the community of practitioners doing the same or similar work, and that is how they judge the success of their own learning.

Given the focus in this study on troubleshooting as a learning opportunity, a review of the literature on troubleshooting was undertaken, beginning with the distinction between well and ill-defined problems.

Well-defined and Ill-defined Problems

In this study the key contextual factor influencing learning was troubleshooting, so it was necessary to understand the troubleshooting process, especially as it related to learning. The most common troubleshooting problems encountered by RHVAC technicians are “hot and cold calls”; the space being heated or cooled (the conditioned space) is too hot or too cold. Returning the conditioned space to the correct temperature is the goal of the troubleshooting. These types of problems are generally well-defined. “Well-defined problems have a clear goal, often one correct answer, and rules or known ways of proceeding that will generate an answer” (Cross, 1996, p. 11). Flesher (1993) used well-structured when referring to well-defined problems and writes that, “Well-structured implies a known problem space, a mental representation of the area in which the fault exists, with clear criteria for testing solutions” (p. 23). Flesher added that many technical problems are not ill-defined in that there is a definite cause and result and a proven algorithm to facilitate solving the problem. Solving these types of RHVAC problems is usually achieved by using logically organized troubleshooting charts or guides. The problem is solved when the conditioned space is at its correct temperature, a clear goal. Though well-defined, Flesher (1993) acknowledged that these types of problems can be difficult to solve.

In contrast to well-defined problems, Newell and Simon (1972) asserted that ill-structured problems, a synonym for ill-defined problems, have one or more of three conditions: (1) no well-defined algorithm for solving the problem, (2) a poorly defined goal structure for the solution and, (3) vague criteria for evaluating a solution.

Well-defined and ill-defined problems can be understood from two perspectives: from the difficulty of the methodology required to solve a problem, and from the troubleshooter’s understanding of a problem. One is a matter of technical skills, the other a combination of technical skill, knowledge, and understanding of system operation, often gained through experience in working on equipment. Johnson (1995) focused on the method used to solve problems and described well-defined problems as those that can be solved by following a standard procedure like a printed troubleshooting guide. An ill-defined problem is more difficult to solve because the procedure is not known by the troubleshooter or a new procedure might be needed to solve the problem. If the method used to solve the problem is difficult to understand and use, even an expert might consider a problem ill-defined; a novice might not be able to solve the problem at all. Therefore, the skill-level and experience of the troubleshooter must be considered when deciding if a problem is well or ill-defined. Relatively commonplace technical problems might seem ill-defined to a novice troubleshooter but well-defined to an expert because of the expert’s greater experience. Lovin (1999) articulated this concept clearly when he discussed routine and nonroutine problems faced by paramedics. “An experience is nonroutine for a paramedic when he or she does not have sufficient skills or knowledge to address the situation” (p. 27).

Perhaps an example from the RHVAC trade will help to illuminate the differences between ill and well-defined problems. How to heat a house is an ill-defined problem since many factors can contribute to keeping the house warm, including who defines warmth. For example, older people often require higher temperatures to feel comfortable. The home owner can heat with wood, electric heat, a gas or oil furnace, or perhaps a heat pump if he or she wants air conditioning in the summer and heating in the winter. The owner could also upgrade the house insulation and install efficient windows but not change the heating system. The best choice of heating system will take into account many factors: the cost and availability (present and future) of the fuel, ethical and environmental concerns, and serviceability. This is an ill-defined problem, but, once the heating system is installed, waking up to a cold house with the furnace not working is a well-defined problem. The tech who comes to solve the problem will work through a series of procedures used to isolate and locate the cause of the problem. Generally the solution for the problem is well-defined: replace a defective component, or correct an operational parameter (Althouse, Turnquest, & Bracciano, 2003; Green & Gosse, 2000; Whitman, Johnson, & Tomczyck, 2005). If the heating system is old or badly damaged and is costly to repair, the owner confronts an ill-defined problem concerning a repair or replace decision (Green & Gosse, 2000).

Given the well-defined nature of most RHVAC service problems, RHVAC techs can usually follow a well-defined algorithm to solve a system problem. The difficulty for new techs is in recognizing the problem and its likely causes, and organizing the troubleshooting process. RHVAC techs are usually trained to use a logical troubleshooting process applicable to most RHVAC troubleshooting problems. An overview of RHVAC and technical troubleshooting processes is presented in the next section.

Troubleshooting Processes

According to the Air Conditioning and Refrigeration Institute (1995), RHVAC students should "Develop a systematic approach to diagnose mechanical or electrical problems" (p. 105). The National Skill Standards for the Heating, Air Conditioning, and Refrigeration Technician (V-TECHS, 1996) frequently listed troubleshooting as a crucial skill, using this standardized language to describe various troubleshooting tasks.

> Diagnostic procedures must be systematic, comprehensive, complete, and follow manufacturer's diagnostic charts, when available. Electrical characteristics, pressures, and temperatures or other diagnostic characteristics outside of the refrigeration system's normal operating parameters must be noted. Blower fans, thermostats, filters, and other system components and safety devices or system components operating outside of manufacturer's specifications must be identified and a plan for repair must be formulated. (p. 41)

The main RHVAC text used in the RHVAC program from which the techs graduated focused on technical, symptom-cause-repair skills, but did not provide a detailed RHVAC troubleshooting process or methodology (Whitman, Johnson, & Tomczyck, 2005). Another popular

RHVAC text, *Modern Refrigeration and Air Conditioning*, (Althouse, Turnquest, & Bracciano, 2003), suggested this process for RHVAC troubleshooting: “(1) Obtain a description of the problem from the owner. (2) From the problem description, determine the possible problem. (3) Identify a specific remedy for the problem” (p. 1086). Techs were then directed to use troubleshooting charts that are organized into problem, possible cause, and remedy columns. In addition to textbooks, two video series were used in the program and one presented a seven-step process (Johnson, 2000).

1. Verify complaint
2. Gather information
3. Visual inspection
4. Solve any obvious problem
5. Isolate root causes if there are no obvious problems
6. Correct problem
7. Complete the call

The program narrator stated, almost in passing, that RHVAC techs will have to become lifelong learners, but maked no direct suggestion that RHVAC techs should learn from troubleshooting (Johnson, 2000).

Though troubleshooting is an important skill for RHVAC techs, there is little detailed guidance as to the process of troubleshooting in most RHVAC texts and *no indication* of how learning might be incorporated into troubleshooting. In light of this deficiency, more detailed methodologies in the technical troubleshooting literature were studied.

Kleifgen and Frenz-Belkin (1996) conducted an observational study of two workers troubleshooting problems with production equipment at a computer board manufacturing plant. They reported a four-step troubleshooting process:

1. Notice the problem
2. Hypothesize
3. Test hypothesis
4. Find optimal solution

Hill and Wicklein (1999) used factor analysis to reduce Wicklein’s 27 mental processes used in technical troubleshooting to five mental constructs, “researching the problem, searching for solutions, innovation, analyzing data, and evaluating results" (p. 8). Hill and Wicklein represented their methodology as linear while admitting that the steps might be used in nonlinear fashion.

An article offering advice to medical equipment troubleshooters presented a six-step process for troubleshooting (Yixiong, 1997)

1. Analyze symptoms of failure
2. Localize trouble to module
3. Isolate trouble to a circuit
4. Locate the specific trouble with a circuit
5. Identify and change defective components
6. Retest the devise completely

In a technical book entitled *Troubleshooting: A Technician's Guide*, Mostia (2000) proposed a seven step process.

1. Define the problem.
2. Collect information regarding the problem.
3. Analyze the information.
4. Is there sufficient information? If not collect more information, if there is, continue.
5. Propose a solution.

6. Test proposed solution. If the solution fails, return to analyzing the information. If the solution succeeds, continue.
7. Repair the problem.

Johnson (1989) created a model for technical troubleshooting based on his review of relevant literature which he then validated through his own research. His model divided technical troubleshooting into two distinct phases, hypothesis generation and hypothesis evaluation. The hypothesis generation phase involved acquiring and interpreting information to generate hypotheses as to the cause of the problem. During the hypothesis evaluation phase, the hypotheses are evaluated until the cause of the problem is located. Johnson’s process is iterative in that steps can be repeated until a viable hypothesis leads to a solution. Troubleshooters utilize their internal resources, declarative and procedural knowledge, and external aids like manuals and sensory evaluations during this process.

My own conception of troubleshooting prior to completing this research had changed from a 16 step process (Green, 1990) to a four step process that included many detailed sub-steps but little detail on learning from troubleshooting. The four parts of that process are (1) investigating problems, (2) isolating problems, (3) remedying problems, and (4) documenting problems (Green & Gosse, 2000). It is during the documenting of problems that improving one’s troubleshooting could occur through reflection and through completing specialized reports that detailed the problem, its solution, and any procedures for preventing similar problems.

Only one the texts used in the techs’ RHVAC training even implied that troubleshooting could be a useful learning opportunity. Accordingly, none provided any suggestions about what learning strategies could be incorporated into troubleshooting. None of the standard troubleshooting processes intimated that troubleshooting was an effective learning opportunity. Naturally, they did not discuss applying learning strategies to troubleshooting. Identifying informal workplace learning strategies that are used in troubleshooting was the goal of question two.

Question Two: What learning strategies did the techs use to learn from troubleshooting?

Informal Workplace Learning Strategies

Gehring (1997) offered this general description of learning strategies.

> The techniques and skills that an individual elects to use in order to accomplish a specific learning task. Such strategies vary by individual and by learning objective. Often they are so customary to learners that they are given little thought; at other times much deliberation occurs before a learning strategy is selected for a specific learning task. (p. 23)

Three dissertations and one corporate study proved particularly helpful in understanding the informal learning strategies used in some workplaces. Cheryl Maben-Crouch (1997) conducted a qualitative study of five human resource development (HRD) workers in a large information processing firm. She found that reflection was important to her subjects’ learning. “Reflection is defined as the process of actively thinking about a problem, either in the midst of the problem or afterwards, to produce learning” (p. 132). Reflection aided in making sense of new learning or in finding a way to apply new learning to a specific task. Several subjects also reported reflection prior to commencing a task. She found evidence that nonroutine problems were important learning opportunities, “Nonroutine problems were also called problem solving activities or challenges” (p. 131). Lower level learning was associated with routine problems while higher levels of learning occurred with nonroutine problems. Maben-Crouch also found evidence of learning through collaborative problem solving. Dialog was an important learning strategy, and one subject described impromptu gatherings in or around worker cubicles that she called “cube action”; work-related interaction that was “necessary for effective and motivated learning” (p. 136).

In addition to “office work” occupations the medical and nursing professions have been studied frequently by informal learning researchers. Linda Rossi (1996) produced a qualitative dissertation, *How Nurses Gain Clinical Expertise through Informal Learning in the Workplace*, in which she studied 23 advanced nurses in a mid-sized urban hospital. Rossi found that the nurses learned alone and from others like supervisors, peers, subordinates, physicians, and patients. She reported these learning strategies: trial and error, observation, role modeling, coaching, preceptoring, and mentoring. She found that trial and error learning was more prominent in the early part of the nurses' careers but became less prominent as they gained expertise.

A recent study that dealt directly with blue collar workers was a dissertation by Julie Brockman (2004), *Problem Solving of Machine Operators within the Context of Everyday Work: Learning through Relationship and Community*. Brockman studied workers who routinely worked in groups, or at least with other workers nearby. She found that, "learning is perceived by machine operators to be intimately bound up with problem solving" (p. 68). They believed they were learning constantly and did not want that to change. They learned by asking for help, and from helping each other, from working through problems, from manuals, from observing, from feedback and recognition, and from trial and error. Brockman stated,

> In brief, the findings suggest that learning is characterized by a dialogic relationship between the machine operator, the task and the machine. Furthermore this dialogical relationship occurs within a community of practice”. (p. 112)

A large study conducted by The Education Development Center, Inc. (1998) surveyed a broad range of workers, both managerial and front line, but did not identify the learning strategies used by particular types of workers. The findings included a ranked list of the learning strategies used by all the workers studied. Using that list as a foundation, Table 2-3 was created to summarize the informal workplace learning strategies mentioned in a variety of studies. The strategies are listed alphabetically, not by ranked order, and the studies consulted are cited. These strategies are written as verbs, something the learner does as opposed to a situation in which learning might take place, a learning opportunity. For example, in one study, shift change was listed as an opportunity for learning. During shift change workers might discuss problems and study a log book, and these were learning

Table 2-3

Informal Workplace Learning Strategies

Informal Learning Strategies
Answering questions
Asking for help
Cooperative problem solving
Daydreaming
Discussion
Exploration
Giving and receiving feedback
Instructing others
Learning by doing/experimenting
Listening
Networking
Observing supervisors and/or peers
Practicing
Problem solving (troubleshooting)
Questioning
Questioning mental models
Receiving help from peers
Reflection after learning
Reflection before learning
Reflection during learning
Rehearsal
Socializing
Story telling
Studying electronic materials
Studying manuals and texts
Trial and error with reflection
Working with others

Sources: Brockman, (2004); Carnevale, Gainer, & Meltzer, (1990); Cunningham, (1989); Education Development Center, (1998); Eraut, (2004); Maben-Crouch, (1997); Rossi, (1996); Zaro, (1993).

strategies applied during the learning opportunity of a shift change. Similarly, coaching is not a learning strategy for the learner, who learns, not from passively receiving the coaching, but though actively listening to or observing the coach, reflecting on the coaching, then practicing what was learned.

Of the studies consulted, only one, Brockman (2004), was somewhat related to RHVAC service work; machine operators troubleshooting mechanical or computer programming problems. As stated previously, Brockman’s chief finding was the negotiated nature of the learning she observed. She also found evidence of learning from problem solving and consulting technical material.

RHVAC techs troubleshoot already installed equipment using a broad range of technical skills as described in Chapter One. Certainly there would be similarities between the learning strategies used by machine operators and RHVAC techs, perhaps even similarities between RHVAC techs and nurses, but the purpose of this study was not to compare workers’ learning strategies. The purpose was to understand the learning of these RHVAC techs and then to make suggestions as to how they could be better prepared to learn on the job. Knowing how the techs learned was critical to accomplishing this goal, but knowing what they learned was necessary to provide a fuller description of the techs' learning. Therefore, determining what was learned was the purpose of the study question number three.

Question Three: What did the techs learn from troubleshooting?

What is Learned from Informal Workplace Learning

The purpose of this section was to present the broad outlines of the content of workplace learning for a wide range of workers. For example, The Education Development Center, Inc. (1998) found that the workers they studied learned:

1. Practical skills
2. Intrapersonal skills like problem solving and prioritizing
3. Interpersonal skills
4. Cultural awareness

Eraut (2004) stated that workers learned the following skills and knowledge informally:

1. Task performance
2. Awareness and understanding
3. Personal development
4. Teamwork
5. Role and performance skills
6. Academic knowledge and skills
7. Decision making and problem solving skills
8. Judgment

In her study of machine operators Brockman (2004) found that her subjects developed “a form of knowledge which comes from a sense of holistic patterns and relationships” (p. 120). The workers were learning to become machine operators and went through three phases of development: newcomer, novice, and experienced worker. They learned about the organization’s culture and expectations as well as operational knowledge related to running and maintaining the production equipment. Knowledge about how to learn and self-knowledge were also gained by the study participants. They learned “automatic knowledge” that is similar to tacit knowledge in that it is incorporated into a person’s thought patterns and skills (Brockman, 2004). Tacit knowledge is difficult to articulate and ascertain (Marsick & Watkins, 2001; Polanyi, 1966; Sternberg, Forsythe, & Hedlund, 2000) and is at least as important as technical proficiency in RHVAC troubleshooting.

Lists of what workers learn through informal learning are helpful in understanding learning but can also lead to ranking knowledge or segregating knowledge and skills into unrelated elements. Learning what knowledge and skills the techs created from troubleshooting was necessary to in understand the techs’ learning. It was also thought that knowing when the techs’ learning occurred could deepen this understanding.

Question Four: When did the techs’ learning occur, during troubleshooting, or as a result of later reflection?

When Learning Occurs

Since troubleshooting a technical problem can be a relatively discrete event with a beginning and end, it is worthwhile to ask if the learning related to troubleshooting is equally discrete. Does learning occur during or after troubleshooting?

The timing of learning can be differentiated into two timeframes, reflection-on-action (after the learning opportunity) and reflection-in-action (during the learning opportunity). Reflection-in-action, as described by David Schön (1987), involves a conscious engagement with ongoing actions and gives rise to on-the-spot experiments. Schön studied professionals' learning and found that effective professionals used reflection-in-action as part of daily practice. Fenwick (2001) argued that reflection during and after an activity is responsible for organizing knowledge.

In Buddhist practice, successful reflection-in-action is called mindfulness and is said to lead to transcendent learning, and Tremmel (1993) has applied this concept of mindfulness to learning in the professions. The Zen Buddhist tradition is associated with a hard-boiled, everyday mindfulness, a multi-dimensional, engrossing engagement within a task (Cleary, 1995). From the cognitive sciences comes the term, sustain. “Sustain is your ability to remain focused on a single object or task for extended periods without becoming distracted” (Johnson, 2004, p. 90). Since people can not pay attention to everything, they must shut out some stimuli to maintain this focus. While reflection-in-action features a sharper focusing of mental powers, reflection-on-action can be more casual, though it can also involve deliberate, conscious mental activity Schön (1987).

Summary

A key distinction between learning in and out of school revolves around how contextual variables are controlled. In school (formal) learning is designed to control variables, while out of school (informal) learning is shaped by the randomness of many contextual variables. Informal learning is constructivist and deeply rooted in the learners’ experiences of the situation. Experiential learning is fluid with previous experiences impacting the present, and is a blend of rational and emotional aspects and can be likened to a conversation between learners and their environments. Situational learning acknowledges this interaction between learner and the environment, and emphasizes the social nature of learning, even if the learner works independently. Even though troubleshooting is acknowledged as a good learning opportunity, most popular RHVAC texts do not explicitly link troubleshooting and learning. Since little research had been done on blue collar workers, it was anticipated that as study of these techs would broaden the knowledge base of how workers learn informally.

This study was designed to understand how RHVAC techs learned from troubleshooting, and then to make suggestions to community college instructors as to how they could better prepare technicians to learn more effectively in the workplace. The design of this study is described in the following chapter.

CHAPTER THREE: DESIGN

As discussed in Chapter One, troubleshooting is an important activity for RHVAC techs, as is informal workplace learning. In addition, there has been little research into the informal workplace learning of blue collar workers like RHVAC techs. The importance of experience in workplace learning was discussed in Chapter Two, as was the lack of explicit linkages between informal learning and troubleshooting, especially in RHVAC and other texts. This chapter details the method used in collecting and analyzing the data required to answer the study questions.

The method chosen for this descriptive qualitative study was the critical incident technique (CIT). CIT was designed for use in occupational studies, and provides flexible procedures for conducting interview-based, workplace research. In CIT the participants are asked to describe incidents important to their work experience. The interviewer seeks to gain deeper understanding of the incident to learn about the phenomenon being studied.

This study was designed as a descriptive qualitative study due to the small population available and the nature of the questions that guided the study. Qualitative research is designed to find meaning, describe a process, and identify recurrent themes (Merriam, 1998). Berg (1998) states that, “Qualitative research thus refers to the meaning, concepts, definitions, characteristics, metaphors, and symbols of things” (p. 3). Qualitative researchers look for data outside of the laboratory or other controlled situations and use inductive reasoning, building theories or concepts as suggested by the data. Data analysis focuses on the processes studied and how the participants understand them (Berg, 1998; Bogdan & Bilken, 1998; Denzin & Lincoln, 2000, Redmann, Lambercht, & Stitt-Ghodes, 2000; Silverman 2000).

Qualitative researchers are often the primary observers and interpreters of their data. Since researchers’ influences shape research findings (Capra, 1996; Zukav, 1979), it was recommended that qualitative researchers disclose their worldviews (Rew, Bechtel, & Sapp, 1993). Worldview is defined as “Weltanschauung, a particular philosophy or view of the world: a conception of the world” (McKean, 2003, p. 1734). Readers of this study should know what biases or intellectual or emotional blind spots might cause me to ask or ignore certain questions, or to interpret data in a certain way.

Researcher Worldview

As the techs’ former instructor as well as a qualitative researcher, it is important that any personal biases and my worldview be disclosed. Therefore, it is important for readers to understand that I believe that the world is fluid, orderly, and built on complex, causal relationships, but that we humans are unable to discern the subtlety of this order and its multidimensional variables. Therefore, either qualitative or quantitative research can help us understand the general outlines of phenomena, but all research is subject to error and omission, because neither offers a complete view of any phenomenon (Capra, 1996; Warren, Franklin, & Streeter, 1998; Zukav, 1979). Consequently, the predictive power of quantitative research must not be overstated, and qualitative research, because of its narrow focus, should not be used predicatively or proscriptively outside of the population studied, though it might be applied, carefully, to similar populations.

I am convinced of the power of informal learning, particularly informal workplace learning. This springs, in part, from my upbringing. I was born in 1950, a child of highly educated, liberal parents in a rural home on the edge of the Canadian bush. I was taught to value formal education but also to respect the modestly educated but skilled people who were our neighbors, highly capable ex-soldiers, trappers, guides, handymen, housewives, and scrubland farmers who learned their livelihoods informally. In 1973, I completed a Bachelor of Arts degree, became a blue-collar worker (tug boat deckhand) and experienced the pervasiveness and power of informal workplace learning while I worked as a laborer and later as a tradesman. Eventually, I became an industrial mechanic by learning RHVAC, mechanical, electrical, and electronics skills through informal workplace learning and self-directed studies. In 1985, I became a vocational instructor (Industrial Plant Maintenance) and learned what and how to teach largely through informal and self-directed studies. Formal education provided guidelines and options, but my most important learning about teaching came from reflecting on my teaching experiences. I take for granted that people learn informally and that much of what they learn informally is of supreme importance to their survival and happiness. Further, I hold that the most potent form of workplace learning is informal and that we formulate our learning from processing our experiences in a constructivist fashion.

It follows then that the philosophical approach that supports this study should acknowledge the power of experience and the importance of practical solutions to practical problems. As a result, I was attracted to classical American Pragmatism (James, 1963; Morris, 1970; Rosenthal, Hausman, & Anderson, 1999).

Pragmatism embraces the study of experience as the prime ingredient in determining truth rather than following the orthodoxy of a particular school of philosophy. “It (pragmatism) means the open air and possibilities of nature, as against dogma, artificiality, and the pretense of finality in truth" (James, 1963 p. 25). To James, truth is largely situational and personal. There are no a priori truths that ensure the utility of philosophical concepts. Pragmatism is often described as a methodology for determining the truth. "Theories thus become instruments, not answers to enigma in which we can rest" (James, 1963, p. 26). Charles Sanders Peirce, the father of American pragmatism, articulated an aloof, scientific approach to pragmatism that championed collective truth seeking, and disparaged individual efforts as being too prone to error (Morris, 1970). Peirce insisted on studying "facts" and did not articulate a practical, everyday philosophy for nonscientists. William James expanded the pragmatic horizons by applying pragmatic methods to individual thought and made space for belief in the formation of philosophical standards. Both James and Peirce influenced John Dewey who championed the importance of experience as the primary educative force.

To Dewey, experience was not a string of isolated occurrences; each experience occurred within a culture. Experience was shaped by that culture “the life history of society” (Menand, 1997, p. 6), and the receiver of the experience interpreted experience based upon his or her unique culture, the life history of the person. Above all, Dewey and other pragmatists argued that it was the practical consequences of applying ideas that determined those ideas’ worth. With its roots in the scientific method, pragmatism demands thought prior to action and evaluation of the results of action.

The pragmatic method of making sense of experience, coupled with my understanding of formal and informal learning, has convinced me that human learning is largely constructivist. Constructivist learning is social, contextual, and individually unique. People learn when they make personal meaning and then apply what they have learned (Brown, Collings, & Duguid, 1989; Doolittle & Camp, 1999; Ertmer & Newby, 1993).

As this was my first attempt at researching others’ experiences, I chose the critical incident technique (CIT), because it provided a flexible structure to follow while gathering and analyzing workplace data.

The Critical Incident Technique

This section describes how the critical incident technique was applied in this study. Anderson and Wilson (1994) described CIT in the following passage.

> The critical incident technique consists of a flexible set of procedures for collecting and analyzing reports of incidents – instances of actual behavior – that constitute job performance at various levels of effectiveness.... The term “critical” refers to the fact that the behavior played an important, or critical, role in determining the outcome. (p. 1)

The critical incident technique was developed for U.S. military research during World War II (Anderson & Wilson, 1994; Dunn & Hamilton, 1986; Flanagan, 1954; Redmann, Lambrecht, & Stitt-Gohdes, 2000). The aviation psychology program of the U.S. Army Air Force was charged with identifying the characteristics and actions of successful and unsuccessful pilots in flight school. The data gathered from interviews, written records, and observations were used to improve flight training. The chief researcher, John C. Flanagan, detailed the process in his seminal article, *The Critical Incident Technique* (1954), and went on to found the American Institute of Research. The following explanations of CIT come from Flanagan's 1954 article.

> The critical incident technique consists of a set of procedures for collecting direct observations of human behavior in such a way as to facilitate their potential usefulness in solving practical problems and developing broad psychological principles. (p. 327)

> ...the critical incident technique is essentially a procedure for gathering certain important facts concerning behavior in defined situations. It should be emphasized that the critical incident technique does not consist of a rigid set of rules governing such data collection. Rather it should be thought of as a flexible set of principles which must be modified and adapted to meet the specific situation at hand. (p. 335)

Flanagan described the general outline for conducting CIT research under these headings: general aims, participants and specifications for the study, data collection, and data analysis.

General Aims

A CIT study begins by defining the general aims of the study and refining these into a simple statement that defines clearly and concisely the aim of the study. The aim of this study was to learn how some

RHVAC techs learned from troubleshooting and how that knowledge could be applied to improve the workplace learning of the graduates of technical training. The resulting driving question that guided this study was: How can community college instructors of technical programs prepare their students to learn more effectively in the workplace?

Participants and Specifications of the Study

Flanagan (1954) wrote that participants “should be selected on the basis of their familiarity with the activity” (p. 339). The population for the study was selected from all program graduates of a community college Refrigeration Heating Ventilation and Air Conditioning (RHVAC) program for the years 2000 through 2004. I was and am the department chair and lead instructor of that program.

Of the 66 people listed as completers of the program in this time frame, 12 had not yet graduated and were eliminated. After eliminating those for whom there was no address or phone number, 35 candidates, 33 males, and two females remained. All received a cover letter explaining the project and asking them to fill out a critical incident report called a Troubleshooting Report which was created for this study. A self-addressed, stamped envelop was enclosed. The Troubleshooting Report asked the respondent to describe a troubleshooting problem that resulted in significant learning. The significant learning gained from the troubleshooting was the critical element of the incident. Critical incidents usually deal with positive and negative occurrences to gather a broad range of worker actions and thoughts. It was decided to focus only on positive incidents so that the respondents would not be threatened by inquiries into their troubleshooting failures.

After the reports were mailed out, eleven people responded, but one was not working as a troubleshooter for more than 50% of the time and was not included in the study, leaving a study population of ten male techs. All the techs performed routine maintenance and troubleshooting of heating and cooling equipment in residential and commercial settings as their major work activity.

Data Collection

Flanagan (1954) suggested that interviewers explain the purpose of the study, explain why the person is being interviewed, and stress the anonymity of the data. He recommended pilot testing of the questions to check for bias and clarity. Therefore, a two-person pilot study was conducted, and those interviews were included in the data analysis since no significant changes were made to the interview questions. The semi-structured interviews started with a discussion of the troubleshooting report then branched off into other troubleshooting problems that helped the techs learn. The study’s informed consent document, contact letter, troubleshooting report and interview protocol are found in Appendices A through D. The semi-structured interviews were tape recorded and transcribed, then the transcripts were corrected while listening to each recording. The transcripts were studied to answer the four research questions that guided the interviewing.

Data Analysis

“The purpose of the data analysis is to summarize and describe the data in an efficient manner so that it can be used effectively for many practical purposes” (Flanagan, 1954, p. 344). CIT analysis does not emerge from a pre-existing model, “Incidents are categorized using inductive judgments rather than pre-existing theoretical models” (Allery, Owen, & Rowling, 1997, p. 2). Three elements of data analysis concerned Flanagan: frame of reference, category formulation, and general behaviors. The frame of reference was the overall troubleshooting of the RHVAC techs and consisted of each particular troubleshooting problem discussed. Category formulation arose from studying the transcripts for similarities that indicated common aspects of the techs’ learning from the troubleshooting problems. The general behaviors were the techs’ learning strategies and were the manifestations of each category; the supporting evidence for category formulation. Data analysis was done manually by sorting through the printouts of the transcripts.

The analysis was checked by an outside reader who read the transcripts and an early draft of the dissertation. He was asked to examine the analysis for signs of bias as suggested by Flanagan, and to determine if the categories formulated and the suggestions made in Chapter Five were supported by the transcripts. He felt that the suggestions were supported by the data. My committee members identified the influence of personal bias in the some of the suggestions made in Chapter Five. These deficiencies were corrected in subsequent revisions of the chapter. In addition, Chapters Four and Five were reviewed by each tech as part of a member checking process. The techs agreed that they had been quoted accurately and fairly and that the suggestions were reasonable. These steps were taken to assure reliability and validity.

Reliability

Reliability is generally a quantitative concept which, “refers to the extent to which research findings can be replicated. In other words, if the study is repeated, will it yield the same results” (Merriam, 1998, p. 205)? In qualitative research, reliable results “are consistent with the data collected” (Merriam, 1998, p. 206), but, “Reliability is problematic in the social sciences simply because human behavior is never static” (Merriam, 1998 p. 205). Gall, Borg, and Gall (1996) agree, “validity and reliability become problematic, however, if one rejects the positivist assumption of a reality that can be known objectively” (p. 575). Still, Bogdan and Biklen (1998) urge qualitative researchers to address reliability.

> Qualitative researchers tend to view reliability as a fit between what they record as data and what actually occurs in the setting under study, rather than the literal consistency across different observations. (p. 36)

Silverman (2000) takes a similar approach,

> Reliability refers to the degree of consistency with which instances are assigned to the same category by different observers or by the same observer on different occasions. For reliability to be calculated, it is incumbent on the scientific investigator to document his or her procedure and to demonstrate that categories have been used consistently. (p. 188)

Table 3-1 lists the techniques for promoting reliability employed in this study. Two important methods for ensuring the reliability of data, triangulation using document review and observations were not available in this study. Documents like work orders and technician logs are the property of the worker’s employer, so accessing them would have required the permission of each tech’s employer, something that had proved impossible to obtain when trying to recruit industrial and facility maintenance techs for a previous study. It was likely that these industrial employers thought that their techs would be threatened by having their troubleshooting scrutinized. It was then decided to focus on RHVAC techs for this study. By forgoing access to company documentation and worker observation, the techs could be interviewed without receiving employer permission. Understandably, information identifying the techs’ employers was not solicited or was not transcribed from the interview tapes.

Table 3-1

Techniques for Improving Reliability

Techniques for Improving Reliability	Application in this Study
Clear description of all research activities	Outside readers, coding checker, member checking of transcripts, committee review
Worldview and biases made public	Found in Chapter Three
Clear, complete audit trail	Outside readers, coding checker
Triangulation	Not available for this study
Pretest	Pilot study conducted
Interviews tape-recorded	Interviews tape recorded
Use of inter-rater checks (Coding checking)	Coding checked
Extensive quoting of participants	Found in Chapter Four
Extensive field notes	Field notes taken

Techniques derived from: Berg, (1998); Bogdan & Bilken, (1998); Denzin & Lincoln, (2000); Merriam, (1998); Silverman, (2000).

Validity

There are two types of validity, internal and external. “Internal validity relates to how research findings match reality” (Merriam, 1998, p. 201). Problems with validity include the argument that conducting research changes the nature of reality (Bogden & Biklen, 1998; Capra, 1996; Zukav, 1979).

Another concern for validity is the veracity of interviewee responses. “Do respondents tell the whole truth and nothing but the truth” (Weiss, 1994, p. 147)? Internal validity is linked to external validity; without internal validity there can be no external validity (Merriam, 1998).

“External validity is concerned with the extent to which the findings of one study can be applied to other situations” (Merriam, 1998, p. 207). The problem with qualitative research is how to generalize, if at all, from a small, non-randomly selected population. The sweeping recommendations espoused by many advocates of quantitative research are not warranted in most qualitative research, especially small scale studies, but limited suggestions are possible. Merriam discusses the possibility of, “Reader or user generalizability (which) involves leaving the extent to which a study’s findings apply to other situations to the people in those situations” (Merriam, 1998, p. 211). The suggestions generated from this study were made under these constraints. Those implementing these suggestions must monitor the results produced and adopt, adapt, or abandon the suggestions as their unique situation warrants. Table 3-2 lists techniques for promoting validity that were employed in this study.

Table 3-2

Techniques for Improving Validity

Techniques for Improving Internal Validity	Application in this Study
Peer examination	Outside readers
Participatory research or member checking	Member checking of Chapters Four and Five
Worldview and biases made public	Found in Chapter Three
Triangulation	Not available for this study
Inter-rater reliability	Coding checked
Interviews tape-recorded	Interviews tape recorded
Full description of context, thick description	Use of descriptive data, personal experience, field notes
Extensive quoting of participants	Each finding was supported by the appropriate data
Investigation of outliers	Not applicable in this study due to the small population

Techniques derived from: Fischer & Oulton, (1999); Gall, Borg, and Gall, (1996); Silverman, (2000); Weiss, (1994); Zaro, (1993).

The techniques listed in Tables 31- and 3-2 were followed as closely as possible. The resulting data and recommendations were scrutinized by the techs, outside readers, and dissertation committee members. Their suggestions were incorporated into this study to ensure its validity and reliability. A suggestion from Merriam (1998) ends this discussion of validity and reliability, “Ensuring validity and reliability in qualitative research involves conducting the investigation in an ethical manner” (p. 198). Therefore, a full disclosure of the ethical considerations regarding this study is presented below.

Ethical Concerns

The American Educational Research Association (1994) suggests these overall ethical standards. “Educational researchers must not fabricate, falsify, or misrepresent authorship, evidence, data, findings, or conclusions (p. 2).”

> Educational researchers should report research conceptions, procedures, results, and analyses accurately and sufficiently in detail to allow knowledgeable, trained researchers to understand and interpret them. (p. 2)

> Educational researchers should communicate their findings and the practical significance of their research in clear, straightforward, and appropriate language to

> relevant research populations, institutional representatives, and other stakeholders. (p. 5)

Most importantly from an ethical perspective, educational researchers must avoid harm to subjects by using rigorous attempts to ensure participant anonymity (American Educational Research Association, 1994). Given the fact that these participants were my former students, complete anonymity was problematic, so the main concern was to prevent any harm to the participants. All participants were given numbers and their work activities were generalized to limit their identification.

Research involving workers creates risks “when the results of the study can affect livelihood or personal security of the worker or other workers” (Rose & Peitri, 2002, p. 482). Workers are vulnerable in the areas of employment retention, job advancement, and personal relationships with their fellow workers. A researcher must ensure that participation is voluntary and based on the informed consent of the participant and that jobs and insurance coverage are not threatened (Rose & Peitri, 2002).

Therefore, no attempt was made to evaluate the participants’ troubleshooting abilities or performance. Any potentially harmful comments were deleted from the transcript. Each participant was asked to review how they were quoted in Chapter Four to ensure that they were satisfied with the efforts to protect them and that they had not been misrepresented. All the techs agreed that they had not been misrepresented and that their anonymity had been preserved.

Characteristics of the Techs

Oregon State University requires all studies involving human subjects to undergo rigorous evaluation to ensure the privacy and anonymity of all participants and to ensure that no participant is harmed as a result of their participation. Given the limited population to draw from, the ease with which someone could identify the community college the techs attended, and the likely region in which they work, this was a difficult promise to fulfill. Therefore, the techs were described in the most general terms. Table 3-3 provides a general description of the techs.

Table 3-3

Characteristics of the Techs

Tech	Previous related experience in their own words	How long working in the trade	Formal technical education	Mobile or stationary tech
One	“Lots”	1 year	1 year	Stationary
Two	“Intermediate level”	18 months	16 months	Mobile
Three	“Very little”	18 months	1 year & seminars	Stationary
Four	Very little”	6 months	1 year	Mobile
Five	“Introductory”	7 months	2 years	Mobile
Six	“Extensive”	2.5 years	2 years	Mobile
Seven	“A little bit”	8 months	2 years	Mobile
Eight	“A lot”	5 years	1 year	Mobile
Nine	“None”	1 year	1 year	Mobile
Ten	“Introductory”	1 year	1 year	Stationary

Each tech was asked for a brief description of their experience related to the RHVAC trade and that information was placed in Column 1 using their own words. Column 2 refers to their RHVAC working experience at the time of each interview. Their formal technical education related to RHVAC is listed in Column 3, but their ages were not provided as this could be an identifier. In Column 4 the term stationary tech means that the tech works in a facility and did not travel extensively, whereas a mobile tech works from a van and travels to various residential or commercial customers.

All the techs interviewed were excellent RHVAC technology students, exactly the kind of people who should be successful in the RHVAC trades. They were all hard workers and had excellent people skills for technical work. Most did well in written exams (worth only about 10% of final grades in their RHVAC program), but they all excelled in their competency-based, hands-on exams. They possessed the unquantifiable attributes of determination and good character that would make them excellent RHVAC techs.

Limitations

Because a small, parochial population was studied, specifically those of my former students who responded to a request for information, the limitations of this study are those common to many qualitative studies, limited generalizability. The lack of triangulation data must also be considered a limitation regarding validity and reliability.

Another limitation was the assumption that learning did result from troubleshooting, and no attempt was made to study other workplace learning opportunities available to the RHVAC techs, for example, performing preventive maintenance. Asking about learning from troubleshooting but not from maintenance is an example of how researchers might change the nature of reality by studying some aspects of a situation and not others. In addition, just asking about informal workplace learning might make it seem more important or prevalent to the study participants, who were my former students.

I maintain cordial relations with most of my graduates and contact them as part of my program reviews, and they contact me frequently with suggestions. Therefore, asking them to participate in this research was a natural extension of our relationships. All my students knew that I was pursuing a Ph.D. and had a general idea of the topic. Still, my position as the participants’ former instructor must be considered when evaluating this research. All the techs held secure, well-paid jobs and were developing skills that would enable them to find better jobs without my recommendation. Still, former students want to impress a former teacher, so, did they say what they thought I wanted to hear? With this in mind, I espoused no theory regarding the nature of the techs’ learning, other than the well-supported evidence regarding the prevalence and importance of informal workplace learning and the potency of troubleshooting as a learning opportunity.

Since I am a Caucasian, middle-class male who has taught Caucasian men almost exclusively, and the study participants were also white males, this study can shed no light on the informal learning practices of females or people from different cultural backgrounds.

Regional differences in technology use might have influenced how the techs learned. In more heavily populated regions, larger RHVAC companies make extensive use of wireless internet technology during troubleshooting. At the time of the interviews most of the techs did not have access to this additional method for retrieving information relevant to troubleshooting. The technology available to the techs would have influenced their learning from troubleshooting.

Summary

This study followed the critical incident method to gather data from 10 male RHVAC service techs. The driving question of this study was: How can community colleges prepare technical students to learn more effectively in the workplace? By understanding the learning of these RHVAC techs, it was hoped that useful suggestions for community college instructors could be formulated. The techs were interviewed and their responses to the four study questions were transcribed and analyzed. Recognized qualitative methods and practices were followed to ensure validity and reliability. The findings from those transcripts are presented in the following chapter.

CHAPTER FOUR: FINDINGS

In previous chapters the need for research into the informal workplace learning of blue-collar workers like RHVAC techs was established, as was the importance of informal learning and troubleshooting to RHVAC service techs. The critical incident technique was used to guide this study as it provided a flexible structure for interviewing and analyzing interview data. The findings in this chapter are organized as responses to the four underlying questions that guided the interviews.

Question One: How did the RHVAC service tech's working conditions and the cognitive context of their jobs shape their learning?

Three major contextual factors impacted the techs' learning and led to the finding that informal workplace learning was an important source of knowledge and skills for the techs.

- They worked alone most of the time.
- They were troubleshooting most of the time.

- Most received little continuing education or structured on-the-job training.

Table 4-1, summarizes these factors using the techs' responses to specific questions.

Table 4-1

Contextual Factors that Influenced the Techs' Learning

Tech	How much of the time do you work alone?	How much of your time is spent in troubleshooting?	How much formal training do you receive?
One	75%	80%	"None"
Two	98%	90%	"More than most, every two months"
Three	75%	60%	apprenticeship training
Four	35%	80%	"Not too extensive"
Five	100%	90%	"Not a lot"
Six	90%	60%	"Quite a lot"
Seven	50%	100%	apprenticeship training
Eight	98%	80%	"Some, not a lot"
Nine	85%	70%	"Not a lot"
Ten	50%	60%	apprenticeship training

The Importance of Workplace Learning

Since most of the techs worked alone most of the time, their independence was a major factor in how they learned. In addition, most of the techs reported a general lack of formal workplace learning or structured on-the-job training. Therefore, much of the techs' learning was informal. Informal learning occurs without a formal curriculum and its attendant professional instructors and grading system. Much of the techs' informal learning resulted from troubleshooting, which was a major workplace activity. RHVAC troubleshooting is stressful; either the troubleshooter fixes or does not fix the problem and failures are obvious. These are the type of significant experiences Eraut (2004) suggested as being likely to promote learning from experience.

It is not surprising then that all the techs agreed that informal workplace learning was their most important source of new learning. This corroborated the Bureau of Labor Statistics' (2003a) assertion of the importance of informal workplace learning in the culture of the RHVAC trades. This finding also supports those researchers citing the importance of informal workplace learning generally (Brockman, 2004; Education Development Center, 1998; Frazis, Gittleman, Horrigan, & Joyce 1998; Livingston, 2001; Marsick & Watkins, 1990). In addition, all the techs asserted that they were conscious of learning from troubleshooting and that learning was a critical aspect of their work.

Tech Four described the important of workplace learning succinctly, “I am always trying to learn. You have to learn, otherwise you are screwed.”

Tech Ten was equally succinct,

> (I am learning) every single day. When I quit learning is when I will probably quit doing it. It is just like anything else I have ever done. Once I know a piece of it, I have got to know it all.

Tech Eight,

> Yeah, to me you are always learning, no matter what, especially in the area (workplace) where I am at, it is constant learning. I am always in the learning stage. I never stop learning.... If I don’t know it, it drives me crazy until I get it, until I know how it is working. I have to know how it works, not halfway, or “I got it working now, I am going to leave it alone.” I have got to know how exactly everything works within that system to make it work. I can’t <u>just</u> fix it.

Tech Nine,

> Like I said before, you just have to keep learning. You can be out there for twenty years and have twenty years of experience or you can have one year of experience twenty times. That, I think, says a lot if you understand what it means. You can't quit learning.... You can't quit learning. I mean everything is changing. Equipment is always changing. You know if you quit learning, you may as well quit working.

As summarized in Table 4-1, three of the techs were apprentices who received both formal classroom training and structured on-the-job training. Only one of the other seven techs reported receiving what he considered "quite a lot" of formal training outside the job or structured on-the-job training. The amount of formal training is elaborated on in the following section.

The Techs Received Varying Amounts of Formal and On-the-job Training

RHVAC techs probably receive less formal job training than outsiders to the RHVAC trades would expect. Continuing training in this region of the U.S. usually means short, one to three-day seminars, commonly sponsored by equipment manufacturers. Such training, though often free or low cost, is still costly to the employer who must pay employees’ wages and company overhead while gaining no income from employees’ work while they are attending class. RHVAC businesses need to have their techs billing hours and bringing in money from installations or service calls to remain profitable. For-profit classes are expensive and are usually offered in a large city, so travel and accommodation must be added into the cost of training. Three of the techs were in apprenticeship programs, so they attended formal classes each week from September through June. Though some local companies offer formal training, continuing formal education is not usually part of the RHVAC culture in this region, and even structured on-the-job training is not guaranteed.

For example, Tech Six got only a small amount of structured on-the-job training when he began working right out of school.

> I worked with the other techs for about a week. I think it was just simply to learn this company’s paperwork process. They kind of kept me under the gun for about thirty days, and then I was totally released, kind of sink or swim, just to see how I did.

He got workshop-type training sponsored by specific manufacturers, “Probably about one every other month.”

Tech Five expected more structured on-the-job training when he started working. “Absolutely. I expected to get way more help.”

Tech Two got two days of ride-along training with a more experienced tech when he started then went out on his own because the company was shorthanded. Since then he has attended several manufacturer sponsored workshops over a few months.

Tech Nine has “taken a couple of four or eight hour classes, but not a whole lot.”

In contrast to the limited training offered to most techs, Tech Eight was a stationary tech who worked for a large facility and received extensive, structured on-the-job training when he started work. “What they will do is they will give you a week with each one of the specialists before they put you on shift. You spend about three months in training.” He also took two classes in specialized technical systems. Tech Eight is part of an established crew in a large facility, so formal training is easier to arrange, because economic survival does not depend on each tech generating profits for the organization.

Given the lack of extensive formal or structured on-the-job training most of the techs' learning was, by default, informal. Still, three of the techs were apprentices and received formal education and structured on-the-job training, though they were working alone at least 50% of the time and were troubleshooting much of that time. The workplace portion of their learning might be considered semiformal with limited grading and a flexible curriculum mentored by a senior worker.

Tech Seven is an apprentice and took his current job, despite its initial low wage rate, because he felt he could learn well in that situation. He has since passed up opportunities to work on his own to keep working with his journeyman and continue their rich learning relationship.

> I could go out on my own, (within the company) but I chose not to. I mean the company offered me a van, (so that he could work alone) but I said no, next year. Next year I will do it, but not right now. I get passed up on some stuff, but on the other

> hand I am never going to be able to replace the experience I am getting from the guy (the journeyman who is mentoring him) and he is going to retire next year. I am opting to take that. He is prepping me to take his spot.... Like everyday I have stuff that I learn from. I mean big things, little things, really important things.

At the other end of the scale, Tech Four worked for a small company in a small economic market where training was much harder to obtain. Tech Four had received just one day of formal classroom training in the previous six months.

As stated earlier, an important factor in the context of the techs’ learning was that they work alone most of the time. This differed from studies of the informal learning of workers who generally worked in groups or were at least near other workers who were doing the same tasks. The RHVAC techs’ choices of learning strategies were shaped, in part, by the independent nature of their work. Because they worked alone and formal training opportunities were not often available, most of the techs were forced to learn in the workplace, while they were working, and the bulk of that learning was informal. How then did the techs learn?

Question Two. What learning strategies did the techs use to learn from troubleshooting?

The RHVAC techs reported that they learned by:

- seeking advice which was facilitated by pride of workmanship
- reflection which manifested itself as working through the troubleshooting problem and root cause analysis after the problem had been solved
- seeking information from manuals
- writing in logbooks or work orders

Seeking Advice

Traditionally seeking advice in the workplace has meant face-to-face help; co-workers helping each other, or a senior person coaching a newcomer. As stated previously most of the techs worked alone, a common situation for RHVAC service techs. Cellular telephone technology has decreased their isolation and created an option for seeking help when troubleshooting. All the techs carried company-supplied cell phones or radios for both safety, and for seeking help from manufacturers and supervisors (formal help networks), or from friends and fellow workers (informal help networks). Formal help networks consisted of manufacturers' technical support, senior techs in the same company, and knowledgeable people like parts suppliers.

Tech One described his formal network, "I definitely have had to get on the phone and call 1 800 numbers, get to the manufacturer and get their recommendations." Tech Three has sought help via cell phone from a knowledgeable sales representative at a local parts distributor. Tech Six has a network of people with whom he can consult. "I use a whole list. We have two guys in the company that I can call." In addition, RHVAC techs can access manufacturer's technical help services, part of their formal help network.

Tech Six,

> All you have to do is give the model and serial number of what you are working on, they will plop it on their computer screen, and they can follow along with you....

> Pretty much every brand out there, there is someone to talk to. It is just a matter of knowing who to call. When I don’t know who to call, I call one of the local parts houses and one of the parts men has worked for other companies and he has a great insight on brands that don’t even exist anymore. You learn who your ace in the hole is.

Tech Nine has made good use of his cell phone in contacting members of his formal help network,

> I have a list of tech support for different companies. I talked to a guy about a furnace. He was in Texas. I told him what the furnace was doing, and he told me (what to do) right over the phone.

Tech Seven explained the tacit procedure for calling within his company. “We all have phones and I have a hit list. We don’t call the boss. The unwritten rule is that we call each other.”

In contrast to formal networks, informal cell phone networks depended on personal relationships rather than professional, obligatory relationships like those with technical support personnel. Members of the informal network could be other techs in the same company or friends who also work in the trade, but for another company.

Tech Nine is part of a three-tech, informal help network. The three techs attended classes together, became friends, and talked almost daily about workplace problems. Tech Ten is part of a separate informal cell phone network with another fellow graduate. They work in similar facilities and therefore have similar problems. They also communicate via email since both have frequent access to computers. He said, “We are always on the cell phone.”

Tech Five has a formal network of experts within his company that he can call, but he also calls friends who work in the trade as part of his informal network for seeking help.

> If I have a control problems I call a guy named (deleted). He has an engineering degree and he has been an HVAC tech for twenty years.... (Another tech) used to be a (specific manufacturer) technical troubleshooting guy over the phone, so if I run into a problem on a (that brand), I call (him). Every once in a while I will work on residential and I will call (Tech _____) because he has worked residential. If I am working on a furnace problem I call (Tech _____).

Tech Two made calls more frequently when he started working.

> When I first started I always worked by myself, but made phone calls to get walk-through help, but now, being more experienced, I have done probably 98% of my work orders by myself.

Most commonly, a cell call results in verbal help for the caller; a fellow worker familiar with the equipment will listen to the symptoms and give suggestions or direct the caller to make certain tests. A call to a manufacturer’s technical support will be similar except that the support tech will have more specific suggestions, for example where to put test equipment probes to test for specific voltage levels. Occasionally a call can summon in-person help as it did for Tech Six when he confronted a problem of a miswired machine that had no wiring diagram. He made a call to a senior tech in the same company and, “He (the senior tech) came out very quickly and showed me a way of troubleshooting it that I had never really played with.... Within a half-an-hour we had it done.”

Informal cell phone networks are based on bonds of friendship and mutual respect between knowledgeable fellow workers. Learning from others in person is also based on similar personal relationships. Tech One works in a large facility. “Sometimes you can refer to an expert that you have made friends with on site and they come and work with you and show you the shortcuts.” He continued,

> I worked with a couple of really good men in electronics. I am getting really familiar with electronic relays, sensors and things like that.... You can’t take a manual and just absorb what you read anymore. You have got to go back to it, and back to it, and back to it. Then you need somebody to talk it over with and bounce it off and get their input. That works real good here. I have two electricians, we will sit there, and we will talk about things. I have got a real good core group going on where I work, and we will round-table issues. We gain a lot of confidence and new ideas how to work out issues through our rapport with each other.
>
> It is very informal. It is over lunch, break, coffee, whatever. We will talk about things like that. We have solved some really major issues by round-tabling.... We figured out that it (a particular problem) was just a failed pump. We ordered another pump for $130 and we saved the company $5000 (which was the quote to replace the system from an outside contractor).

When asked about the role of friendship and good personal relationships in getting help from others, in person or on a cell phone, all the techs agree that such relationships were critical.

Tech One amplified this sentiment,

> (Friendship is) Very important. If you don't build rapport with people, you are going to find yourself pretty well isolated, especially in dirty jobs where not many want to go. If they like you, they will be very willing to go in there and help, talk you through a problem.

By contrast, Tech Four works for a small company and often works with another tech, but when he does work alone his,

> ...supervisor is available all the time. I call him. I kind of bug him a little too much sometimes, try to pick his brain for information and stuff. It seems to be difficult to pull it out of these manuals we have. (He then referred to a specific problem.) Who would have known that you had to (do a specific and not intuitive procedure) to get it (the bad part) out of there or even if that is a common problem? I mean things like that you don't get out of a textbook.

Still, Tech Four wanted more help, "because I would like to know more about what I am doing, but that might be impatience." The availability of help is, in part, dependent on the culture within the company. He had been working for six months and found it difficult to get meaningful help.

> They (the other techs he works with) have done it for a long time, and they are not always so willing to give up information, or

> perhaps they think it is more than you need to know or that kind of thing. They are real reluctant to give up what they know. This situation is just like, “Well I learned by the seat of my pants, good luck to you” kind of thing. I spoke up and said something about it last week so things have changed a little bit.

Reluctance to help one another can spring from different causes, personal dislike of the fellow worker or a reluctance to share information for competitive reasons. Based on evaluations during the RHVAC program he completed, Tech Four possessed excellent and proven people skills, so his predicament was likely caused by the reluctance of his fellow workers to share their knowledge. To some technicians, possessing exclusive knowledge makes them more powerful. Possession of such knowledge helps to assure their economic security, so there is often great reluctance to share valuable knowledge. Extracting help from such people can be extremely difficult.

By contrast to Tech Four’s less than ideal learning situation, Tech Seven, who is in a formal apprenticeship, is expected to learn from his journeyman.

> The journeyman I am with, he gives me what he thinks I can handle. He is pretty good. He is really patient, and he will take the time to explain it to me. He is actually a really good guy and he lets me stretch my wings a little bit. He goes, “Well the only way you are going to learn is to do it, and I will watch you.” He is an old guy, so I don’t mind it. A lot of times he says, “No, I wouldn’t do it quite that way, but why don’t you look at it at this angle.” That is thirty or forty years of experience. Everyday I learn something from him.
>
> He is really kicked back and we get along really good. I am a hard worker and he likes that. He doesn’t have to hold my hand. That is one reason why we get along so well. We shoot ideas back and forth to each other then we go for it. I might not see him all day, but we have discussed it (the work order) before I did it.

Note the bond of respect between Tech Seven and his journeyman. Even though the journeyman is expected to help train his apprentice, these bonds of respect facilitated the training.

Tech Ten, also an apprentice, was assigned to an older, part-time worker whose teaching methods were not the most effective.

> He was really willing to (show me stuff) but he was teaching me while I was standing on the ground, and he was up there (on a ladder) doing it. It was all word of mouth, it wasn’t me doing it. Then once I proved to him that I could do it, that I knew what he was talking about.... He (eventually) let me

> do all the climbing and getting the wiring from here to there, but he still wanted to wire all the (important equipment).

Though Tech Eight was not an apprentice, he worked in a large facility could call on more experienced workers who were expected to help each other,

> What helped me learn on this problem is having experienced older people around on the job that still knew the older part of the system. You learn that you need those people.

Tech Nine talked with his fellow workers when they met,

> ...at the shop, you run into them. I got a guy (an experienced worker) now who just starting working for us.... I run into him at the shop and we talk, “What would you have done. This is what I found.” It is good to see how they would handle it compared to how I did.

The inverse of seeking help as a learning strategy is giving advice, especially in a problem solving situation like troubleshooting. This cooperative problem solving can be a learning strategy for the person asking for help and a learning opportunity for the person offering help. As stated above, Tech Five had a formal network of experts and co workers, and an informal network of friends he called for help, but he also helped those friends with their troubleshooting problems. He even took a call while in the doctor's office and asked the doctor to wait while he worked on the problem with his fellow tech.

> If (Tech _____) is working on cooling he calls me. If (Tech _____) is working on cooling he calls me. Tech _____ had a problem one time and couldn't figure it out. His boss went out there and couldn't figure it out, and I actually figured it out (over the phone) because I had had one (a similar piece of equipment) do that.

Tech Seven sought and received requests for help from others in his company.

> ...some days I get like two calls a day and I might call someone twice a day. It just depends. I might go a week without calling anybody or getting a call.

Tech One, who worked in a large facility, worked cooperatively with other workers in a process he called "round tabling." This face to face process involved both asking for help and offering help with problems in a give and take opportunity rich in learning potential for all participants.

Mutual respect and friendship are important in facilitating learning between technicians. When the relationship is between a successful, more experienced troubleshooter and a less experienced troubleshooter, the more experienced worker is often looking for more than respect from the subordinate; he or she is likely looking for signs of pride of workmanship in the subordinate. If the more experienced worker is giving away valuable knowledge and skills he or she wants it go to a worthy recipient, someone who will work to the standards held by the more experienced worker.

For example, Tech Seven received this advice from his journeyman,

> Do the job right and you will be the hero, but if you do it the way they (less competent workers) are doing it...you don’t want that because that (reputation) travels with you.

This stress on reputation is part of an almost old-fashioned pride of workmanship expressed by the techs. Though it is not a learning strategy on its own, this pride of workmanship is a personal attribute that can facilitate a learning relationship between a more and a less experienced worker.

This pride of workmanship was a personal characteristic of the techs, part of their work ethic, but it also sprang from their desire to be accepted in the RHVAC community of practice, to be known as “good troubleshooters.” This is important since it signifies acceptance and status within their workplace and even in other workplaces in the region. This pride powerfully motivates the techs’ learning and engenders a determination to excel as troubleshooters.

In the RHVAC community one’s reputation is important. Tech Two, “So reputation to me is very important, and talking to other technicians in my company it is for them as well.”

Tech Seven has been offered jobs at other companies because he has a good reputation, and he describes his reputation as, “Building.”

Tech Eight described his feelings towards doing high quality work as,

> Pride of workmanship.... I like it when people like what I do. It is my reward.... For me, I am kind of like a bulldog. If I can’t fix something right there and now,

> rather than hand it over to somebody else to look at, I will keep it and work on it and run it into the ground. If I absolutely can't get it within a certain amount of time, then I will ask for help.

Tech Five spoke of not being able to solve a problem,

> Nothing bothers me worse than going to something (a troubleshooting problem) and not being able to figure it out, calling (names a senior tech) and having him say, "Oh well we do this all of the time." (The senior tech) will explain it to you and you just want to jump off the building.

But when he made a good diagnosis and repair, "Then you feel like a genius."

All the techs were asked, "Do you take it personally when you get a callback?" A callback occurs when the tech is called back to a job because the problem was not fixed on the initial visit. Tech Nine replied, "Yes! You have to. I mean that is your job.... I mean it is what I do. When something like that (a call back) happens it bugs me for days."

Though pride of workmanship traditionally applies to skilled trades like fine woodworking or automobile painting with its aesthetic qualities, it can apply to troubleshooting. There is efficiency of effort and a simple elegance in the solution to a technical problem which is a “good fix.” No artifact is produced for others to admire, and the troubleshooter leaves no trace; but the equipment now works properly and will do so for the foreseeable future.

Along with pride of workmanship and concern for reputation comes the fear of not doing well. Tech Eight,

> There was a fear at the beginning (when he started work), even today, but it was stronger at the beginning. It is a fear of not being able to solve the problems.

Tech Four, “Again, you don’t want to screw something up.”

Not surprisingly then, it is very satisfying to solve a troubleshooting problem. Tech Three,

> I would say the way I like to learn best is probably in troubleshooting, even the complicated stuff, because there is a certain victory that you experience when you do finally get the problem resolved, and I think that is kind of maybe a selfish type of feeling.

Tech Three also mentioned the stress of troubleshooting, especially when he started working. “Apprehension, fear, and intimidation,” was how he described it. In describing how he felt after making an expensive repair that did not correct the problem he said, “It was pretty ugly.”

Tech Five, after finding that a tiny spider web had blocked air flow into gas furnace said,

> On the way home (after fixing the problem) I was really upset because if I had been working with someone and they knew (the type of equipment). They could have said, “You know sometimes that little tube gets clogged, and the first time they try to use it in the winter it will do that.” I know it now and it will never fool me again, but sometimes you wonder what cost it has to your soul by standing there for three hours and not to mention charging somebody.

And finally, Tech Eight linked his pride in successful troubleshooting to his learning.

> For me, it (a difficult problem) is something I have to solve. I don’t look at it as being a headache or “I hate this or I hate that.” If I don’t know it, it drives me crazy until I get it, until I know how it is working. I have to know how it works, not halfway or “I got it working now, I am going to leave it alone.” I have to know how exactly everything works within that system to make it work. I can’t just fix it. You are going to have a lot of people that just fix stuff and go on. I can’t do that. I have to know how it is working, every little bit. I can fix it and go on, but it doesn’t solve the problem. The problem just resurfaces.

The social nature of learning was evident, even amongst these independent workers. They sought help from others in person when possible, or through cell phone technology when they were working alone. Interpersonal relationships were critical in facilitating learning from others whether in person or on a cell phone. Learning from more experienced workers was facilitated by the techs' pride of workmanship which was also a motivator for learning to troubleshoot well. As part of their learning from troubleshooting, the techs reflected upon their actions and the causes of particular problems.

Reflection

All the techs reported using some kind of reflection when learning from troubleshooting. The type of reflection ranged from the hard, often fast-paced, analytical work of testing components, to the slower-paced work of finding the root cause of the problem. The techs' responses revealed two types of reflection: working through the problem and root cause analysis.

Working Through the Troubleshooting Problem

The techs learned as they were working to solve the troubleshooting problem. Working through the troubleshooting problem combined action, speculating, testing, then analysis; it was not passive reflection. It was hard mental work involving analysis and interpretation of test results and acute observation, and is similar to Schön’s reflection-in-action (Schön, 1987).

For example, Tech Two was working on a commercial air conditioning unit that was not cooling the building properly. In troubleshooting the problem he focused on the electrical system. Working from the electrical schematics he used a sophisticated electrical test meter and, “checked for 24 volts at RY1 and RY2.” These were the input terminals from the thermostat and the meter registered 24 volts so the cooling compressor should have been working. He then tested,

> ...both the high and low pressure (safety) switches, and they were closed (as they should be). So after reading the schematics (Reading a schematic involves interpretation of abstract symbols that represent electrical and electronic components and their operational relationships.) and looking at things over and over again, I could see that those two switches were the only switches in the circuit. I checked them again and racked my brain, and then I realized that there was an option for the economizer module (a device that controls airflow for maximum efficiency). So I tested

> (electrical) power into the economizer terminals, which I got, but no (electrical) power out, and so it had a bad economizer module (which was then replaced).

Tech Seven described how he applied reflection to a problem,

> I just look. I look and I think and then I look some more and then I watch. That is how I learn.... I definitely try to figure out what went wrong and at that point I know I am learning from experience.

Tech Three engaged the problem directly,

> I don't do well with books as far as something that is actually going to stick. I think that doing stuff is a better method for me than reading a book.... You start thinking when you can't resolve a problem with what you think is obvious, then you start thinking about a lot of other possibilities (possible causes of the problem), and you even create some possibilities that you are not even going to have to fix. The next time you do something like that you are going to have a broader range of possibilities.

Tech Ten had learned to troubleshoot using a computer-operated, climate control system. He learned, "Hands-on. Just sitting in front of the computer." He, "Just started playing with it. I started putting two and two together." He also used manuals and printed out many help documents, draining a complete color ink cartridge with all the printing, but his learning process was one of reflection-in-action.

This active, working-through-the-problem reflection seemed to provide experiences that could be analyzed at a later time. After the troubleshooting problem had been solved, the techs described a subsequent type of reflection, root cause analysis.

Root Cause Analysis

Root cause analysis is applied to discover the true cause or causes of a failure after a repair has been made, or after a serious accident (Ammerman, 1998; Rooney & Heuval, 2004; Stein, 2003; U.S. Department of Energy, 1992). At one extreme it is a scripted, engineering procedure for determining root causes of a failure. As it was described by the techs it was more casual, more a determination to get to the root cause of the problem. The techs were not practicing formal root cause analysis, but they were thinking about how to find the root cause of a problem and that led to useful learning.

A simple example of root cause analysis is the process that should follow the tripping of a circuit breaker. Because circuit breakers trip in response to a potentially serious electrical problem, techs must try to find out why a circuit breaker tripped to prevent a repetition of the problem or to forestall an even more serious problem like a fire.

Tech One described an example of root cause thinking. After he had solved an intermittent problem he thought about the cause of the failure and determined that dirt encrusted equipment might be the cause of the initial problem.

> The whole unit itself was very dirty. It had been running hot for a long time. The condenser coil was hot, and the fan kind of worked intermittently. The bushings were bad in the fan. It would run, but it would run slow at times.... The (excess) heat may have had a chance to melt some of the insulation on the (defective part).

When describing a multilayer problem Tech Nine said,

> Basically what we were doing was just following through the system, and when you would find the potential problem you make the fix, so (sometimes) you didn’t get to the root cause of the problem until three or four tries.

Tech Three described how root cause analysis helped him solve a problem with a furnace that was caused by undersized ductwork (leading from the furnace to the chimney). The problem manifested itself in the furnace malfunctioning, but all the furnace components were operating correctly. The problem resulted from restricted airflow into the furnace caused by the too small ductwork leading out of the furnace. Determining this took extended testing and resulted in disagreements with the contractor who had installed the improper ductwork, but the ductwork was replaced and the problem was solved.

Tech Seven described one problem he solved,

> There were like five things wrong.... All of them could have been the cause of the problem, but the final thing I came out with was it had a bad (computer) board because it kept resetting on the power (going off). It wouldn’t hold its values (possibly because of power fluctuations)...so I just flipped the breaker (off)...and it (the board) reset to factory (settings, not the settings needed for that particular operation). It should hold it (the correct settings) and that was our problem there, but there were other things too, like the filters were collapsed and so all of the coils were completely plugged so they were getting no air flow at all.

Tech Eight prevented repeated refrigerator freeze-up by rearranging how material was placed in the refrigerator. The usual repair had been to simply shut down and defrost the refrigerator then to bring it back into service. He decided to look more deeply into the problem and realized that the refrigerator was not the correct type for the intended use. After experimenting with several fixes he had the refrigerator users place the products differently inside the refrigerator. This prevented the freezing problem by allowing for better air circulation inside the refrigerator. In this case the problem (freezing) and the easy solution (defrosting) hid the root cause of the problem.

> So I started thinking, it is basically an airflow problem. So I did some other things and made some other changes in the refrigerator and it kind of helped. I asked them to just not fill up the refrigerator on the top shelf.

> You are going to have a lot of people that just fix stuff and go on. I can’t do that.... I can fix it and go on, but it doesn’t solve the problem. The problem just resurfaces.

Tech Nine expressed consternation with the “magic fix” where it is not possible to find the cause of the problem.

> You have a no heat problem, you go there, and they have had the furnace off, you turn it on and it fires right up. The problem kind of fixes itself. You are going, “What? It is just not right.” That always bugs me.

> I think about that for days, just understanding why something happens the way it did.

Tech One was expected to take what he learned through troubleshooting and apply it to preventive maintenance procedures. This is a major goal of root cause analysis in industrial settings, modifying preventive maintenance routines to prevent future problems. Applying what is learned through preventive maintenance work reinforces the learning created by solving the problem.

Tech One,

> You get a premise or an initial idea through troubleshooting that really doesn’t get driven home until you apply it to the maintenance side of it. You see that when you take care of those issues, to make sure that what has failed doesn’t happen (again) and you are successful at that.

Similarly, after Tech Five found a wasp nest blocking air flow in a furnace, he added searching for and removing wasp nests and other debris from heating units during maintenance inspections.

Tech Seven was aware of people who do not put in the time-consuming, conscientious effort required by root cause analysis procedures.

> What I do know is that people automatically assume that they fix something right away, and they don't take the extra half hour or so to watch it (run). They fix something and it is not fixed, or they break it more. I don't like doing that. I like to know why. If I don't know why, then I didn't fix it.

The techs were thinking and doing, working through the problem, and thinking about the deeper levels of causation, root cause analysis. They were learning from both activities. Often there is not enough time to practice root cause analysis when one is moving from job to job in RHVAC service work, C. Morris (personal communication, May 25, 2006), but that does not preclude thinking about root causes, and was, as the techs described it, a form of constructivist learning.

Seeking Information from Manuals

Traditionally manuals have meant paper documents that were often missing when they were needed most. Manuals are still published on paper, but increasingly the technical material found in manuals is located online, available for downloading, printing, or viewing onscreen. Several of the techs briefly mentioned using online resources, but focused mostly on paper manuals.

Nine of the 10 techs reported using paper manuals frequently. The techs reported using the manuals in two ways, to understand the operation of equipment and using troubleshooting charts. All nine agreed that they would use a manual when working on new or unfamiliar equipment but were less likely to use a manual on familiar equipment.

A troubleshooter cannot repair a modern RHVAC system without knowing the normal operation for each component; therefore techs used manuals to learn about machine operation and to determine acceptable operational parameters. The troubleshooting section of manuals usually offers suggestions for possible causes of certain symptoms and may prescribe step by step testing procedures.

Tech One, “Manuals are a big help, especially if they have at least a troubleshooting section.” But he does not always use them if he is familiar with the equipment.

Tech Five has a library of manuals, “I keep them all. They are all in shelves in the back of my van. I mean tons of it. I mean every book I have ever gotten;

it is in the back, all the tech manuals." When I interviewed Tech Six he had been studying manuals in his home office.

Tech Eight refers to manuals when encountering unfamiliar equipment,

> Some of these (brand name) refers (refrigeration systems) that we have, I have to read the manuals to understand exactly everything that is going on with (it).... I study it before I ever start working on it.

Of the all the techs, only Tech Two did not commonly use manuals,

> We don't have any manuals. The first manual I looked at was with this walk-in freezer because I had to, but mostly I don't look at manuals. I will sometimes call tech support instead of the manual, so I guess you could kind of call that a manual.

Tech Two, who did not like reading, would rather learn by doing then remember what he has learned. Tech Two shared membership in an informal cell phone network and the other two members marveled at his power of recall. Tech two described how he learned,

> Yes, pure memory and pure experience. Like I said, once I do it then I, most of the time, remember it. It is pure hands on. If I read a book, it is not there. It (my best learning) is pure hands on.

The techs were reading technical material for specific information like machine operation and troubleshooting help, but this activity became less frequent as the techs became more experienced with specific equipment. In conjunction with reading, the techs were also learning from writing in log books or work orders.

Writing in Log Books or Work Orders

In some technical settings like boiler rooms, keeping a log book is a legal requirement. Many RHVAC techs keep a small notebook for recording relevant information regarding their work. All RHVAC service techs fill out work orders that provide some level of detail regarding the work completed. Increasingly these work orders are entered into a portable computer rather than being written on paper. The techs were asked specifically about their learning from writing in log books or work orders since they were required to keep a logbook in their RHVAC training program.

About half the techs reported learning from writing in a log book or through completing work orders. However, they indicated that the logs served mostly as reminders for technical information.

Tech One used a log for technical information, but kept troubleshooting experiences in memory, “Because it is something that stays in my head well. Numerical information does not stay in my head as well as some manufacturer screw-up.” He used his log for,

> ... going back and measuring what my results were with like kinds of issues.... Trying to go through in my mind, taking each issue and measuring it against what I had to go with on a similar issue.

Tech Three also kept a log book. When asked how much he learned from working through the problem versus writing it down in his log, he replied,

> Probably 95% working through the problem. Writing it down in the log book is good too because when you write it down, it places a picture in my brain about what happened.

Tech Six described how filling out his work orders aided his learning, “It does because I have to explain on the work orders what I did, why, what is my opinion.”

Tech Eight used a PDA (personal digital assistant, a palm-sized computer). He kept mostly technical data on the PDA.

> There are so many things going on within my areas I have had to keep a PDA. There is so much stuff it is so massive, I can’t keep it all in my memory anymore, so I wear a PDS which I call my brain on a belt.”

Tech Five carried a small notebook with him.

> I have my book, I keep it here (his shirt pocket). I have got a couple of things in there, just notes and stuff that I have fixed. I write little things in there that make sense to me.

Tech Nine was,

> ...always writing down what I am doing, anything I have done from the day. It might be something simple or if it is something bothering me I write in detail the way I handled the situation, especially if the customer is unhappy. You want to make sure you note everything you did.

Tech Two, who learned best from doing rather than studying written material, remarked that he felt pressure from his company to work quickly and did not have time to keep a log book.

Personal preferences seemed to guide the techs writing regarding content and the amount of writing done by each tech, yet there was some indication that it was helpful in the techs’ learning. The content of that learning was the focus of question three in this study.

Question Three: What did the techs learn from troubleshooting?

The techs were learning:

- personalized troubleshooting scenarios
- how to analyze electrical schematics
- to be more confident in their troubleshooting skills.

Personalized Troubleshooting Scenarios

The techs were learning personalized troubleshooting scenarios that were cause and effect scenarios being built by each tech as he gained experience with a variety of troubleshooting problems. These scenarios are personalized because they are somewhat unique to each tech’s experience. For example, a tech who worked on commercial boilers would be building an experience base of boiler problems and their causes.

As an example of how personalized troubleshooting scenarios might be used each tech was asked to comment on a quotation from *The RHVAC News* (Skaer, 2004), a weekly magazine of business, sales, and technical articles of interest to RHVAC business owners and techs. The quotation was read to each tech, and then each responded. The quotation read:

> When responding to a refrigeration service call at a supermarket, the refrigeration technician immediately plays “problem percentages” upon entering the store. Most refrigeration equipment breakdowns are repeat problems to some degree. Playing the percentages when responding to a service call enables the technician to get to the root source of a problem as quickly as possible to prevent perishable product loss. (p. 1)

Playing the percentages means running through a list of possible causes for the technical problem being confronted. For example, a slow refrigerant leak might be suspected when an air conditioning system that has worked well for years is not producing cool enough air, but is otherwise working well. It is possible that enough refrigerant has leaked out of the system so that it can no longer cool the premises.

All the techs agreed that they were learning something akin to problem percentages. They were creating personalized troubleshooting scenarios, symptom and cause “troubleshooting charts” that they constructed mentally, and then recalled from memory when troubleshooting. This constructivist learning can be understood as creating a matrix of personalized troubleshooting scenarios, using the word scenario as a, “sequence of events, framework, structure” (McKean, 2003, p. 1347). The symptom and cause organization is a possible framework or structure of the scenarios that would be familiar to the techs.

Tech Four described how he applied this type of cause and effect knowledge while working on an electric heating system that was not shutting off.

> Having a little experience with sequencers (an electrical switch) not shutting off that was kind of my first choice.... I knew that sequencers were a frequent problem (with these types of systems) and I tested all of the sequencers on it and one of them was welded shut (therefore it would never shut off the heat. He replaced the sequencer to solve the problem).

Tech One, who worked on the same equipment most of the time described his growing familiarity with the equipment he was working on.

> You know which units usually give you what kind of problems. Different manufacturers usually have the same issues with their units. A certain icemaker will usually have one certain relay that goes bad or a water sensor that goes bad. It is very typical. It seems like each manufacturer will have at least one major weakness that percentage

> wise will be the one that I will look for first.

The longest serving tech, Tech Six, had developed many troubleshooting scenarios, “After you have done a couple of thousand units, a lot of it just becomes repetitious.... Anymore, it is just kind of like it is all repetition.”

Tech Four, a tech who had just a few months experience, was building his experience base

> I just don’t feel like I have had a whole lot of experience to start narrowing it down to the different problems.... (When the furnace won’t come on.) We get a lot of, “My thermostat is bad.”, and right away you know it is not...right away I am starting to look for (electrical) power coming from the (electrical circuit) breaker.

Tech Two began his day by looking over his work orders and was already thinking through the possibilities and preparing for troubleshooting.

> We look over our jobs and if there seems to be a job that we may know what is already wrong with it, we have a parts room and we will grab that part. There are a lot of (manufacturer’s name deleted) furnaces that have a problem with their modules. We usually have them in our vans anyway, but we grab them to be on the safe side.

Tech Nine described his use of use of personalized troubleshooting scenarios,

> When we get our calls, or we get a page, our dispatcher is really good about (letting us know what is going on) and right away you just start, “Okay, what would cause that?” You get an idea in your head before you even pull in the driveway where the problem may be.
>
> ...the more familiar you get with the equipment and the more you work on it, obviously the more knowledge you have. So when you get the call, to start thinking, “Okay, I have heard this before. Other customers have said this is what was going on.” You just kind of remember and break it down.

Tech Three described similar thinking: “Since I am working on the same equipment typically, I know it well enough to know what a possible cause of a problem could be and right where to start looking.”

Tech Eight agreed that he was building personalized troubleshooting scenarios, but he had reservations regarding scenarios that become “received wisdom.” In an incident described earlier, he described a refrigerator that froze up frequently. The long-time fix was to defrost the refrigerator then bring it back into service, but the problem kept recurring. The received wisdom of defrosting the unit did not solve the problem so that it would not repeat.

In a similar vein, Tech Seven was hesitant about becoming too rigid in his thinking even as he was gaining experience,

> I go inside a building not knowing what is going on right now, and I think that kind of helps me because I don't have any preconceived ideas at this point. Maybe down the road I might get that way, but I am hoping not to. Right now everything is an open book.

Tech Five described a problem where his previous experience led him away from the correct cause of a problem.

> I showed up at the call and the inducer draft motor was running, which usually indicates a problem somewhere else like a safety circuit.... I probably spent forty-five minutes up there trying to figure out what the problem was. I couldn't figure it out. I finally pulled the panel (a cover on part of the machine) there with the schematic on it (schematic diagrams are usually glued onto the inside of machine panels) and realized that it was the centrifugal switch on there.

The centrifugal switch was attached to the motor shaft and closed a set of electrical contacts when the motor was spinning fast enough to supply enough air to the gas furnace. Without the correct amount of air the gas furnace could explode. The closing of the switch sent a signal to the unit's computer to indicate that the motor was running correctly. If the motor was not running correctly the computer would not allow the gas valve to open and the furnace would not light, avoiding an explosion. In this case, the motor was running, but because the centrifugal switch would not close, the computer was not receiving the electrical signal and would not allow the furnace to light. He continued with his description of the incident.

> I went back, looked at the schematic and traced it, and the first place it goes is through the centrifugal switch...so I wired around the centrifugal switch and it (the furnace) fired right up.

This final quotation illustrated both the benefits and drawbacks of building these personalized scenarios. The scenarios allowed the techs to solve problems more quickly, but could become too automatic and lead away from the cause of the problem. Building personalized troubleshooting scenarios is an example of the type of learning attributed to experts (Beriter & Scardamalia, 1993), and the techs were building their expertise through their learning from troubleshooting. A particularly important skill was learning to analyze electrical schematics.

Analyzing Electrical Schematics

As indicated in the descriptions of RHVAC tech work cited in Chapter One, electrical and electronic controls have become more important in the operation of RHVAC equipment. Therefore, the importance of electrical skills in troubleshooting has increased dramatically. Analyzing electrical schematics is a skill used in solving almost every electrical problem, and all the techs indicated the importance of using electrical schematics in their troubleshooting. They all agreed that troubleshooting with schematics taught them how to analyze schematics more effectively.

Tech Five, when asked what he learned from solving a particular problem, said,

> Well most importantly, once again, how nice it is to know how to read a schematic. I talk to guys that don’t really understand schematics. I have had a guy who has been working in the field for seven years call me because he knew that I know how to read them (schematics).

Tech Six emphasized the importance of reading (analyzing) schematics,

> Reading schematics would be, “numero uno.” You have to be able to know where it is.

> Otherwise you are going to poke your head in there going well maybe, well maybe. There are a lot of brands that have these itty bitty clear six/eight prong relays on them that you can’t see because they are turned around backwards. You can’t get your probes (of a test meter) in there, so you grab your line diagram (a type of schematic). It is right there.
>
> One of the senior techs where I work, that was the biggest thing he did with me when I was learning.... He would just simply hand me the back of a panel (that had a schematic glued to it) and he goes, “Tell me how this (equipment) works.” I fumbled around the first few times and finally I figured it out.

In some situations Tech Six said, “I have got wires running all over the place. I will build my own wiring diagram (a type of schematic).”

Tech Seven described his use of schematics,

> If they have a wiring diagram (a type of schematic) I use it. As I am doing that (inspecting the equipment), I am reading the schematic that is hopefully (glued) on the (equipment access) door. If it is not on the door, then it takes a little bit more time because I have to go, “Okay this goes to here.”

Generally schematics refer to electrical diagrams, but blue prints and installation design sketches are also used in electrical troubleshooting. In one situation Tech Ten was working on a piece of equipment that had been installed incorrectly.

> The electrician says, “Take a look at these plans (installation drawings) and see if you can come up with anything.” I sat down and looked at the plans. I am looking at the plans, looking at how we are standing at the motor, and the motor is facing me. I think, “Well, wait a minute that motor is facing me.” That means the fan, all the duct work is going to be on the other side.... Once they put the motor in then they built everything around the motor and it looked perfectly fine, but it was turning the fan backwards.

The techs often used sophisticated digital electrical test equimpent in conjunction with the schematics. All the techs graduated with fundamental electrical troubleshooting skills which included using such meters.

Tech Two was working on a commercial air conditioning unit when he used his meter in conjunction with the electrical schematics and, “checked for 24 volts at RY1 and RY2.” These were the input terminals from the thermostat and the meter registered 24 volts so he knew that the cooling compressor should have been working. He then used the meter to test,

> ...both the high and low pressure (safety) switches, and they were closed (as they should be). So after reading the schematics .... I realized that there was an option for the economizer module. So I tested (electrical) power into the economizer terminals, which I got, but no (electrical) power out, and so it had a bad economizer module.

Tech Four used electrical testing equipment to test specialized timing devices to learn if they were damaged “...I tested all of the sequencers on it (an electric heat element), and one of them was welded shut.”

In the last two instances, the techs consulted electrical schematics to identify and locate components, and to determine what test results would indicate if the components were working correctly or were malfunctioning. The increasing electrical and electronic complexity of RHVAC equipment absolutely requires that techs understand electrical troubleshooting. Indeed, electrical troubleshooting skills are the most requested technical skills by employers who hire graduates from the RHVAC program where the techs took their formal training.

Tech Seven stressed the importance of his electrical learning “If you don’t have a grasp on that (electrical) I don’t think you can do the job.”

All the techs agreed that, through troubleshooting, they were improving their understanding of how to use electrical test equipment as well as improving their analytical use of schematics.

Gaining Confidence

The techs reported gaining technical skills, but Tech one also described how his confidence had improved regarding his ability to troubleshoot. As described previously, troubleshooting RHVAC equipment is stressful, and troubleshooters must be confident to survive in the RHVAC trades. It takes confidence to say to customers, “I’m here, and I am the person to fix this problem.” That confidence comes from success in troubleshooting and in one’s ability to learn what is needed to be successful.

Tech One,

> With the confidence then you know that you have established in your own mind that you

> have learned something.... Then you are more confident to put yourself in places where you were kind of unwilling to go because you know that you will learn. It takes time. You start learning what your absorption pace is for knowledge and you know it is going to come to you. You figure out what paths you need to take, either in your mind or with manuals, tools, or who you are going to talk to.
>
> It (learning to troubleshoot) is like moving into a new neighborhood, you have your home base and you are comfortable with it and then one day you get tired of being there. Then you walk down this one street and get to know what is down the other street and you get to know it. Pretty soon, over time, you get to know your neighborhood, you branch out and you know your city, and then you know your state.

He described the confidence of being a good troubleshooter, “When you know you are not going to get lost. You know you are not going to get into the wrong neighborhood and get beat up.”

Question Four: When did the learning occur, during troubleshooting, or as a result of later reflection?

When the Techs Learned

This question was asked in an attempt to determine the relative importance of learning before or after troubleshooting, but the results were inconclusive.

Table 4-2 lists the techs’ responses to the question of when they learned.

Table 4-2

When the Techs Learned

Tech	Reflection after troubleshooting	Learning during troubleshooting
One	50%	50%
Two	Less	More
Three	Less	More
Four	More	Less
Five	More	Less
Six	More	Less
Seven	50%	50%
Eight	50%	50%
Nine	More	Less
Ten	Less	More

The results do indicate that learning was not strictly confined to the actual troubleshooting and that later reflection was often required to make sense of what went on during troubleshooting.

Tech One said this about whether he learned during or after troubleshooting,

> It would have to be both, because obviously you are putting two and two together while you are performing the different functions (troubleshooting tests). Afterwards, you know, when you are patting yourself on the back, you have time to reflect on how it really came together, what it really took to get the job done, the patience, the knowledge of the tools, your knowledge of the refrigeration cycle. It all comes together right there. Mostly afterwards when you have been successful. When you are in the middle of troubleshooting you don't have time to put it all together.

Conversely, Tech Three felt that he learned more during troubleshooting, because he had to think through things on the spot. Tech Six had a library of technical material in service van and in his home, as does Tech Five. Both men refer to technical manuals as part of their troubleshooting and occasionally after work in their homes. Tech Seven also does some work at home, often figuring out the next day's work. Tech Four takes home manuals and studies equipment that he has helped install or troubleshoot. Tech Ten also works on understanding technical issues after work, "I have to because there is a lot of my apprenticeship job so far that hasn't made sense to me."

Tech Nine felt he learned more after troubleshooting.

> I would say for me, on something that is difficult, it is probably more so after (troubleshooting), as I start thinking about what I did and talking to other people and kind of bouncing ideas off of each other. I probably pick up as much or more afterwards.

Tech Eight,

> I do some of my best work just before I fall asleep. It is hard for me to go to sleep, so I tend to think about what I did in the day and what actually happened. I can actually sometimes, just before I fall asleep, piece it together and kind of watch it work as I am sleeping and then in the day I come up with a clearer idea what is going on.

Tech Three,

> After I went to bed, and I was thinking about trying to figure out this problem (with a gas furnace) and I remembered that it had a humidity sensor that had failed. I came the conclusion that the humidity level was not reading properly on the computer (controlling the furnace) and that is actually what it ended up being.

Tech One,

> Obviously, I will take issues home that I have not corrected yet and that I am still learning on, and I will think about those through the day or the night and try to think up a proper way to troubleshoot it (and) where I can go to get information. I will try to develop a path through the night, and obviously when you are there on

> the job you try to do the same thing. So after work you mull it over. You think about what you need to get accomplished, what the unit should be doing, what the unit actually is doing, what kind of result that you should get when you do your testing with your tools, and so forth.

Tech Two, a mobile tech, is under a great deal of pressure to complete jobs. He felt that there was not enough time to reflect on the job, but after work he did reflect about troubleshooting problems he had encountered.

> I feel like I am rushed a lot. There are always like five jobs. Sometimes there are less and sometimes there are more, and there is always that push... they are hounding you to get these jobs done.

Tech Five used reflection after troubleshooting.

> If you fix something you really didn't know how to fix, a lot of times it is just luck, kind of stumbling upon it.... On the way home I sit there and I never listen to the radio, it is always quiet in my van, and I run over everything through my head a million times and try to figure out how I could have done it better and faster. That is when I kind of figure it out and it makes sense. A lot of times I have fixed them and made them work and not really understood why or what actually caused it in the first place. That root cause thing you talked about (in class) is really important.
>
> During (troubleshooting) it is more mechanical than anything. You just get going and kind of check down and do what you do to

> fix it, and then you think about it on the way home.

This question failed to elicit a clear either/or answer regarding when learning occurred in troubleshooting. Clearly the techs were learning during and after troubleshooting.

Summary

The techs identified the importance of informal workplace learning and the importance of learning from troubleshooting. In the RHVAC community of practice it is expected that techs will learn much about their jobs as a result of their work experiences, informal learning. Another feature of the RHVAC community of practice, at least for service techs, was a pride of workmanship which manifested itself in being able to troubleshoot problems quickly, efficiently, and completely. This pride of workmanship helped facilitate learning from others. The amount of formal and structured on-the-job training varied depending on the company culture and economic condition of individual RHVAC employers, but the techs did expect more formal training than they received. The stationary techs working in facilities generally received more training than did mobile techs, in part because these facilities do not require their techs to be billing hours to maintain their economic viability.

The techs learned on the job by seeking advice and help from others, in person when possible, but also via cellular phone. Five of the ten techs were involved in informal cell phone networks of people they had met while attending school. Formal phone networks consisted of tech support personnel and more experienced workers. Reflection during troubleshooting occurred in two stages, working through the problem while trying to get the equipment running, and root cause analysis which consisted of trying to understand the root cause of a particular problem once the repair had been made. The techs also sought information from manuals for two general purposes, to understand the systems they were working on, and for assistance in troubleshooting. Some of the techs felt they learned from writing in log books and on work orders, but most seemed to prefer learning by doing, in this case, troubleshooting.

The techs were constructing personalized troubleshooting scenarios that featured symptom and cause organization; what cause or causes could create this symptom? These scenarios had the same function as troubleshooting charts or flow diagrams except that they were personalized, based on the experiences of the troubleshooter. The techs were improving their ability to use electrical schematics and electrical test equipment when troubleshooting. They were also gaining confidence in both their skills and their ability to learn on the job. Finally, the techs were almost evenly divided about when they were learning, during or after troubleshooting.

CHAPTER FIVE: DISCUSSION AND SUGGESTIONS

This chapter presents a discussion of the findings reported in Chapter Four and suggestions for community college instructors who train technicians. These suggestions are presented in the spirit of reader or user generalizability, Walker (1980).

> The problem of generalizing ceases to become a problem for the author. It is the reader who has to ask, what is there in this study that I can apply to my own situation, and what clearly does not apply? The question 'What use is the case study?' raises more clearly the issues of the relationship of research to the making and taking of decisions. (p. 34)

It is anticipated that technical instructors will adopt, adapt, or abandon the suggestions in this chapter according to the results of implementing those suggestions into their training exercises. This chapter is organized under the following headings:

- integrating informal learning strategies into technical training
- pride of workmanship as a motivator of and facilitator of informal learning
- learning from seeking and giving advice

- learning from reflection
- learning from manuals
- learning from writing in log books or work orders
- learning personalized troubleshooting scenarios
- the importance of electrical skills
- when the techs learned
- learning from troubleshooting
- suggestions for future research
- conclusion

Integrating Informal Learning Strategies into Technical Training

Informal workplace learning was important to the techs and was expected of them as a cultural condition of employment. This finding strongly supports Brockman’s (2004) assertion that the machine operators she studied relished their informal learning opportunities and saw them as an important type of learning. Brockman’s subjects also reported that workplace problem solving was a significant learning opportunity, and all the RHVAC techs agreed that troubleshooting was an excellent learning opportunity.

The importance of informal workplace learning resulted, in part, from the inherent limitations of most formal technical training (Kleifgen & Frenz-Belken, 1996). Lectures, demonstrations, use of hands-on trainers, and computer simulations used in formal training are all effective teaching strategies, but, even in the best of circumstances they cannot portray the complexity of workplace troubleshooting problems. Formal technical training can simulate the most common problems, their diagnosis and repair, and this uncluttered approach is sound educational practice for students who could be overwhelmed by complex variables. Technical education at community colleges might be strengthened if students understood that they will eventually learn the majority of their troubleshooting skills in the workplace because of the richer complexity of workplace problems.

In addition, the techs learning from troubleshooting was informal, in part because they received varying, usually modest, amounts of formal workplace education and structured on-the-job training. There are reasonable economic explanations for this emphasis on informal workplace learning; formal training removes profit-generating employees from work, yet company overhead does not stop during their absence. This “school of hard knocks” thinking is also prevalent because it is how many company owners and senior techs learned their troubleshooting skills. The techs working for organizations as stationary techs reported receiving more on-the-job training than the mobile techs, and apprentices were receiving classroom and structured on-the-job training.

Technical instructors preparing students for work in trades where informal workplace learning is important could counsel their students to consider the availability of and types of training, including informal learning opportunities, offered by employers as part of their job search. This will require individualized advising based on the learning skills and needs of particular students.

Given the variability of formal training available in some occupations and the overall prevalence of informal learning discussed in Chapter Two, technical students in community colleges could benefit from learning about informal workplace learning strategies while in school. To facilitate this augmentation of technical training, research into the effectiveness of various informal workplace learning strategies should be undertaken. When the results of such research are made available to community college instructors they could integrate informal workplace learning strategies into their technical training.

Pride of Workmanship as a Motivator and Facilitator of Informal Learning

The techs' comments indicate that they hold effective troubleshooting in high esteem as do their employers and their fellow workers. The techs wanted to join the RHVAC community of practice and to be known as "good troubleshooters" not only because it pays well but from a strong sense of pride akin to pride of workmanship. The concern of the techs for their reputation, their insistence on wanting to learn all they could from their work and their persistent efforts to find the root cause of difficult problems are all constituent attributes of pride of workmanship in troubleshooting. Thus, for these techs at least, pride of workmanship was a powerful motivator for learning. Their striving to be accepted as good troubleshooters also supports the notion of the importance of communities of practice setting standards for acceptable learning and competence (Bredo, 1994; Clancy, 1995; Wenger, 1998).

To promote pride of workmanship, technical instructors could model pride of workmanship in their teaching by keeping current in their trade skills and by insisting on rigorous, competency-based standards in their own and their institution’s technical training. Technical students could learn that practicing pride of workmanship is one way to convince more experienced workers to pass on important skills and knowledge.

Learning from Seeking and Giving Advice

As postulated in constructivist thought (Doolittle & Camp, 1999) and situated cognition literature (Bredo, 1994; Brown, Collins, & Duguid, 1989; Lave and Wenger, 1991; Lemke, 1997), learning is socially organized. Even though most of the techs worked alone most of the time, they compensated for their isolation by using cell phones but still used face to face help when it was available. They described two general types of cellular phone help networks: formal networks that consisted of manufacturers’ tech support services and more experienced workers, and informal networks of friends, associates, and fellow workers.

The techs indicated that bonds of personal friendship and respect facilitated learning from others through informal cell phone networks and in person. As Tech Ten reported, some of his fellow workers were reluctant to assist him in his learning. It is likely that some technicians withhold their knowledge and skills from others to protect their own economic security, the infamous “job security.”

Techs got help from more experienced workers based on bonds of mutual respect and as a result of the techs’ willingness to learn and work diligently while respecting the conventions of a particular workplace. This could be described as “positive apprenticeship relationships”, relationships between a more and less knowledgeable worker that promote learning. Therefore, the need to develop such relationships with fellow workers is a fact of economic life that could be included in people skills training for RHVAC and other technical workers. Understanding the culture of the community of practice that students are entering might help them understand how to approach more experienced workers when asking for help.

While seeking help is recognized as a learning strategy initiated by a learner, giving advice or help is not always considered a learning opportunity for the person giving the help. Depending on the expertise of the person giving help and the type of problem encountered, it might be possible to learn from giving advice, especially when all concerned could witness the results of applying that advice. Brockman (2004) described workplace learning as a negotiation, and in some negotiations all parties can benefit. Therefore, students might learn more effectively on the job if they became aware of the learning possibilities when receiving <u>and</u> giving advice.

Learning from Reflection

These techs thought carefully and analytically during troubleshooting in two distinct phases: (1) working through the problem and (2) root cause analysis.

Working Through the Problem

Doing the troubleshooting is the first phase in learning from troubleshooting, the action phase, and it can be highly analytical. The RHVAC techs reasoned, used their senses, recalled past experience, and coupled these data with their knowledge of system operation, then evaluated test and observational data to solve troubleshooting problems. This mental and physical work provided experiences the techs processed into knowledge and skill during later reflection in a process similar to Schön’s (1987) reflection in action.

Root Cause Analysis

These techs had learned about root cause analysis as part the troubleshooting process but not as a learning strategy. Root cause analysis means discovering the true cause or causes of a failure after a repair has been made. In addition to pursuing root cause analysis as part of troubleshooting, the RHVAC techs appeared to be using root cause analysis as a learning strategy, or as a way of thinking that promoted learning. In manufacturing facilities, root cause analysis is often incorporated into a computerized maintenance management system and is an important source of institutional learning. In the techs' troubleshooting, the analysis engendered by root cause analysis promoted learning by forcing them to think through the complete operation of the system and any related systems. They had to consider any variables acting on the system to determine cause and effect relationships that were not immediately obvious.

College instructors might be able to promote learning from troubleshooting by presenting root cause analysis techniques as a maintenance procedure and as a personal learning strategy. The publishers and producers of RHVAC training materials could consider including material relating to learning from troubleshooting. Based on this finding root cause analysis became a central learning strategy in an augmented troubleshooting process that is discussed learning later in this chapter.

Learning from Manuals

All the techs mentioned learning from manuals; though several did not use them frequently, indicating that using this learning strategy is a matter of personal preference. Still, the use of manuals by most of the techs indicated that using manuals and other types of reference material can be an effective informal learning strategy.

Technical instructors could help to prepare their students for this type of workplace learning by devising learning activities focused on using all types of technical material in troubleshooting simulations. Reading level prerequisites of students entering RHVAC and other technical programs should be adequate for reading the technical material used in the particular trade, including electronic media of all types.

Learning from Writing in Log Books or Work Orders

A majority of techs wrote in log books or on electronic devices both during and after troubleshooting, and this writing was governed by personal preference, and/or the paperwork requirements of their employers. The personal log books kept by the RHVAC techs generally contained information important to each tech, ranging from descriptions of work processes to technical data.

If technical instructors were to promote keeping a log book while students were in school, the habit might continue into the workplace. Such logs could record school activities and serve as a place to record learning important to the students. To stimulate greater awareness of their own learning preferences, the students could note what learning strategies and situations they found most effective. Possibly these logs could be evaluated as writing assigenments, thus contributing to the integration of writing instruction into technical education programs.

Learning Personalized Troubleshooting Scenarios

In learning to troubleshoot more effectively, all the techs were developing personalized troubleshooting scenarios, a clear demonstration of constructivist learning. These scenarios were becoming the experiential shortcuts that would allow them to operate more expertly in similar troubleshooting situations.

Introducing technical students to constructivist learning theory might help them to view learning from a more proactive perspective. In technical training, students are often guided through learning by teachers; students follow, teachers lead. In the workplace, where teachers are few and far between, workers must take the initiative in their own learning. Learning how experts think and learn (Bereiter & Scardamalia, 1993) might help students cultivate these mental constructs as they learn from experience.

The Importance of Electrical Skills

Though all the techs knew how to interpret and analyze electrical schematics upon graduation from the RHVAC program they attended, all agreed that they had learned this skill more completely through troubleshooting. They agreed that analyzing electrical schematics was a critical troubleshooting skill. Typically the techs were using schematics in conjunction with the equipment upon which they were working, moving their attention back and forth from the schematic to the equipment, tracing the equipment wires while studying the schematics. This combination of tactile learning from the equipment and analytical thought from using the schematics can be a powerful learning strategy because it promotes understanding of equipment operation. An effective learning strategy in technical training would be to mimic the workplace practice of referencing between schematics and equipment whenever possible.

All the techs stated that understanding electrical systems was critical to their success as troubleshooters. They were testing system operation by using digital test equipment and comparing the results against expected normal parameters. Many electrical training classes emphasize understanding circuit operation through mathematics, the engineers' and designers’ way of understanding electrical circuits. Flescher (1993) conducted research which indicated that how technicians were trained impacted their troubleshooting performance; those trained as troubleshooters performed better at troubleshooting than those trained as designers or equipment operators. Therefore, electrical training for effective troubleshooting could more effectively focus on using electric meters and analyzing schematics.

When the Techs Learned

In retrospect this question seems ill-conceived, as if informal learning can be isolated into discrete, measurable events as is common in formal education. The techs described having a troubleshooting experience, making sense of it in relation to rectifying the problem, then using reflection to incorporate that experience into a knowledge base for use in future troubleshooting. Their learning was not necessarily linear and could occur at any time, not just in the time-bound conventions of a structured lesson or a study session. Having students understand that learning can happen in stages, at different rates, and not necessarily in school might help them become comfortable with learning fundamentals in school and then expanding on those skills in the workplace through informal learning.

Learning from Troubleshooting

The troubleshooting models and RHVAC training materials discussed in Chapter Two did not explicitly link learning and troubleshooting, but the techs agreed that troubleshooting was an excellent learning opportunity. Based on these findings it was thought that a more effective troubleshooting process would incorporate methods for promoting learning from troubleshooting. Therefore, an existing troubleshooting process (Green & Gosse, 2000) was modified to incorporate informal learning strategies. Called Surefire Troubleshooting to promote its acceptance by technical students, it is the product of many years of work and incorporates the ideas of other writers in a way that defies academic citation. It is not an original approach, having been modified frequently for over ten years (Green, 1991; Green & Gosse, 2000; Green & Gosse, 2006). The techs’ descriptions of their root cause analysis thinking led to the addition of root cause analysis as an activity during the designated learning phase of troubleshooting, after the problem had been solved. By asking troubleshooters to think more deeply about the equipment problem through root cause analysis, and then asking them to broaden their analysis to include related systems, it is thought that constructivist learning will be stimulated.

This process is an entry-level, linear troubleshooting method that students are expected to modify to meet their unique experiences when troubleshooting in the workplace. That any linear process represents how experienced troubleshooters actually think is debatable (Zaro, 1993). It provides a preliminary approach to troubleshooting and is designed for use in technical training programs, in cooperative work experiences or internships, in apprenticeship programs, or in self-directed learning projects. To augment its use in the workplace The Surefire Troubleshooting Workplace Guide was developed. The

Surefire Troubleshooting process is located in Appendix E and The Surefire Troubleshooting Workplace Guide is located in Appendix F.

Recommendations for Future Research

One purpose of this study was to examine the informal learning in an unstudied population, RHVAC techs. Further studies of other occupations and studies of larger, heterogeneous populations would add depth of understanding of informal workplace learning. Since the workers in this study were all male and from similar cultural backgrounds, studies of male and female workers from diverse racial and cultural backgrounds would increase the understanding of how workers learn. The techs were recent graduates of an RHVAC training program, with only two having significant related experience. How would learning from troubleshooting be different for these techs after five or even 10 years of experience?

While this study focused on learning from troubleshooting, there were some indications in the techs’ interviews that they were also learning from maintenance and installation of RHVAC equipment. How would learning differ when doing maintenance and installation work, and might learning from troubleshooting and maintenance work compliment each other? Not all the techs' learning was informal; they reported limited amounts of more formal training like workshops. How does learning proceed from formal or semiformal training into informal learning?

Due to the lack of triangulation in this study a future study of learning from troubleshooting could incorporate observations of troubleshooters and examinations of log books and work orders. Do communities of practice with their expected learning strategies and body of accepted knowledge and skills inhibit learning new technologies or learning in other communities of practice?

If, as Resnick (1987) suggests, tools shape learning, how will learning be influenced by accessing technical data or technical support services via cell phones, computers, and forms of electronic media?

If informal workplace learning strategies are to be incorporated into community college technical programs, additional research is needed to describe and understand how to apply the strategies effectively. For example, researchers could survey a large population to determine the most useful informal workplace learning strategies from a selection of such strategies. Another study might explore how the change from using printed technical material to using electronic media impacts technicians’ learning on the job.

Before the teaching of informal workplace learning strategies in technical training is adopted, the effectiveness of various methods for teaching informal learning strategies should be determined through both qualitative and quantitative studies.

The effectiveness of a troubleshooting process like Surefire Troubleshooting could be the focus for a useful study that would ask: does learning the process improve troubleshooting effectiveness and result in significant informal learning?

Conclusion

This study set out to understand how 10 RHVAC service techs learned from troubleshooting. It was expected that such knowledge would lead to suggestions that could help community colleges better prepare technical students to learn in the workplace. Successful RHVAC troubleshooters, and technical troubleshooters in many trades are well-paid, respected, and work more autonomously than other types of technicians. Wanting to become a successful troubleshooter is a powerful motivator for learning in many technical occupations.

Troubleshooting was also an excellent workplace learning opportunity for RHVAC techs, and probably for other technicians also. Troubleshooters must observe, categorize, call on past experience, recall accumulated knowledge, work alone or with others, and then act on their best judgments, often in front of an impatient customer or boss who counts the minutes or hours taken to make the repair. Their success or failure in troubleshooting provides knowledge of results similar to high stakes, up-or-out examinations, except that troubleshooters move on to another problem, then another, then another. Troubleshooting for a living is constantly facing a series of examinations, all pass or fail, and all harshly graded.

As the techs indicated, they were gaining confidence through successful troubleshooting, and they were becoming more confident in their ability to learn the skills and knowledge they needed to troubleshoot effectively. Effective troubleshooting skill is a core competency required of RHVAC service techs and for many other technicians. Enhancing technicians’ ability to learn from troubleshooting in the workplace should help novice troubleshooters gain the skills to become great troubleshooters.

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APPENDICES

Appendix A - Informed Consent Document

INFORMED CONSENT DOCUMENT FOR RESEARCH PARTICIPANTS

I am hoping that you will agree to participate in my Ph.D. research. This form describes the research and explains your rights should you decide to participate.

I will use the information and ideas you share with me to complete my Ph.D. dissertation, write academic articles, and to create a workplace learning course for technical students.

This consent form gives you the information you need to decide if you want to be in the study or not. Please read the form carefully. Please ask any questions about the research; what you will be asked to do, the possible risks and benefits, your rights as a volunteer, and anything else about the research or this form that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

This process is called “informed consent”. You will be given a copy of this form for your records.

Principal Investigator: Dr Sam Stern, Dean, College of Education, Oregon State University

RESEARCHER: Denis Green, Ph.D. Candidate, (content removed to protect participant confidentiality).

PURPOSE
The purpose of this research is to identify and understand the workplace learning strategies used by RHVAC technicians when they troubleshoot malfunctioning equipment. Examples of workplace learning strategies are studying a manual and getting advice from others. The results of this research will help me (Denis Green) create a workplace learning program for technical students in community colleges.

PROCEDURES

I am inviting you to participate in this research study because you are a skilled technician who successfully troubleshoots RHVAC equipment and systems problems.

The interviews will be tape recorded and transcribed (written out) by a typist. I will analyze the transcripts and tapes, then write up my conclusions in a Ph.D. dissertation.

You will have an opportunity to review the transcript and have any sections deleted. You will also be able to see my dissertation before it is sent to my professor to ensure yourself that you have been quoted accurately and that I have not embarrassed you or harmed you in any way.

Only I, Dr Sam Stern, another person who will check my work, and the typist will see the transcripts or listen to the tapes.

You will be given a code name to protect your identity and the name of your workplace will not be mentioned. Transcripts and tapes will be stored in a locked file cabinet in a secure location.

RISKS

The possible risks associated with participating in this research are as follows. Your name will not be associated with any of your responses. Your identity will be disguised by using a code name or number, so only you and I will know what you have said during the interview. I will not include any information in the final report that might have any impact on your employment status (like if you were to say something unkind about your employer or co-workers or if I were to evaluate your abilities). Since your name will not be linked to your answers (a code name will be used during the interview), no one, besides us, will know which comments you have made.

You will be able to see my dissertation to ensure yourself that you have been quoted accurately and that I have not embarrassed you or harmed you in any way.

BENEFITS

There may be personal benefits if you participate in this study. You might become more aware of your learning and be able to learn more quickly on the job. Community college students and their instructors could be helped by the results of this research.

COSTS AND COMPENSATION

You will not have any costs for participating in this research project. You will not receive any compensation for participating in this study.

CONFIDENTIALITY

Records of participation in this research project will be kept confidential to the extent permitted by law. However, Federal Government regulatory agencies and the Oregon State University Institutional Review Board, a committee that reviews and approves research studies involving human subjects may inspect and copy records pertaining to this research. It is possible that these records could contain information that personally identifies you.

Therefore you will receive a code name or identification number, and neither the name of your workplace, nor its location will be disclosed.

If any report or other publication results from this study, your identity will not be disclosed. Results will be reported in a summarized manner in such a way that you cannot be identified.

VOLUNTARY PARTICIPATION

Taking part in this research study is voluntary. You may choose not to take part. If you agree to participate in this study, you may stop participating at any time. You are free to skip any of my questions that you would prefer not to answer. If you decided not to take part, or if you stop participating at any time, your decision will not result in any penalty or loss of benefits to which you may otherwise be entitled. Any examples that you generated and any tapes or transcripts will be destroyed.

AUDIO RECORDING

By initialing in the space provided you verify that you have been told that audio recordings will be generated in the course of this study as described above. Initials __________.

QUESTIONS

Questions are encouraged. If you have any questions about this research, please contact me at (phone and email omitted for this appendix). You can also contact my major professor Dr. Sam Stern (phone and email omitted for this appendix). If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator at (phone and email omitted for this appendix).

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant’s Name (printed):

____

____

Signature of Participant and Date

RESEARCHER STATEMENT

I have discussed the above points with the participant or, where appropriate, with the participant’s legally authorized representative, using a translator when necessary. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

____

Signature of Researcher and Date

Appendix B – Contact letter

Dear (Graduate Name)

I am still working on my Ph.D., trying to learn how workers learn informally when they are troubleshooting. I am asking for your assistance. I would like to study how you learn when you troubleshoot.

I am asking you to fill out the enclosed troubleshooting report and return it to me in the stamped, self-addressed envelop in a week or ten days. Filling out the troubleshooting report should not take more than twenty minutes. The troubleshooting report gives me a brief description of how you learned from particular troubleshooting problems. I might also ask you to be part of a one-to-one interview regarding your learning on the job. The interview will be brief, about an hour, and I can interview you at your convenience at any location, or even on the phone. Of course you do not have to answer any interview question you would prefer not to answer.

I will keep your identity confidential by assigning you a code name, by not describing where you work, and by destroying tapes, then storing transcripts in a secure location. There are no foreseeable risks or direct benefits as a result of participating in this project.

If you have any questions about the survey, please contact me at (content removed to protect participant confidentiality). If you have questions about your rights as a participant in this research project, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator (content removed to protect participant confidentiality). The IRB reviews research to make sure that people will not likely be harmed by participating in research conducted at OSU.

Thanks for your time and help with this. I look forward to talking with you. Please understand and believe me, if you decide not to complete the reports this will not effect our relationship.

Yours truly,

Denis Green

Appendix C - Troubleshooting Report

Troubleshooting Report

The purpose of this troubleshooting report is to gather information regarding a troubleshooting problem from which you learned important skills and/or knowledge. The important information is what you learned, and how you learned it.

1. Briefly describe a troubleshooting problem from which you learned important skills or knowledge.

2. On what date did the problem occur?

3. How did you solve the problem?

4. Did you use any written material to help you to solve the problem?

5. What did you learn from solving the problem?

6. What did you do that helped you learn in this situation?

7. Did you use any records, manuals, or consult with others during the troubleshooting?

8. Where you conscious of learning during the troubleshooting?

9. When did your learning occur, during and/or after the actual troubleshooting?

- o I would be willing to be interviewed about what I learned from solving this problem.
- o I would not be willing to be interviewed about what I learned from solving this problem.

Name ___________________ Phone or email

Appendix D - Interview Protocol

Semi-structured Interview Questions

Introduction to interview

1. Purpose of study

2. Assurances (no assessment or evaluation, no sharing with others)

3. Assurances of anonymity, privacy, confidentiality

4. Answer interviewee's questions

Interview questions (taped and transcribed)

1. Please describe a troubleshooting problem that led to important learning.

2. Please describe the problem, and how you solved or helped solve the problem.

3. What was the cause or causes of the problem?

4. How did you repair the problem?

5. What tools or resources did you use to help you solve the problem?

6. What did you learn from working on the problem?

7. What did you do that helped you learn from the problem?

8. When troubleshooting this problem were you aware that you were learning?

9. When did your learning occur, during or after the actual troubleshooting?

10. Did any of the tools you used help you to learn?

11. Do you consciously think about learning on or off the job?

12. What other learning situations do you have on your job (maintenance and/or installation)?

13. How much do you work alone?

14. How much on-the-job training did you get?

15. Do you get any education through your job?

16. Tell me about any other workplace learning that you do.

Debriefing

1. Reiterate the study's purpose and give assurances

2. Give each participant my business card and invite further input

3. Ask where additional records or documentation could be found (NA)

4. Answer all questions

5. Leave the door open for further discussion

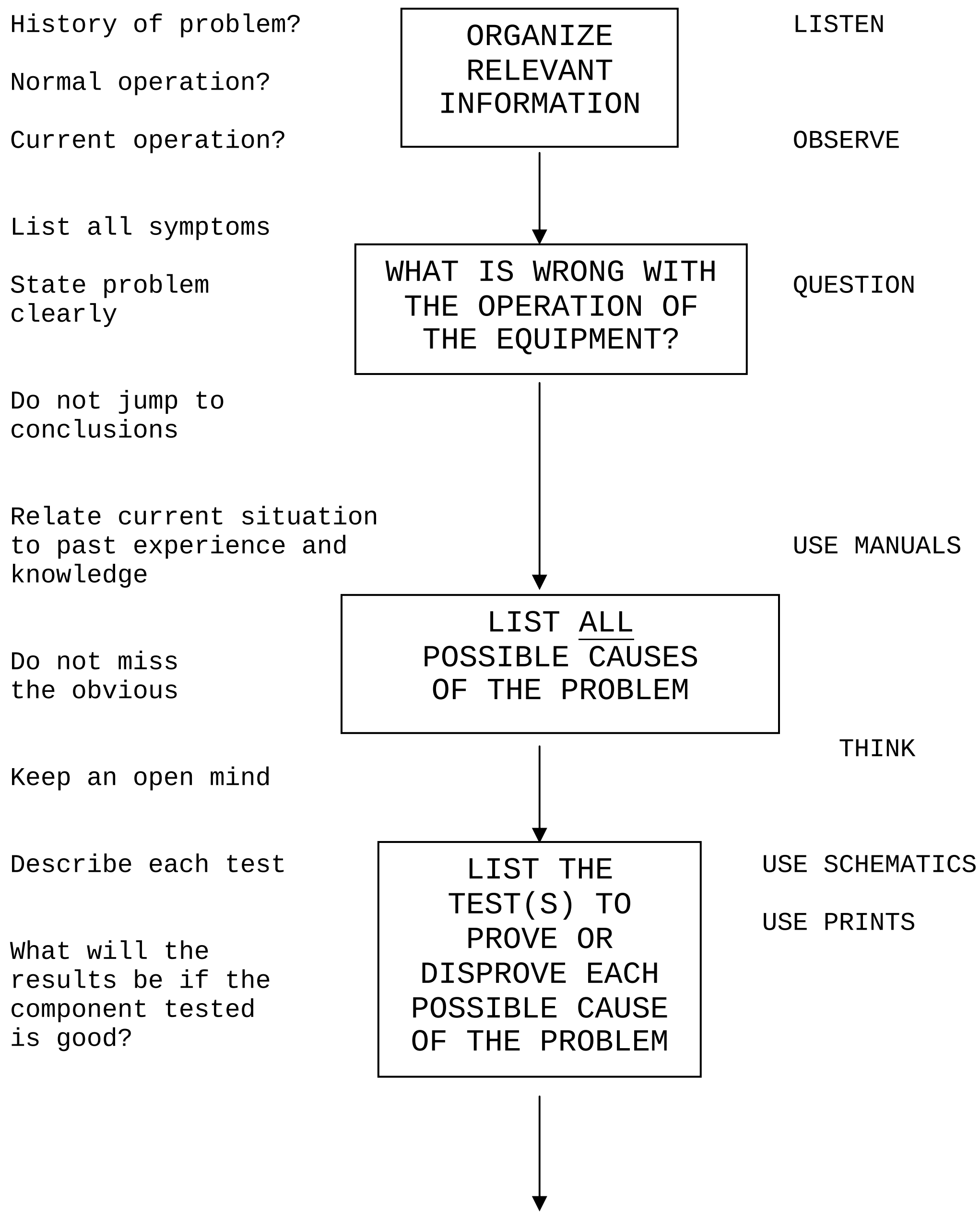
6. Assurances

7. How to contact me

8. Thanks

Appendix E – Surefire Troubleshooting

Learning from Troubleshooting



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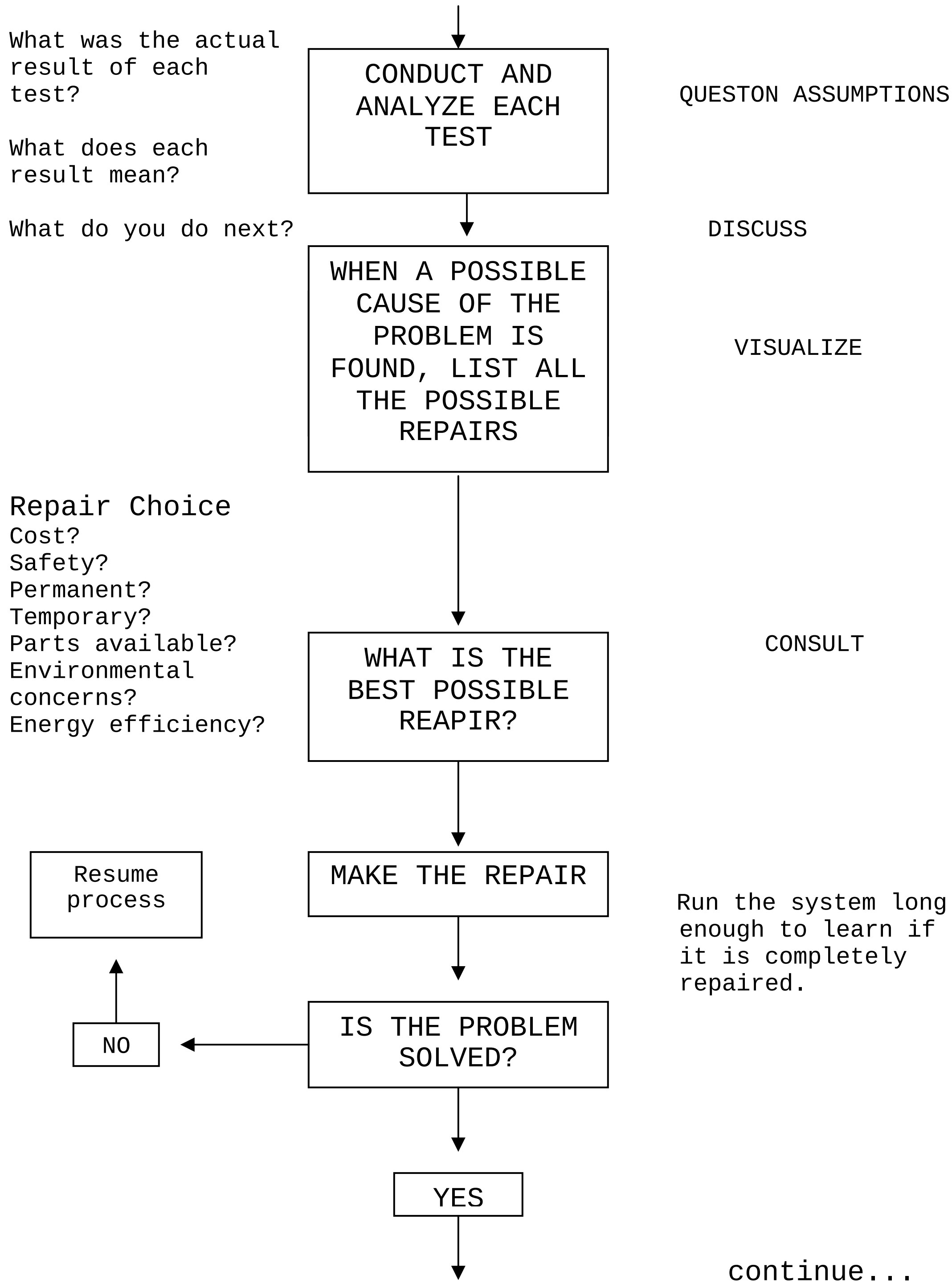
What was the actual result of each test?
What does each result mean?
What do you do next?
CONDUCT AND ANALYZE EACH TEST
QUESTON ASSUMPTIONS
DISCUSS
WHEN A POSSIBLE CAUSE OF THE PROBLEM IS FOUND, LIST ALL THE POSSIBLE REPAIRS
VISUALIZE
Repair Choice
Cost?
Safety?
Permanent?
Temporary?
Parts available?
Environmental concerns?
Energy efficiency?
WHAT IS THE BEST POSSIBLE REAPIR?
CONSULT
Resume process
MAKE THE REPAIR
Run the system long enough to learn if it is completely repaired.
NO
IS THE PROBLEM SOLVED?
YES
continue...

COMPLETE DOCUMENTATION

EVALUATE YOUR TROUBLESHOOTING	PLAN YOUR LEARNING	ROOT CAUSE ANALYSIS

EVALUATE YOUR TROUBLESHOOTING

What did you do well?

What could you do better next time?

What safety concerns did you encounter?

PLAN YOUR LEARNING

What did you learn?

How will you remember what you learned?

Relate what you learned to what you already know.

What do you need to learn so solve similar problems?

How will you learn it?

How will you know that you have learned it?

ROOT CAUSE ANALYSIS

List all the causes of the problem.

What was the root cause of the problem?

Completely inspect the whole system, not just the problem equipment.

Describe how each part of the system works and how the parts interact.

What future problems might develop?

How would you prevent future problems?

What did you learn from doing a root cause analysis?

Appendix F - Surefire Troubleshooting: Workplace Guide

These exercises are designed to be used by troubleshooters as a supplement to the Surefire Troubleshooting process. They will complete the exercises while working through a troubleshooting problem in the workplace. Worksheet #1 is both a checklist and guide for troubleshooting. Worksheet #2 provides space for listing symptoms and possible causes. Worksheet #3, “Troubleshooting Test Chart”, serves as a guide for planning and tracking the testing of components. It is critical for troubleshooters to conduct testing by comparing actual test results with expected results, then deciding what to do next: another test, attempt a repair, or seek more information. The “Repair Plan”, Worksheet #4, is intended to provide structure for thinking through the repair process. Once the repair is completed and the equipment is operating correctly then Worksheet #5, “Root Cause Analysis” provides questions to guide troubleshooters. The last worksheet, “Planning Your learning”, helps the troubleshooters decide what they need to learn and how to learn it.

Surefire Troubleshooting: Workplace Guide

Checklist

Worksheet #1

Date ____________________ Name ____________________

Equipment ______________________

Observations Actions Comments

1. Inspect equipment	
2. List safety concerns	
3. Question operator	
4. Gather troubleshooting resources	
5. Operate equipment, if possible	
6. List all symptoms (Worksheet # 2)	
7. List possible causes (Worksheet # 2)	
8. Testing sequence (Worksheet # 3)	
9. What was the cause of problem?	
10. List possible repairs (Worksheet # 4)	
11. Repair plan (Worksheet # 4)	
12. Make repair	
13. Observe operation	
14. Fill out documentation	
15. Root cause analysis (Worksheet # 5)	
16. Planning your learning (Worksheet # 6)	

List all Symptoms and Possible Causes

Worksheet #2

Symptoms	Possible Causes	Component(s) Involved

Notes:

Troubleshooting Test Chart

Worksheet #3

Component tested	Test equipment used	Results if good	Results if bad	Actual results	Next action

Notes:

Repair Plan

Worksheet #4

Possible Repair	Factors
	Expected equipment life Costs Safety concerns Production demands Code/legal demands Ethical problems
	Expected equipment life Costs Safety concerns Production demands Code/legal demands Ethical problems
	Expected equipment life Costs Safety concerns Production demands Code/legal demands Ethical problems

Notes:

Root Cause Analysis

Worksheet # 5

1. List the root causes of the problem.

2. What other systems were impacted by the initial problem?

3. Describe how you determined the root cause of the problem.

4. What changes would you make to the maintenance of the problem equipment?

6. Does the equipment need to be modified? If so how?

7. Do any workers need additional training? If so what type of training?

8. List any other suggestions for improving the equipment or system operation.

Planning your Learning

Worksheet #6

1. What did you learn from this job?

2. What would you do the same when you next do a similar job?

3. What would you do differently?

4. What skills or knowledge do you need to improve to complete similar jobs?

5. How you plan to improve these skills or knowledge?

6. How will you know when you have learned these skills or knowledge?