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Henry J. Sredl

The purpose of this study was to determine if there was a significant difference in the amount of technical subject matter learned during a fixed period of instruction by students working with a computer expert system and students working with human experts from a technical field.

All students participating in the study were enrolled in a manufacturing processes course at Oregon State University during the spring term, 1986, and, as part of the course were learning to diagnose defective castings. Prior to the experiment, students were given initial instruction in casting processes and randomly divided into two experimental groups for treatment.

The students in Group I completed a laboratory exercise that provided opportunity for hands-on practice diagnosing defective castings. They were given access to a laboratory

instruction manual and allowed to ask for assistance from two individuals who were present, both experts in casting processes.

Students in Group II completed the same exercise with the same defective castings and lab instruction manuals. They were not, however, given access to human experts; they instead worked with a computer expert system, TELECAST, that interacts with the user and provides diagnoses for defective castings.

Students' knowledge of casting defect diagnosis was evaluated with a test instrument prior to the treatment and again following treatment. The analysis of covariance was the statistical tool used to analyze the test results.

Statistical analysis revealed there was no difference in the amount learned by the two groups of students (calculated F = .002). The TELECAST expert system proved to be no more and no less effective than the human experts at effecting learning.

The words of the wise are like goads, and the words of scholars are like well driven nails, given by one Shepherd.

And further, my son, be admonished by these. Of making many books there is no end, and much study is a weariness to the flesh.

Let us hear the conclusion of the whole matter:

Fear God and keep His commandments,
For this is the whole duty of man.
For God will bring every work into
    judgement,
Including every secret thing,
Whether it is good or whether it is evil.

Ecclesiastes 12: 11-14
New King James Version

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Typed by Kim E. Ruyle

DEDICATION

To Mary, my dearest;
and to our precious children:
Benjamin, Emily, Nathanael,
Christopher, Daniel, and Rebecca.

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Table of Contents

List of Figures

List of Tables

EFFECTIVENESS OF AN EXPERT SYSTEM FOR TEACHING CASTING DEFECT DIAGNOSIS IN ENGINEERING AND TECHNICAL EDUCATION

Chapter 1

Introduction

Computers have had a profound effect on our society over the past several decades. They have made possible (or been responsible for) the shift from an industrial society to the information society described by Naisbitt (1982). Education in the United States has not been exempt from the effects of the computer: Computers in American educational institutions now number well over 1 million ("Computers in Education," 1985) and are being used for administrative and teacher record keeping, instructional management and instruction in all areas of the curricula (Schuttenburg, McArdle, and Kaczala, 1985).

One of the most promising and exciting fields of computer science research, one that is likely to impact education considerably, is artificial intelligence (AI). Artificial intelligence is the ability of machines to accomplish tasks that are generally thought to require human intelligence to perform (Jackson, 1985). AI has its roots in both computer science and in psychology (Hayes, 1984), a melding of disciplines which Herbert Simon (1980) terms cognitive science, "...the domain of inquiry that seeks to understand intelligent systems and the nature of intelligence" (p. 35).

Practical applications of AI have up to now been mostly limited to specialized problem solving tasks. The computer programs written to solve such tasks embody the specific, in-depth knowledge associated with experts in a particular field. Thus, these specialized programs are called expert systems (Gevarter, 1985).

Human experts have traditionally played a vital role in technical and vocational education as classroom teachers and sometimes as partners in a master craftsman/apprentice relationship (Evans & Herr, 1978). However, little is known about the role expert systems might play in such situations.

Statement of the Problem

The purpose of this study was to determine if there would be a significant difference in the amount of technical subject matter learned during a fixed period of instruction by students working with a computer expert system and students working with human experts from a technical field. The students were from industrial engineering, mechanical engineering and pre-engineering programs at Oregon State University and were all enrolled in a Manufacturing Processes course during spring term, 1986. As part of the course, these students were learning to diagnose defects in aluminum castings that had been poured in green sand molds.

The study involved the following phases:

1. Development and validation of an expert system to assist users (students) in identifying and diagnosing defects in aluminum sand castings. The system was named TELECAST.

2. Creation and administration of a laboratory exercise that required students to identify and list probable causes of defects in actual aluminum castings. A large collection of defective castings was produced to allow hands-on diagnosis.

3. Construction and validation of an evaluation instrument to measure students' knowledge of the causes of casting defects.

4. Analysis of data gathered from the testing procedure.

Significance of the Study

Many advantages are attributed to computer-based learning (CBL). Computers can provide individualized and flexible instruction, immediate feedback, motivation for some students, and a host of other cost-effective bonuses (Kleiman, 1984). Most of these advantages also pertain to the use of expert system teaching tools.

Unlike their human counterparts, expert systems reliably and generously furnish the user with all their available resources (knowledge) without partiality or regard for the weather, time of day, or other circumstances that often influence humans. Knowledge is preserved permanently in an expert system; expert systems will not die, retire, or decide it's time for a career change like humans are prone to do. And expert systems are likely to be widely available in the near future as the price of microcomputers continues to fall and the concomitant development of microcomputer-based expert systems continues.

If indeed an expert system is a valid educational tool, it is possible that teachers may soon be able to purchase or develop an applicable program for any of a wide variety of technical subjects. Such an expert system could act as "resident expert" in the classroom or laboratory, reliably sharing its expandable knowledge base with students.

Limitations of the Study

This study was limited by several factors. Subjects which participated were students in a single course offered at Oregon State University. All students except one were from the college of engineering; one was from the college of science. The total course enrollment for the spring of 1986, when the experiment was conducted, was 84 students. Of this number, 73 were able to participate in this experiment and were divided randomly into two groups for the two treatments.

The fact that one specific expert system, TELECAST, and two specific individual experts provided the treatments must be considered. Altering any of these variables or varying the content to an area other than casting would very possibly have affected the results of the experiment.

<u>Definition of Terms</u>

1. Amount of technical subject matter learned:

The level of knowledge possessed by the subjects as indicated by scores derived from the evaluation instrument.

2. Fixed period of instruction:

A three-hour block of time during which students received a specific treatment. A pilot study was conducted to determine this optimum time span.

3. Computer expert system:

A tool created by the researcher with the EXSYS authoring system and entitled TELECAST. It operates on an IBM PC or PC-compatible computer with a minimum of 256K memory, interacting with the user to provide a diagnosis for a defective aluminum casting. Students in one group worked with TELECAST in order to learn to diagnose defective castings. TELECAST was validated by a panel of three experts.

4. Human expert in the subject:

A person with extensive training and experience in foundry applications, selected to work with the second group of students learning to diagnose casting defects. Two human experts were used in this study to assure all students had ready access to their expertise.

5. Manufacturing processes course:

A course, numbered IE 311, which is taught by the researcher every term during the academic year at Oregon State University. The course is required by all industrial and mechanical engineering students and typically has an enrollment representing sophomores, juniors and seniors. IE 311 is a study of the industrial processes, including casting, used to alter materials for the creation of a desired product.

6. Aluminum castings:

Objects that are made by pouring molten aluminum into molds which are often made of sand.

7. Green sand molds:

A mixture of silica sand, clay and water often used as a molding material in which to produce castings. The term "green" refers to the moisture content.

8. Evaluation instrument:

A 50-question multiple choice test developed by the researcher and used to evaluate the subjects' knowledge of the causes of defective castings. The instrument was validated by a panel of three experts.

Chapter 2

Review of the Related Literature

Artificial intelligence is a science in its infancy. Its principal goal, that of building "a robot that is to have its childhood, to learn language as a child does, to gain its knowledge of the world by sensing through its own organs, and ultimately to contemplate the whole domain of human thought" (Weizenbaum, 1976, p. 203) is no doubt many years away. But the research that quest entails may help us answer many of the fundamental questions about the ways humans think and learn. Indeed, in order to build a machine that simulates (or possesses) a human-like intelligence, one must understand what human intelligence is and something about its operating system.

Much of the work in AI has been an attempt to reproduce in a computer the heuristic methods of problem solving described by Polya (1957). Heuristic methods are mental shortcuts, often unconsciously followed, that lead to a problem solution. While humans have a propensity for such intuition and flexibility in their thought processes, computers are much less adroit, usually following the instructions of a rigid algorithm which directs a search down every path that might possibly lead to a solution. When computers are able to make decisions which reduce the number of paths taken to a given solution and base those decisions on previously gathered knowledge, they are able to appear (some would say are) intelligent.

Work in the AI field has led to the development of machines with this attribute, though at the present time they only operate efficiently in a very limited, predetermined environment. These expert systems, as they are called, are possibly the forerunners of the much more powerful general purpose intelligent machines AI pioneers dream about.

Expert System Operation

The guiding concept behind the development of expert systems was developed, according to Waterman (1986), in the late 1970's: AI scientists concluded intelligent systems would best be served by utilizing "extensive, high-quality, specific knowledge about some narrow problem area to create very specialized programs" (p. 4).

These programs are normally produced by several individuals: A domain expert, a human expert in the selected field, provides the knowledge and heuristic techniques he or she has gained over possibly years of study and experience. This information is collected by the knowledge engineer, modified so it's compatible with the expert system, and finally installed in the system so it can be manipulated efficiently. This collection and modification of the domain expert's knowledge is called knowledge engineering (Feigenbaum, 1979). The knowledge engineer works with a programming language or authoring tool to create the expert system.

Most authoring tools permit the knowledge engineer to structure information in the form of if-then statements called rules (Duda & Gaschnig, 1985). The rules represent the heuristic strategies followed by the domain expert in problem solving. "Expert systems use heuristics because the tasks these systems undertake...are typically difficult and poorly understood. They tend to resist rigorous mathematical analysis or algorithmic solutions" (Waterman, 1986, p. 17).

In operation the expert system extracts from the user information about a problem and then uses its own set of rules to test hypotheses, comparing information given by the user with its own knowledge base. A built-in part of the expert system called the inference engine determines which rule to activate and when it should be activated. It then draws inferences from the comparisons. Conclusions which are generated are often given in the form of probabilities rather than hard and fast statements of fact.

Several variations of the rule-based expert system have been developed. One type, called a fuzzy system, is a sophisticated expert system which uses a slightly different form of reasoning. Fuzzy systems are often able to "understand" natural language in a limited way because of a built-in parser that skips over unrecognizable words and tries to make sense of recognizable words (Negoita, 1985;

Fletcher, 1985).

Intelligent systems are yet another refinement of the expert system concept. Basically they are a hierachy of conventional expert systems, each with a specific area of expertise and responsibility (Waterman, 1986).

Expert System Applications

Expert systems have been developed for an extremely wide variety of applications and many more are sure to follow. But some problem solving arenas are definitely better suited to expert systems than others, and that determination can be made by following the clear guidelines listed below which are adapted from charts by Waterman (1986, pp. 129-130, 132).

Expert system development is possible when all of the following conditions apply:

1) The task does not require common sense
2) The task requires only cognitive skills
3) Experts can articulate their methods
4) Genuine experts do exist
5) The experts agree on solutions
6) The task is not too difficult
7) The task is not poorly understood

Expert system development is justified when any of the following apply:

1) The task solution has a high payoff
2) Human expertise is being lost
3) Human expertise is scarce
4) Expertise is needed in many locations
5) Expertise is needed in a hostile environment

An expert system system approach is appropriate when all of the following apply:

1) The task requires symbol manipulation
2) The task requires heuristic solutions
3) The task is not easy
4) The task has practical value
5) The task is of manageable size

While these guidelines put some restraints on expert system applications, it is evident that there is a great latitude for growth of this technology by looking at a fractional list of the fields that have already been impacted by expert systems.

Barr & Feigenbaum (1982) discuss the significance of several systems including: MYCIN, CASNET, INTERNIST, IRIS, and EXPERT -- all systems for use in the medical field. They also write about expert systems for scientific fields: TEIRESIAS, DENDRAL, CONGEN, Meta-DENDRAL, CRYSALIS, MACSYMA, and PROSPECTOR. Waterman (1986) has cataloged many expert systems from a wide variety of disciplines, including: agriculture (3), chemistry (14), computer systems (10), electronics (22), engineering (8), geology (7), information management (9), law (10), manufacturing (3), mathematics (3), medicine (53), meteorology (1), military science (25), physics (2), process control (2), space technology (7). Though this list is incomplete, it will give the reader some idea of the scope of possible expert system applications.

The vast majority of these systems, however, have only been used as research or demonstration prototypes. This may be due in part to computing requirements (most of these systems require mainframe or minicomputers to operate). However, there appears to be an increasing trend toward microcomputer-based expert systems that, while lacking in sophistication, nevertheless are capable of making meaningful contributions (Shafer, 1985). Part of the success of these microcomputer-based systems is due to authoring tools that are now available to enable the knowledge engineer to structure the knowledge base without building an inference engine. In other words, the authoring tool provides a skeletal network which includes the inference engine, and the knowledge engineer simply fleshes out the system by adding the appropriate knowledge. Very little or no programming skills are required.

Utilizing such authoring tools may save considerable time during the creation of an expert system. Waterman (1986) gives examples of expert systems that required more than 30 person-years to develop, and states that a system of moderate complexity can be expected to consume two to four persons' time for up to about six years. One can then easily understand why commercially available expert systems often carry a very high price tag. For instance, Bulkeley (1986) described two different expert systems which provide assistance with financial affairs. One, which has been developed for private investors, sells for $45,000. The other, produced for corporations, sells for $90,000.

As time and monetary constraints are relieved by the increased exploitation of microcomputers and the use of disencumbered authoring systems there is an increased possibility that expert systems will soon be within the reach of educational institutions with limited resources. How much influence expert systems will exert on the future directions taken by computer-based learning is yet to be determined.

Overview of Computer-Based Learning

The first thing one is struck with when investigating the literature on CBL instruction is the profusion of terminology and acronyms used to describe slightly different philosophies and methodologies. Merrill (1982) uses the CBL acronym as an umbrella term which encompasses several sub-disciplines. Computer-based instruction (CBI) (O'Neil & Paris, 1981) and computer-aided learning (CAL) (Godfrey & Sterling, 1982) are other umbrella terms used in much the same way but which include some type of instructional management capabilities.

Whatever the terminology used, computers do have several distinct and important roles to play in education. Merrill (1985) asserts the three primary categories into which CBL activities currently fall are computer-assisted instruction (CAI), simulation (SIM), and artificial intelligence.

"In computer-assisted instruction, the computer is modeling the teacher. Those functions ordinarily performed by a teacher in presenting and controlling instructional activities are carried out by the computer as it interacts with students" (Merrill, 1985, p. 27). To describe the functional components in the CAI process Manion (1985) introduced the term "modes of delivery and interaction" (p. 26). Six modes are set forth in a hierarchy which represent different levels of cognitive activity and learner-computer interaction.

These levels compare in some respects to Bloom's (1965) hierarchical structuring of educational objectives. They are:

1. Drill and practice. "The drill and practice mode has been the most widely researched, is the most frequently used, and is the least sophisticated CAI mode. It emphasizes basic knowledge" (Manion, 1985, p. 27). Although this form of CAI has been widely criticized (Kohl, 1984), it does have its place in leading students to a mastery of basic concepts (Gagne', 1982).

2. Tutorial mode. A tutorial works independently with students to help them acquire the fundamental concepts of the subject matter, tests their comprehension, and then provides remedial instruction as required (Manion, 1985).

3. Educational gaming. Educational games provide the student opportunity to apply knowledge and skills in a motivating diversion from traditional instructional methods (Manion, 1985).

4. Simulation. As in an educational game, the student has an opportunity to apply knowledge and skills, but in a simulated real-world environment. To solve the problems,

"students must interact with and become part of the simulated reality" (Manion, 1985, p. 27).

5. Problem-solving. In this mode the student takes a far more active role in the learning process, manipulating the computer as a problem solving tool rather than being directed by the computer. This level of cognitive activity is highly desirable but very often not achieved according to several experts (Papert, 1980 1984a; Agee, 1985; Manion, 1985).

6. Word processing. Manion justifies the inclusion of word processing as a mode of CAI because it involves high level thought processes; "it is an analytical, synthetic, and evaluative exercise, and ...constitutes an even higher-level cognitive task than programming a computer" (1985, p. 28).

In the model proposed by Merrill (1982), simulation is considered an entity set apart from CAI and is accompanied by artificial intelligence, the third component of CBL. "The emphasis for each of these approaches to CBL is different: Computer-assisted instruction stresses skill acquisition; simulation stresses high-fidelity performance; and artificial intelligence stresses realistic conversational interaction" (1985, p. 27).

Merrill goes on to suggest a merging of these three subdisciplines of CBL is currently underway, forming several new ones: (a) computer-assisted instructional simulation (CAIS); (b) intelligent computer-assisted instruction (ICAI); and (c) intelligent simulation (ISIM).

> The ultimate system is a combination of all three CBL areas -- an intelligent computer-assisted-instruction simulation (ICAIS). Such a system would include the expertise, the environment in which that expertise is exercised, and a set of structured exercises leading the student to the acquisition of that expertise (1985, p. 28).

The work that goes into developing effective software for these applications can be herculean; to be justified then, the CBL approach selected must provide some significant, identifiable advantages over traditional means of instruction. O'Neil and Paris (1981) acknowledge two categories in which the benefits of CBL are perceived. The first category includes those factors that lead to a diminishment of costs: (a) training time is reduced; (b) dependence on skilled instructors is reduced; (c) need for sophisticated training equipment is reduced; and (d) the rate of instructional material updating is increased. The other category involves the enhancement of educational effectiveness: (a) high-quality instruction can be consistently provided on a large scale; (b) instruction at remote sites is possible; (c) instruction in hands-on, performance-oriented tasks can be provided; and (d) the instruction can be individualized.

In addition, contrary to the opinion of some that computer interaction is undesirable and dehumanizing, there may be some students who actually find their emotional and social needs better met, or at least supplemented, by dealing with a computer (Gaylord & Franklin, 1985).

In any case, the real key to the success of CBL is its effectiveness in providing instruction and its ability to be administered with a minimum of effort (Roblyer, 1981). The computer's role in education is summed up as follows by Magidson (1978):

> The educational promise of CAI lies in its ability to individualize and personalize the instructional process and to simulate experiences not readily available. CAI lessons (courseware) can serve as text, test, and tutor while compelling students to be active participants in their own learning. Students work at their own pace while their CAI lesson monitors their progress and commonly prevents them from continuing to more advanced instruction unless mastery is demonstrated. Students are kept informed of their progress through immediate feedback and achievement summaries. Students have varying amounts of control over their learning in that they can review previous instruction, request special help, or continue on to enrichment activities. The instruction can be systematically prepared, sequenced, tested, and revised (p. 5).

When courseware performs in this manner, teachers may actually have more contact with students than less, as might be expected, and improved student performances may be readily observable (Holmes, 1982).

To be successful, computer courseware, like any courseware, must be developed with certain principles in mind. Gagne', Wager and Rojas (1981) recommend beginning development of computer-assisted course material by categorizing the learning outcome desired as one of the following types: (a) verbal information; (b) intellectual skills; (c) cognitive strategies; (d) motor skills or (e) attitudes. The next step then is the preparation and ordering "of a series of displays that stimulate the learner so as to make learning readily occurable" (p. 18). These steps are formulated by considering the internal learning processes, or events of instruction (Gagne', 1977; Gagne' & Briggs, 1979), and then designing appropriate external instructional events. For instance, if the internal learning process desired is alertness, the external instructional event would be designed to gain attention (Gagne', Wager, & Rojas, 1981).

Smith and Boyce (1984) recommend an analysis of the instructional medium be undertaken before software design work begins because computer-assisted instruction is not the most suitable medium for every instructional event. If the computer does seem appropriate, the instructional designer should prepare performance objectives and criterion-referenced tests just as would be done for conventional instructional methods (Bloom, 1965; Mager, 1975; Smith & Boyce, 1984).

Different courseware philosophies are adhered to by CAI authors. Some programs are designed to place considerable control in the hands of the student, even to include selection of the learning activities. Feedback may be highly tailored in such programs. A different approach is more structured and directed by machine (Roblyer, 1981). "Apparently, there are types of students and/or content for which these highly-structured, machine-controlled exercises are very applicable" (p. 49).

Whatever tack taken by the CAI author, the guidelines which are given by Gagne', Wager, and Rojas (1981) are most likely applicable. They include:

> (a) leaving the pace of the lesson under the control of the user;
> (b) avoiding the placement of too much text on a screen display;
> (c) providing the learner with instructions on what to do next (p. 21).

In addition, "an instructional statement in CAI must be almost monumentally clear. It should mean approximately the same thing to many different people, who may have cause to refer to it again and again" (Meredith, 1971, p. 29). The computer should be user-friendly, able to respond to any input by the user without giving perplexing error messages. A help screen that is readily accessible to the user on request is often beneficial (Vockell & Rivers, 1984).

There are a number of authoring systems available commercially that may be of great assistance in designing a computer-based learning program that meets these criteria. These systems function primarily by supplying procedures which facilitate communication between the instructional designer and the computer itself (Dean, 1978). Creators of CBL courseware are then free to concentrate on content rather than on the coding of computer instructions.

The latest of the CBL authoring systems are designed to incorporate aspects of artificial intelligence, creating a "bridge between the sophisticated, expensive approach used by AI research, with its emphasis on the active participation of the learner, and the easily written and easily modified approaches of contemporary course-writing systems" (Morris, 1983, p. 14). Such authoring systems may well allow the opening of the prominent CBL frontier, intelligent computer-assisted instruction, a frontier that signals greatly increased flexibility and effectiveness for computers in education. Herbert Simon (1983) says it this way: "The computers that do a good job at CAI are going to be intelligent computers. Whether artificially or naturally, they are going to have to be intelligent in one way or another" (p. 19). Intelligent computer-assisted instruction systems will permit greatly elevated levels of interaction with the learner and will stimulate a more sophisticated and appropriate use of the computer as a general purpose problem solving tool rather than use as an expensive novelty (Papert, 1984b; Agee, 1985).

Intelligent Computer-Assisted Instruction

Intelligent computer-assisted instruction is the result of efforts to instill some learning capabilities in a CAI program. Doing so greatly enhances its flexibility and effectiveness, enabling the computer tutor to acquire knowledge about the student's needs and abilities and about the effectiveness of the instructional strategies that are employed. Evidence that a particular strategy is proving futile with an individual learner causes the system to alter its strategy to something more promising (Hartley, & Sleeman, 1973; Hartley, 1973).

Not only are ICAI systems able to improve their teaching performance, they are also often able to converse with the student in a natural dialogue, react to unexpected responses, and actually understand the nature of the student's errors (O'Shea, 1979; 1982). The ability to construct these ICAI systems will be very much facilitated by authoring tools for which some models have already been developed (Self, 1977; O'Shea, Bornat, Du Boulay, Eisenstadt, & Page, 1984; Scandura, 1984).

There are three major components of ICAI. The first is the expertise module which contains pertinent subject matter knowledge to be used to formulate problems and for comparison to assess the accuracy of the learner's responses (Clancey, Barnett, & Cohen, 1982).

> The knowledge of subject matter may be represented by one or more of the following methods: (a) semantic nets in a huge, static database that incorporate all the facts to be taught; (b) procedural experts that correspond to subskills that a student must learn in order to acquire the complete skill being taught; (c) production rules that are used to construct modular representations of skills and problem-solving methods; and (d)

> multiple representations that combine the semantic nets of facts and the procedures of functional behaviors of the facts (Roberts & Park, 1983, p.7).

The second ICAI component is the student module, a model of an individual student's knowledge of the subject matter and of progress made toward an educational objective.

> Typical uses of AI techniques for modeling student knowledge include (a) simple pattern recognition applied to the student's response history and (b) flags in the subject-matter semantic net or in the rule base representing areas that the student has mastered. In these ICAI systems a student model is formed by comparing the student's behavior to that of the computer-based "expert" in the same environment. The modeling component marks each skill according to whether evidence indicates that the student knows the material or not (Clancey et al., 1982, p. 231).

The final element of ICAI is the tutoring module which provides the communications link between the ICAI system and the student.

> The strategy in the tutoring module is based on one of the following methods: (a) a diagnostic or debugging approach in which the system debugs the student's misunderstanding by posing tasks and evaluating his or her response; (b) the Socratic method, which involves questioning the student in a way that will encourage him or her to reason about what he or she knows and thereby modify his or her conceptions; or (c) a coaching method in which the student is engaged in some activity like a computer game to encourage skill acquisition and general problem solving ability (Roberts, 1984, p. 43).

Eight representative ICAI systems have been described by Clancey et al. (1982). One of them is SCHOLAR, a computer-based tutoring system that teaches South American geography. SCHOLAR is a pioneer in the ICAI field: it was the first system developed that not only generates a dialogue by presenting questions to the student, but also responds to unanticipated questions from the student. The Socratic method is used by SCHOLAR. It attempts to first diagnose misconceptions held by the student and then asks questions and presents material to unobtrusively lead the student to see the error.

The WHY program builds upon SCHOLAR, again using Socratic methods this time to tutor students on the causes of rainfall. Heuristics are incorporated in the system to guide the interaction between student and computer tutor.

> A sample heuristic is:
>
> If the student gives as an explanation of causal dependence one or more factors that are not necessary,
>
> Then select a counterexample with the wrong value of the factor and ask the student why his causal dependence does not hold in that case.
>
> This rule forces the student to consider the necessity of a particular factor (Clancey, et al., 1982, p. 243).

WHY does not pursue long-term goals during the dialogue as a human tutor would. Instead, it focuses on bugs (misconceptions) in the student's reasoning that are apparent from the immediate dialogue (Clancey, et al., 1982).

BUGGY is another ICAI system that has been developed to diagnose bugs in student problem solving. BUGGY analyzes students' answers to arithmetic problems and formulates a model of the student's knowledge in enough detail to predict the errors the student is likely to commit given a certain problem. It also explains the nature of the bugs, so teachers can use BUGGY as a guidepost when developing their own diagnostic capabilities (Clancey, et al., 1982).

In the SOPHIE system, a student works "with a computer-based 'expert' who helps him come up with his own ideas, experiment with these ideas, and, when necessary, debug them" (Clancey, et al., 1982, p. 247). SOPHIE (for SOPHisticated Instructional Environment) has been applied initially to teaching electronic troubleshooting.

> SOPHIE was designed to fulfill three main objectives: the first was to demonstrate that the notion of using AI techniques to build an "intelligent" CAI system (ICAI) was not purely a pipe dream ... The second objective was to explore some new dimensions for CAI which exploit the significant increase in computational power provided by current hardware technology....The third was to fulfill the need of an environment in which to experiment with new ways of teaching problem-solving skills, such as electronic troubleshooting, without being constrained only to pose problems having extensionally defined solution sets (Brown, Burton, & Bell, 1975, p. 676).

SOPHIE has a highly refined natural language system and powerful inference mechanisms which give it the ability to answer difficult questions (Brown, Burton, & de Kleer, 1982).

A different learning environment that can be very motivational is associated with educational games. When an instructional program monitors a game played between a student and a computer and gives occasional instruction and advice on strategy, the program is said to be coaching the student. This technique is used in two ICAI systems described by Clancey, et al. (1982).

WEST is a coaching system that operates with a game modeled after a computer-simulated board game. The original version of the game, "How the West Was Won," was non-tutorial and developed to give elementary students practice in arithmetic. During each turn students advance toward their goal by manipulating three numbers with addition, subtraction, multiplication, or division. In the tutored version, students are occasionally coached in basic math concepts or game playing stategy (Clancey, et al., 1982).

A similar concept is used with WUMPUS, a game in which players attempt to find the imaginary Wumpus monster in his cave and kill him, all the while taking care to avoid being attacked by bats or falling into a pit. To be successful, players must make logical decisions based upon knowledge of probability and geometry. The computer tutor assists the player with suggestions and explanations (Clancey, et al., 1982).

Successful coaching in gaming situations does not happen by chance. A tutor should provide the player help when confusing situations are encountered, but if it interrupts too often or when help is not genuinely needed, it can greatly diminish the fun of the game. Knowing how, as well as when to interrupt is important. The coach should lead the student to solutions, not giving away any more information than necessary (Burton, & Brown, 1982).

EXCHECK is an ICAI system that checks the validity of a student's mathematical proof. It has been used extensively at Stanford University with courses dealing with logic, set theory, and proof theory. There are powerful inference procedures in EXCHECK's expert module that enable it to make assumptions about the reasoning ability of the student and then to interact "in a natural style that closely approximates standard mathematical practice" (Clancey, et al., 1982, p. 283).

The Basic Instructional Program (BIP) is another Stanford project developed to research tutorial interaction in computer-assisted instruction. The BIP program tutors students learning to solve introductory BASIC programming problems (Barr, Beard, & Atkinson, 1976).

All the ICAI programs described so far utilize AI techniques to some degree and are thus related to the conventional form of expert systems that are used as consulting tools. In fact, it may be said that ICAI programs are indeed expert systems -- expert at teaching.

But there have been limited educational applications of traditional expert systems, those developed without specific educational intents for commercial and industrial problem solving tasks.

Jones (1984) suggests the use of expert systems in the special education field for diagnosing learning disabilities as well as for teaching and tutoring. At the Utah State University's Development Center for Handicapped Persons expert systems have been used and some authoring systems evaluated (Ferrara, Parry, & Lubke, 1985). "Prototype programs in the areas of diagnosis, classification, program evaluation, classroom management, and videodisc control are currently in various stages of development and testing" (p. 39).

Expert systems can be a valuable tool in educational research. Good (1984) compares human expert problem solving techniques with those used by machine expert systems and, while acknowledging the emotional and cognitive differences between the two, asserts it is not irrational to examine "machine systems to see whether they can provide insights that might be valuable in our search to learn more about how scientific problem solving is learned" (p. 338).

An interesting application of expert systems in engineering education is reported by Starfield, Butala, England, and Smith (1983). Students in a senior mining engineering course at the University of Minnesota were introduced to the basic operational concepts of expert systems by lecture and were then assigned the task of building an expert system related to a suitable topic. The systems were constructed on paper by simply writing out the rules that made up the system.

The results were noteworthy. Students reported the assignment was an effective way to thoroughly learn their selected subject matter.

> Students were especially positive about expert system building as an alternative to essays or term papers on similar subjects. The formal structure of the expert system imposes a discipline that:
> 1) Clearly defines what is expected of students;
> 2) Forces them to identify and concentrate on the essential features of the subject;
> 3) Requires them to search for, evaluate and synthesize specific information, ie., they are forced to read the literature purposefully;
> 4) Encourages them to interact with faculty and ask carefully prepared questions;
> 5) Encourages them to interact productively with each other in a group effort (students were required to work in groups of two or three);
> 6) Eliminates much of the busy work involved in writing a paper (Starfield, et al., 1983, p. 107).

Expert systems then may have considerable value in and of themselves when used as a problem solving tool by students. Buchanan and Shortliffe (1984) assert that it may be possible to allow students to view "..the kinds of quick associations, patterns, and reasoning strategies that experts build up tediously over long exposure to many kinds of problems -- the kind of knowledge that tends not to be written down in basic textbooks" (p. 456).

The first resolved attempt to provide access for students to the expertise embodied in an authentic expert system was conducted with MYCIN, an expert system that provides diagnosis and therapy information about infectious diseases. MYCIN is a valid, operational system that has proved to provide diagnoses about as well as the infectious disease faculty at Stanford University's School of Medicine (Clancey, 1982).

MYCIN has a built-in explanation system that allows the user to ask for reasons behind the questions the system asks and the conclusions it reaches. This feature makes it easier to follow the line of reasoning used by the system during a consultation session. When system developers set out to apply MYCIN specifically to education however, they felt this to be an inefficient means for students to assimilate the contents of the knowledge base because "the MYCIN program is only a passive 'teacher.' It is necessary for the student to ask an exhaustive series of questions, if he is to discover all of the reasoning paths considered by the program" (Clancey, 1982, pp. 204-205). For that reason, an intelligent tutoring system, termed GUIDON, was developed to work with the MYCIN program.

GUIDON works by a case study method whereby one of the stored cases previously diagnosed by MYCIN is presented to the student. The student must then play the physician's role and ask pertinent questions of the system in an attempt to provide a diagnosis. GUIDON contrasts the student's questions and conclusions with MYCIN'S and then critiques the student in a prolonged mixed-initiative dialogue (Clancey, et al., 1982; Clancey, 1984).

The approach used by GUIDON is not without some restraints. Since the domain expert's reasoning that was used to formulate the rules in MYCIN is not explicitly represented, there is no practical way for GUIDON to justify all the case data sought and conclusions drawn (Ford, 1984). Also, unless the tutorial rules closely control the options available for discussion topics, the dialogues tend to be protracted and monotonous (Clancey, 1982).

Nevertheless, research with GUIDON has proved that access to an expert system's knowledge base can be enhanced and used in a practical way for educational purposes. Yet there is still a lot of research to be done. Empirical studies will give a better understanding of how knowledge is transmitted from person to machine and also from machine to person. The degree of assistance needed to provide students with maximum access to an expert system's knowledge base is still to be determined. Varying the way the rules in a rule-based expert system are structured and worded may also contribute to improved learning. Studies need to be conducted with other systems and with domains of knowledge other than medicine. This study is an attempt to add to the existing knowledge about the role of expert systems in education.

Chapter 3

Research Methodology

All three sections of the IE 311 course which were taught during the spring 1986 term at Oregon State University participated in this study. All sections were taught by the researcher and received instruction in the fundamentals of casting prior to the beginning of the experiment. Instruction was provided through lecture and supplemented with audio-visual aids. There was little or no mention of casting defects before the experiment began, but students were taught the basics of green sand molding procedures and gating practices.

Students from all three sections were randomly divided into two experimental groups. The first group, Experimental Group 1 interacted with human experts during the experiment while Experimental Group 2 interacted with the TELECAST expert system. Randomization was achieved by assigning a number to each of the 84 students listed on the instructor's preliminary class list. The first number was assigned to the first student on the alphabetized list of the first section and subsequent numbers were assigned to students according to their placement on the class lists. The last number then was assigned to the last student on the alphabetized list of the third section. A simple program for a micro-computer was then written to generate a list of pseudo-random numbers between 1 and 84. The first

42 different numbers generated were matched with the students' assigned numbers and were the basis for formation of Group 1. The remaining 42 students were placed in Group 2. See Appendix H for details of the randomization procedure.

Each group was scheduled for two four-hour time spans to participate in the testing and laboratory activity. Group 1 was scheduled in the morning the first day and in the afternoon the second day. Group 2 had the alternate time slots. Since the experiment was conducted on two consecutive Saturdays, not regular class days, students were assigned to a group very early in the term so they could plan accordingly. Because the randomization and group assignment were performed early in the term, the group rosters contained several students who dropped the course and thus did not participate. Students unable to attend both experiment sessions (for whatever reason) were given an alternate assignment so some did not participate in the experiment. The final groups then each contained less than 42 students: Experimental Group 1 had 35 students; Experimental Group 2 had 38 students.

The experiment began with the administration of a pre-test to measure students' knowledge about the causes of casting defects. Definitions were printed on the chalkboard in the front of the classroom during the test administration so new vocabulary would not be the limiting factor in test performance.

Immediately after pre-testing, students formed small teams of three or four students each and were assigned to a computer and given a lab manual, lab activity sheets and several defective castings.

Instructions to the two groups varied. Group 1 was told to perform a diagnosis of the defective castings with the help of the lab manual and the experts who were available to answer any questions they had. The two experts were directed to move freely about the lab area, dividing their time equally, as much as possible, among the groups of students. The students were told to obtain the computer diagnosis for each casting and discuss the differences between it and their diagnosis. The computer program used with Group 1 did not provide an "intelligent" diagnosis. Rather, it simply produced a diagnosis based on the identification number of the casting that had been entered by the students. The program generated the same diagnosis for every casting that started with the same digit, a scheme that was worked out ahead of time to provide answers that, while certainly not exact, were close enough to seem plausible. The purpose of the auxiliary computer program was to ensure that both groups had interaction with a computer to negate the Hawthorne effect as much as possible. A complete program listing can be found in Appendix D.

Group 2 was also divided into groups of three or four students each and received lab manuals and lab activity sheets. The difference in treatment between Group 1 and Group 2 was in the source of additional assistance. Students in Group 2 were told the two persons present could answer questions about the operation of the TELECAST expert system which was to be their source of help with diagnosis. The experts were directed to provide assistance only with regard to program operation. Students were asked to record their diagnoses on sheets and turn them in at the conclusion of the lab period. The sheets used for the two groups varied only slightly; they are shown in Appendix F.

Students spent three hours in this lab activity after the pre-test on the first day of the experiment. One week later they returned and were again evaluated with the same evaluation instrument. Following the post-testing, students from both groups were allowed access to TELECAST and asked to perform a subjective evaluation of the expert system to assess the accuracy of the system in diagnosing casting defects and to state an opinion regarding the effectiveness of an expert system as a teaching tool. Some representative comments are recorded in Appendix J.

Population

As stated previously, subjects in this experiment were Oregon State University students. As individuals they differed considerably, and no attempt was made to determine factors from their backgrounds that might have contributed to their success or lack of success in the tasks they were assigned as part of this experiment. However, some data were gathered regarding their major field of study, gender, and grade level; they are presented in Table 1 below.

FACTOR	NUMBER OF STUDENTS
MAJOR FIELD	
Mechanical Engineers	
Group 1	13
Group 2	10
Industrial Engineers	
Group 1	2
Group 2	4
Pre-Engineering	
Group 1	19
Group 2	24
Science	
Group 1	1
Group 2	0
GENDER	
Female	
Group 1	6
Group 2	5
Male	
Group 1	29
Group 2	33
GRADE LEVEL	
Freshman	
Group 1	0
Group 2	3
Sophomore	
Group 1	8
Group 2	13
Junior	
Group 1	17
Group 2	11
Senior	
Group 1	10
Group 2	9
Post-Bac	
Group 1	0
Group 2	2

Table 1: Population Characteristics

Expert System Development

The development of TELECAST was the major effort of this study. Authoring software from EXSYS Inc. (EXSYS, 1985) was used by the researcher to create the expert system. The software was found to be straightforward and fairly easy to use.

TELECAST is a rule-based system which consists of 27 choices, 23 qualifiers, and 69 rules. The choices are actually the causes that are to be identified by the system as contributing to the defect. Qualifiers are the variable conditions that must be considered in order to hypothesize about the choices and reach a valid conclusion. Qualifiers are presented to the user in order to identify the correct condition that describes the casting defect or possibly the pouring or molding conditions that may have influenced the success of the casting procedure. Rules are the if-then representations of the qualifiers, the logic that drives the system. A complete listing of the rules, qualifiers, and choices used in TELECAST is found in Appendices A, B, and C.

EXSYS is a backward-chaining expert system; it starts by hypothesizing about a choice and then questioning the user to draw inferences about that choice. EXSYS continues questioning until it gathers the plenary evidence to positively identify the cause as either contributing or not contributing to the defect (or until the qualifiers related to that choice are exhausted). It continues with each choice in turn until all are investigated fully.

TELECAST is limited in scope to diagnosing defective aluminum castings. It assumes the castings it deals with have been poured in green sand molds, but it should be able to be used with castings poured in petro-bond or dry sand molds if the user is cognizant of the fact and responds to TELECAST's questioning accordingly. Since aluminum is one of the easiest metals to cast, has a relatively low melting temperature, and is cast with techniques similar to those used for many other metals, it is often the material selected for teaching casting processes in high schools and technical schools. TELECAST could therefore be applicable to many secondary and post-secondary educational programs as well as foundry training programs in private industry.

The researcher played the role of both domain expert and knowledge engineer in the development of the TELECAST system. The knowledge base was built with reference to technical literature (La Rue, 1980; Sylvia, 1972; Cowles, 1964) and the researcher's experience as a technical educator and tradesperson. Figure 1 depicts the model used for development of the system.

Validation of TELECAST was achieved by allowing three experts from the field, all industrial educators with extensive experience in nonferrous foundry work, to examine the rules, qualifiers, and choices to ascertain the

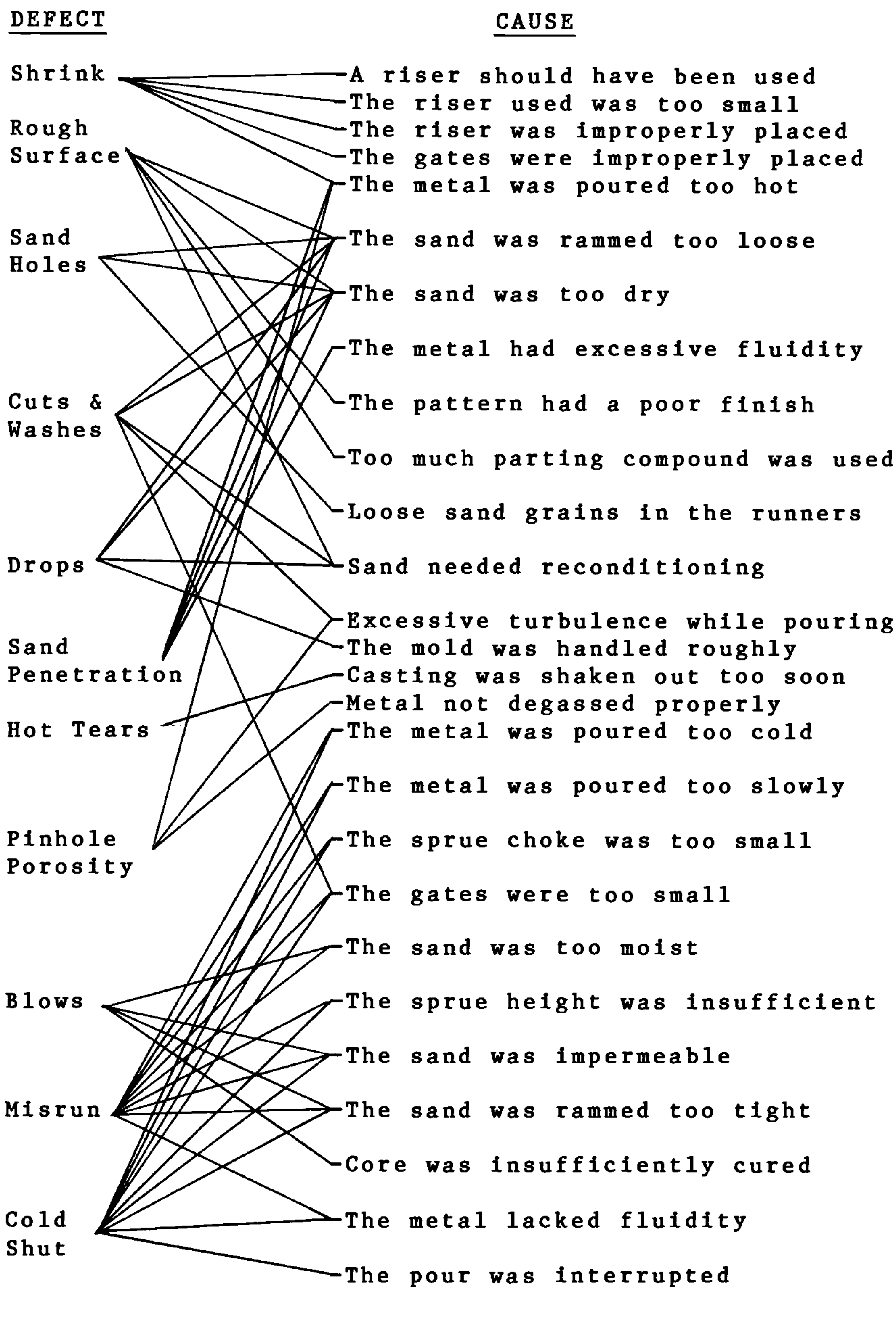

Figure 1: Model Used for TELECAST Development.

completeness of the system and the correctness of the logic used to reach a conclusion. Floppy disks containing TELECAST were also sent to allow hands-on use of the expert system. Recommendations received were used as the basis for revision of the system.

Evaluation Instrument Development

A single evaluation instrument for both pre- and post-testing was written by the researcher. It consists of 50 multiple-choice questions; each question lists one defect followed by five possible causes of that defect. Only one of the listed causes is a valid selection. The entire instrument is listed in Appendix E.

The same model followed for construction of TELECAST was used for the test construction to assure congruity of the two. The evaluation instrument was validated by the same panel of experts that validated the expert system. Revision of the instrument was made to reflect their suggestions.

Laboratory Exercise Development

Approximately 50 castings with various defects were produced to allow students opportunity for hands-on experience during the laboratory exercise. Classic textbook examples were desired, but were found hard to produce. Very often one defect was accompanied by another, and the resulting casting was not a vivid example of a single defect but instead a specimen with multiple and vague flaws. About 30 castings were deemed acceptable, cataloged according to defect, and tagged with an identification number. Almost all of the possible defects from the development model (Figure 1) were represented in the resulting collection, but the specific cause was usually not readily evident. Photographs of several typical defective castings are included as Appendix I.

The auxiliary computer program and the expert system used respectively by Experimental Group 1 and Experimental Group 2 have have already been described. Both of these programs operate on an IBM PC or IBM PC-compatible computer, and since there was access to 14 of these computers for the experiment, students divided into groups of three or four students.

Pilot Study

A pilot study was conducted one week prior to the experiment to identify any flaws in the planned lab activity and to determine the optimum time span for the treatments. Three industrial education students with limited foundry experience volunteered to form a group and spend one hour performing the Group 1 lab activity and another hour doing the Group 2 activity. Both persons who acted as expert consultants for Group 2 were present during the pilot study and each rehearsed his role for the actual experiment. The researcher was present as observer.

The students worked with the same equipment, in the same location, and under the same conditions as the experimental groups did. All the software and hardware used performed well during the pilot study. The computers were well spread out and surrounded with ample table surface so there was an area for the students to handle and examine the defective castings with plenty of room for all the participants to see the castings and the computer screen.

The students spent about 15 minutes with the first casting in both activities. After the first two or three were diagnosed, the time spent with each casting dropped off to about 10 minutes. It was determined that a three-hour block of time during the experiment would allow students to diagnose all or almost all of the defective castings and provide adequate exposure to the treatments to significantly effect learning.

Hypotheses and Statistical Methods

This experiment tested the effectiveness of two experimental treatments. The first treatment involved human experts interacting with students to assist them in learning technical subject matter. The second treatment involved a computer expert system performing a similar task.

The following hypotheses were formulated:

Null Hypothesis

Ho : Mean Exp1 = Mean Exp2

There is no significant difference between treatments.

Alternate Hypothesis 1

H1 : Mean Exp1 > Mean Exp2

Treatment 1 (using human experts) is significantly superior to treatment 2.

Alternate Hypothesis 2

H2 : Mean Exp2 > Mean Exp1

Treatment 2 (using an expert system) is significantly superior to treatment 1.

The .05 significance level was selected for testing these hypotheses. With the sample cell sizes of 35 and 38, a .30 effect size corresponds with a .70 power level (Cohen, 1969). Thus, there was a 5% chance of Type I Error (rejecting the null hypothesis when it was actually true) and a 30% chance of Type II Error (retaining the null hypothesis when it was actually false).

An analysis of covariance was used as the statistical tool because contrasting was involved and pre-test scores were available. The following assumptions for this test were made:

1. Assignment of individuals to groups was random.

2. Data representing the dependent variable were of the interval scale type.

3. Both the dependent variable and independent variables were normally distributed in each treatment group.

4. Regression lines representing the data were linear and of equal slope.

Both pre- and post-tests were hand-scored, and the data were analyzed by the Oregon State University Computer Center through a grant received by the researcher from OSU.

Chapter 4

Presentation of the Results

This study was to contrast two teaching methods, one utilizing human experts and the other a computer expert system, to find if there was a significant difference. To make this determination, students were evaluated before treatment and again following the treatment.

Results of the pre- and post-testing are shown in Table 2. The table values reflect the raw scores obtained on the 50-question multiple choice test. The frequencies of scores obtained is given in Table 3.

It is evident from these tables that neither of the two treatments resulted in improved test scores for 100% of the students, though each group as a whole did significantly improve in post-test performance. The failure of some students to improve may be explained, at least in part, by the definitions that were given during the pre-test only. As stated previously, definitions of the defects were written on the chalkboard at the front of the classroom during the pre-test so students' vocabulary deficiencies would not handicap them. It is highly probable that higher scores would have been achieved on the post-tests had definitions also been given.

Table 4 shows the computed mean pre-test scores as well as sums of raw scores, standard deviation, and variance for both experimental groups and the entire population; the

Group 1 (Human Experts)		Group 2 (Expert System)	
Pre-test	Post-test	Pre-test	Post-test
28	27	43	46
31	35	37	45
32	43	29	34
44	45	9	22
32	37	37	44
36	38	33	34
32	30	34	38
40	47	33	41
38	43	45	42
31	34	36	44
28	31	31	40
36	41	33	39
37	39	15	14
39	45	36	33
18	20	35	28
17	16	40	41
33	28	32	41
36	35	28	20
33	41	19	27
42	47	25	27
31	31	33	38
18	22	30	37
36	38	20	20
28	30	32	35
14	20	30	38
33	29	25	35
24	25	32	34
27	26	25	34
38	48	27	35
22	37	29	43
29	38	35	39
26	44	29	28
27	32	36	44
15	24	28	20
34	37	23	26
		37	43
		32	35
		31	31

Group 1: N = 35
Group 2: N = 38

Table 2: Raw Scores Obtained by Experimental Groups (50-Question Multiple Choice Instrument)

	Group 1 (Human Experts)		Group 2 (Expert System)	
	Frequencies			
Score	Pre-test	Post-test	Pre-test	Post-test
9	0	0	1	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	1	0	0	1
15	1	0	1	0
16	0	1	0	0
17	1	0	0	0
18	2	0	0	0
19	0	0	1	0
20	0	2	1	3
21	0	0	0	0
22	1	1	0	1
23	0	0	1	0
24	1	1	0	0
25	0	1	3	0
26	1	1	0	1
27	2	1	1	2
28	3	1	2	2
29	1	1	3	0
30	0	2	2	0
31	3	2	2	1
32	3	1	4	0
33	3	0	4	1
34	1	1	1	4
35	0	2	2	4
36	4	0	3	0
37	1	3	3	1
38	2	3	0	3
39	1	1	0	2
40	1	0	1	1
41	0	2	0	3
42	1	0	0	1
43	0	2	1	2
44	1	1	0	3
45	0	2	1	1
46	0	0	0	1
47	0	2	0	0
48	0	1	0	0

Entire Population: N = 73

Table 3: Frequencies of Test Scores

****

	Mean	Sum	Std. Dev.	Variance
Group 1 (Human Experts)	30.4286	1065.00	7.6285	58.1933
Group 2 (Expert System)	30.6316	1164.00	7.1373	50.9417
Entire Population	30.5342	2229.00	7.3259	53.6689

Group 1: N = 35
Standard Error = 1.28945

Group 2: N = 38
Standard Error = 1.15782

Entire Population: N = 73
Standard Error = 0.85743

****

Table 4: Pre-test Scores Data

****

	Mean	Sum	Std. Dev.	Variance
Group 1 (Human Experts)	34.3714	1203.00	8.5787	73.5933
Group 2 (Expert System)	34.6053	1315.00	8.1325	66.1373
Entire Population	34.4932	2518.00	8.2918	68.7534

Group 1: N = 35
Standard Error = 1.45006

Group 2: N = 38
Standard Error = 1.31926

Group 3: N = 73
Standard Error = 0.97048

****

Table 5: Post-test Scores Data

same information is given for post-test scores in Table 5.

Analysis of Covariance

The analysis of covariance was the statistical tool used to evaluate the data, and Table 6 summarizes the results of the evaluation.

The F value of .002 indicates there is no significant difference between the two groups. Thus, the null hypothesis is retained. This determination is not surprising considering the almost identical post-test means for the two groups: 34.3714 (Group 1) and 34.6053 (Group 2).

* * * Analysis of Covariance * * *

One-Way Fixed Model

Post-test by Group with Pre-test

* * * * * * * * * * * * * * * * *

Source of Variation	DF	Mean Square	Computed F	Significance of F
Group	1	.049	.002	.966
Residual	70	26.259		
Total	71			

Table 6: Analysis of Covariance

Chapter 5

Summary, Conclusions, and Recommendations

The purpose of this study was to determine the effectiveness of an expert system in transferring technical knowledge to a learner. This was done by comparing the amount learned by students who worked with an expert system to that learned by students who worked with human experts during technical training.

Summary

An expert system, named TELECAST, that diagnoses defective aluminum castings was created by the researcher. In addition, a laboratory activity was designed that allowed the students hands-on training and interaction with the expert system or with human experts.

A collection of defective castings was produced, cataloged, and arranged to allow students to diagnose selected defects with the use of a laboratory manual. Students were also given additional help according their random group assignment. One group had access to human experts; the other group had access to TELECAST.

The students participating in the study were from the College of Engineering at Oregon State University and enrolled in a course in manufacturing processes during the spring term, 1986. Their knowledge of casting defect diagnosis was evaluated with a test instrument prior to the treatment and again following treatment.

The null hypothesis (treatments effects are equal) was tested by analyzing the test results with an analysis of covariance. Subjective evaluations of the expert system by the student participants were also recorded and included in the study for the reader to assess as he or she deems appropriate.

Findings and Conclusions

The statistical analysis of the test scores reveals there was no difference in the amount learned by the two groups of students. The expert system proved to be no more and no less effective than the human experts at effecting learning.

It is not possible to make wide-ranging inferences from this study. A particular expert system, TELECAST, was used, and a specific population and subject content area was involved. A change in any of these variables may well have altered the outcome. One can only say that the equality of treatment effectiveness suggests possibilities for the use of expert systems in education. Further study is definitely needed in this area.

If expert systems are, generally speaking, as efficient at transferring knowledge as human experts, there is a great potential for their use in education. They may provide cost-effective, individualized instruction while removing the variabilities associated with human interaction.

This study has demonstrated that it is possible to develop an expert system that can be used for technical instruction with results equal to those achieved by human experts. The subjective comments of the students who used the expert system may give valuable clues to attitudes that develop while working with an expert system.

This study examined one instructional approach, but there are others that may be even more effective. The notion of assigning students the task of creating an expert system, even on a real system, may become practical as the prices decline. One can imagine the extensive learning required to enable a student to provide the expertise needed for a knowledge-based system. Such an academic assignment might soon be applicable to typical real world work assignments because of increased interest in expert systems.

Recommendations for Further Study

This study suggests that expert systems may prove to be at least as effective as human experts in effecting the learning of technical material. Additional studies are needed to determine the limitations of expert systems in education and to discover the most advantageous methods of employing them.

The following are suggestions for further study:

1. Replication of this study with the TELECAST Expert System and the same student population.

2. Refinement of TELECAST and replication of this study with the same student population.

3. Replication of this study with a refined TELECAST system and a different population, i. e. secondary technology students or post-secondary industrial education students.

4. Utilization of EXSYS or similar authoring systems to construct expert systems for other technical subject matter domains.

5. Application of other expert systems and content areas to similar studies.

6. Studies that investigate the effectiveness of student-developed expert systems as a learning exercise.

7. Studies to investigate the nature of the interaction between learner and machine expert, i. e. determination of the most effective means of communication between human and machine.

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APPENDICES

Appendix A:

TELECAST Rules

TELECAST Expert System Rules

Subject: Diagnosis of defects in aluminum castings poured in green sand molds.

Author: Kim E. Ruyle

Starting text: This expert system will assist you in diagnosing a defective aluminum casting by asking you questions. Answer the questions based on your observation of the defective casting. Also, use any other information you have concerning the specific procedures used to produce the casting. If you do not understand the rationale for a question asked, you can type "why" for an explanation.

Ending text: The system has completed its diagnosis of the casting and will now present the possible causes, listing them in order -- the most likely first. The numbers listed with the causes indicate the likelihood of occurrence. For example, a "10" indicates the cause was without a doubt involved in producing the defect. A "5" is a neutral value and indicates no positive or negative evidence has been gathered for that particular cause. The causes that will now be displayed are only those that have received a value of "6" or greater.

Uses all applicable rules in data derivations.

RULES

RULE NUMBER: 1

IF:

THE CASTING APPEARS TO BE INCOMPLETE, AS IF THE CAVITY FAILED TO FULLY FILL WITH METAL

and VENTING OF THE CAVITY WAS ABSENT

THEN:

THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 9/10

NOTE: A MISRUN IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 2

IF:

VENTING OF THE CAVITY WAS PRESENT

THEN:

THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 0/10

NOTE: VENTING IS IMPORTANT TO PREVENT MISRUN AND COLD SHUT.

REFERENCE: LAB MANUAL, PAGES 1 AND 2. SEE MISRUN AND COLD SHUT

RULE NUMBER: 3

IF:

VENTING OF THE CAVITY WAS POSSIBLY PRESENT -- NOT SURE

THEN:

THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 5/10

NOTE: VENTING IS IMPORTANT TO PREVENT MISRUN AND COLD SHUT.

REFERENCE: LAB MANUAL, PAGES 1 AND 2. SEE MISRUN AND COLD SHUT

RULE NUMBER: 4

IF:
VENTING OF THE CAVITY WAS ABSENT

THEN:
THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 6/10

NOTE: VENTING IS IMPORTANT TO PREVENT MISRUN AND COLD SHUT.

REFERENCE: LAB MANUAL, PAGES 1 AND 2. SEE MISRUN AND COLD SHUT.

RULE NUMBER: 5

IF:
AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT
and THE DEPRESSION IN THE CASTING HAS AN EXCESSIVELY SMOOTH SURFACE APPEARANCE

THEN:
THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 8/10
and THE SAND WAS TOO MOIST
Probability = 8/10
and THE SAND WAS RAMMED TOO TIGHT
Probability = 7/10

NOTE: A BLOW IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 4. SEE BLOWS.

<u>RULE NUMBER: 6</u>

IF:

THE CASTING APPEARS TO BE POSSIBLY PARTIALLY INCOMPLETE -- NOT SURE

THEN:

THE METAL WAS POURED TOO COLD
Probability = 6/10

and THE METAL WAS POURED TOO SLOWLY
Probability = 6/10

and THE SPRUE CHOKE WAS TOO SMALL
Probability = 5/10

and THE GATES WERE TOO SMALL
Probability = 5/10

and THE SAND WAS TOO MOIST
Probability = 5/10

and THE HEIGHT OF THE SPRUE WAS INSUFFICIENT
Probability = 5/10

and THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 5/10

and THE SAND WAS RAMMED TOO TIGHT
Probability = 5/10

NOTE: A MISRUN CAN BE CAUSED BY ALL OF THE ABOVE FACTORS.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 7

IF:

THE CASTING APPEARS TO BE COMPLETE -- NO MISSING PORTIONS

and THE SURFACE OF THE CASTING APPEARS TO HAVE NO APPARENT CRACKS OR TEARS IN THE SURFACE

THEN:

THE METAL WAS POURED TOO COLD
Probability = 2/10

and THE METAL WAS POURED TOO SLOWLY
Probability = 2/10

and THE SPRUE CHOKE WAS TOO SMALL
Probability = 3/10

and THE GATES WERE TOO SMALL
Probability = 4/10

and THE SAND WAS TOO MOIST
Probability = 4/10

and THE HEIGHT OF THE SPRUE WAS INSUFFICIENT
Probability = 2/10

and THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 4/10

and THE SAND WAS RAMMED TOO TIGHT
Probability = 4/10

and THE METAL LACKED FLUIDITY
Probability = 2/10

NOTE: MISRUN AND COLD SHUT DEFECTS ARE NOT INDICATED.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 8

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE A FAINT CRACK OR A WEAKNESS THAT MIGHT LEAD TO A CRACK

THEN:

THE METAL WAS POURED TOO COLD
Probability = 7/10
and THE METAL WAS POURED TOO SLOWLY
Probability = 7/10
and THE SPRUE CHOKE WAS TOO SMALL
Probability = 6/10
and THE GATES WERE TOO SMALL
Probability = 6/10
and THE HEIGHT OF THE SPRUE WAS INSUFFICIENT
Probability = 6/10
and THE SAND WAS IMPERMEABLE (NOT VENTED)
Probability = 6/10
and THE SAND WAS RAMMED TOO TIGHT
Probability = 6/10
and THE METAL LACKED FLUIDITY
Probability = 6/10
and THE POUR WAS INTERRUPTED
Probability = 8/10

NOTE: A COLD SHUT IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 2. SEE COLD SHUT.

RULE NUMBER: 9

IF:

THE CASTING APPEARS TO BE INCOMPLETE, AS IF THE CAVITY FAILED TO FULLY FILL WITH METAL
and MONITORING OF THE POURING TEMPERATURE WAS NOT ATTEMPTED AT ALL -- SO THERE WAS NO CLUE AS TO THE POURING TEMPERATURE

THEN:

THE METAL WAS POURED TOO COLD
Probability = 9/10
and THE METAL WAS POURED TOO SLOWLY
Probability = 6/10
and THE HEIGHT OF THE SPRUE WAS INSUFFICIENT
Probability = 6/10

NOTE: A MISRUN IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 10

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE A FAINT CRACK OR A WEAKNESS THAT MIGHT LEAD TO A CRACK

and MONITORING OF THE POURING TEMPERATURE WAS PERFORMED WITH A PYROMETER AND CLOSELY CONTROLLED

THEN:

THE METAL WAS POURED TOO SLOWLY
Probability = 7/10

and THE SPRUE CHOKE WAS TOO SMALL
Probability = 6/10

and THE GATES WERE TOO SMALL
Probability = 6/10

and THE HEIGHT OF THE SPRUE WAS INSUFFICIENT
Probability = 6/10

and THE METAL LACKED FLUIDITY
Probability = 6/10

NOTE: A COLD SHUT IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 2. SEE COLD SHUT.

RULE NUMBER: 11

IF:

THE MOLDING SAND WAS PROPERLY TEMPERED -- NOT TOO MOIST AND NOT TOO DRY

THEN:

THE SAND WAS TOO DRY
Probability = 4/10

and THE SAND WAS TOO MOIST
Probability = 4/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 4/10

NOTE: TEMPERING IS THE PROCESS OF ADDING MOISTURE TO THE SAND TO INCREASE ITS AS-MOLDED STRENGTH (SOMETIMES CALLED "GREEN STRENGTH").

REFERENCE: LAB MANUAL, PAGES 2 AND 3. SEE SAND HOLES AND CUTS AND WASHES.

RULE NUMBER: 12

IF:

THE MOLDING SAND WAS OF UNDETERMINED TEMPER -- NOT SURE

THEN:

THE SAND WAS TOO DRY
Probability = 5/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 5/10

and THE SAND WAS TOO MOIST
Probability = 5/10

NOTE: TEMPERING IS A PROCESS OF ADDING MOISTURE TO THE SAND TO INCREASE ITS AS-MOLDED STRENGTH (SOMETIMES CALLED "GREEN STRENGTH").

REFERENCE: LAB MANUAL, PAGES 2 AND 3. SEE SAND HOLES AND CUTS AND WASHES.

RULE NUMBER: 13

IF:

THE CASTING APPEARS TO BE INCOMPLETE, AS IF THE CAVITY FAILED TO FULLY FILL WITH METAL

and THE MOLDING SAND SEEMED TO BE POSSIBLY TOO MOIST

THEN:

THE SAND WAS TOO MOIST
Probability = 8/10

NOTE: A MISRUN IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 14

IF:

THE MOLDING SAND SEEMED TO BE POSSIBLY TOO MOIST

THEN:

THE SAND WAS TOO MOIST
Probability = 6/10

NOTE: EXCESSIVE MOISTURE CAN CAUSE SEVERAL DEFECTS.

REFERENCE: LAB MANUAL, PAGES 1, 2, AND 4. SEE MISRUN, COLD SHUT, AND BLOWS.

RULE NUMBER:15

IF:

THE CASTING APPEARS TO BE INCOMPLETE, AS IF THE CAVITY FAILED TO FULLY FILL WITH METAL

and THE COMBINED CROSS-SECTIONAL AREA OF THE GATES WAS OF UNKNOWN CROSS-SECTIONAL AREA

THEN:

THE GATES WERE TOO SMALL
Probability = 7/10

NOTE: A MISRUN IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 16

IF:

THE COMBINED CROSS-SECTIONAL AREA OF THE GATES WAS LESS THAN THE SPRUE CHOKE

THEN:

THE GATES WERE TOO SMALL
Probability = 10/10

NOTE: GATES SHOULD BE LARGER IN CROSS-SECTIONAL AREA THAN THE SPRUE CHOKE TO PREVENT PRESSURIZING THE GATING SYSTEM AND TO ALLOW SUFFICIENT FLOW TO PREVENT PREMATURE FREEZING.

REFERENCE: LAB MANUAL, PAGES 1, 2, AND 3. SEE MISRUN, COLD SHUT, AND CUTS AND WASHES.

RULE NUMBER: 17

IF:

THE COMBINED CROSS-SECTIONAL AREA OF THE GATES WAS GREATER THAN THE SPRUE CHOKE

THEN:

THE GATES WERE TOO SMALL
Probability = 3/10

NOTE: GATES SHOULD BE LARGER IN CROSS-SECTIONAL AREA THAN THE SPRUE CHOKE TO PREVENT PRESSURIZING THE GATING SYSTEM AND TO ALLOW SUFFICIENT FLOW TO PREVENT PREMATURE FREEZING.

REFERENCE: LAB MANUAL, PAGES 1, 2, AND 3. SEE MISRUN, COLD SHUT, AND CUTS AND WASHES.

RULE NUMBER: 18

IF:

THE SHAPE OF THE CASTING APPEARS TO BE NOT ALTERED BY SAND EROSION

THEN:

THE SAND WAS RAMMED TOO LOOSE
Probability = 4/10

and THE SAND WAS TOO DRY
Probability = 4/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 4/10

and THERE WAS EXCESSIVE TURBULENCE WHILE POURING
Probability = 3/10

and THE GATES WERE TOO SMALL
Probability = 5/10

NOTE: CUTS AND WASHES ARE NOT INDICATED.

REFERENCE: LAB MANUAL, PAGE 3. SEE CUTS AND WASHES.

RULE NUMBER:19

IF:

THE SHAPE OF THE CASTING APPEARS TO BE ALTERED BY SAND EROSION

THEN:

THE SAND WAS RAMMED TOO LOOSE
Probability = 7/10

and THE SAND WAS TOO DRY
Probability = 7/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 7/10

and THERE WAS EXCESSIVE TURBULENCE WHILE POURING
Probability = 6/10

and THE GATES WERE TOO SMALL
Probability = 6/10

NOTE: CUTS AND WASHES ARE PRESENT. SMALL GATES CAN CAUSE PRESSURE IN THE WHOLE GATING SYSTEM THAT WILL ERODE THE MOLD.

REFERENCE: LAB MANUAL, PAGE 3. SEE CUTS AND WASHES.

RULE NUMBER: 20

IF:

THE SPRUE CHOKE WAS AT LEAST .5-INCH DIAMETER

THEN:

THE SPRUE CHOKE WAS TOO SMALL
Probability = 4/10

NOTE: THE SPRUE CHOKE SHOULD BE LARGE ENOUGH TO ALLOW SUFFICIENT FLOW INTO THE CAVITY, BUT NOT LARGER THAN THE COMBINED CROSS-SECTIONAL AREA OF THE GATES.

REFERENCE: LAB MANUAL, PAGES 1 AND 2. SEE MISRUN AND COLD SHUT.

RULE NUMBER: 21

IF:

THE SPRUE CHOKE WAS LESS THAN .5-INCH DIAMETER

THEN:

THE SPRUE CHOKE WAS TOO SMALL
Probability = 8/10

NOTE: THE SPRUE CHOKE SHOULD BE LARGE ENOUGH TO ALLOW SUFFICIENT FLOW INTO THE CAVITY, BUT NOT LARGER THAN THE COMBINED CROSS-SECTIONAL AREA OF THE GATES.

REFERENCE: LAB MANUAL, PAGES 1 AND 2. SEE MISRUN AND COLD SHUT.

RULE NUMBER: 22

IF:

THE CASTING APPEARS TO BE INCOMPLETE, AS IF THE CAVITY FAILED TO FULLY FILL WITH METAL

and THE SPRUE CHOKE WAS LESS THAN .5-INCH DIAMETER

THEN:

THE SPRUE CHOKE WAS TOO SMALL
Probability = 8/10

NOTE: A MISRUN IS INDICATED.

REFERENCE; LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 23

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE A FAINT CRACK OR A WEAKNESS THAT MIGHT LEAD TO A CRACK

and MONITORING OF THE POURING TEMPERATURE WAS PERFORMED BY "EYE" SO THE TEMPERATURE WAS NOT KNOWN EXACTLY

THEN:

THE METAL WAS POURED TOO COLD
Probability = 7/10

NOTE: A COLD SHUT IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 2. SEE COLD SHUT.

RULE NUMBER: 24

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE A FAINT CRACK OR A WEAKNESS THAT MIGHT LEAD TO A CRACK

and MONITORING OF THE POURING TEMPERATURE WAS NOT PERFORMED AT ALL -- SO THERE WAS NO CLUE AS TO THE POURING TEMPERATURE

THEN:

THE METAL WAS POURED TOO COLD
Probability = 8/10

NOTE: A COLD SHUT IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 2. SEE COLD SHUT.

RULE NUMBER: 25

IF:

MONITORING OF THE POURING TEMPERATURE WAS POSSIBLY PERFORMED -- NOT SURE

THEN:

THE METAL WAS POURED TOO HOT
Probability = 5/10

and THE METAL WAS POURED TOO COLD
Probability = 5/10

NOTE: IMPROPER POURING TEMPERATURE CAN CAUSE A RAFT OF PROBLEMS.

REFERENCE: LAB MANUAL, ALL PAGES. SEE MISRUN, COLD SHUT, SHRINK, BLOWS, PENETRATION, AND PINHOLE POROSITY.

RULE NUMBER: 26

IF:

MONITORING OF THE POURING TEMPERATURE WAS NOT ATTEMPTED AT ALL -- SO THERE WAS NOT CLUE AS TO THE POURING TEMPERATURE

THEN:

THE METAL WAS POURED TOO HOT
Probability = 6/10

and THE METAL WAS POURED TOO COLD
Probability = 6/10

NOTE: IMPROPER POURING TEMPERATURE CAN CAUSE A RAFT OF PROBLEMS.

REFERENCE: LAB MANUAL, ALL PAGES. SEE MISRUN, COLD SHUT, SHRINK, BLOWS, PENETRATION, AND PINHOLE POROSITY.

RULE NUMBER: 27

IF:

MONITORING OF THE POURING TEMPERATURE WAS PERFORMED BY "EYE" SO THE TEMPERATURE WAS NOT KNOWN EXACTLY

THEN:

THE METAL WAS POURED TOO HOT
Probability = 5/10

THE METAL WAS POURED TOO COLD
Probability = 5/10

NOTE: IMPROPER POURING TEMPERATURE CAN CAUSE A RAFT OF PROBLEMS.

REFERENCE: LAB MANUAL, ALL PAGES. SEE MISRUN, COLD SHUT, SHRINK, BLOWS, PENETRATION, AND PINHOLE POROSITY.

RULE NUMBER: 28

IF:

MONITORING OF THE POURING TEMPERATURE WAS PERFORMED WITH A PYROMETER AND CLOSELY CONTROLLED

THEN:

THE METAL WAS POURED TOO HOT
Probability = 1/10

and THE METAL WAS POURED TOO COLD
Probability = 1/10

NOTE: IMPROPER POURING TEMPERATURE CAN CAUSE A RAFT OF PROBLEMS.

REFERENCE: LAB MANUAL, ALL PAGES. SEE MISRUN, COLD SHUT, SHRINK, BLOWS, PENETRATION, AND PINHOLE POROSITY.

RULE NUMBER: 29

IF:

THE CASTING APPEARS TO HAVE SMALL HOLES CONTAINING SAND AND SMALL HOLES CONTAINING BLACK SPECKS (NOT SAND)

THEN:

THE METAL WAS POURED TOO HOT
Probability = 8/10

and THERE WERE LOOSE SAND GRAINS IN THE CAVITY OR RUNNERS
Probability = 7/10

and THERE WAS EXCESSIVE TURBULENCE WHILE POURING
Probability = 7/10

and THE METAL WAS NOT DEGASSED PROPERLY
Probability = 7/10

NOTE: PINHOLE POROSITY AND SAND HOLES MAY BOTH BE PRESENT.

REFERENCE: LAB MANUAL PAGES, 2 AND 6. SEE SAND HOLES AND PINHOLE POROSITY.

RULE NUMBER: 30

IF:

THE CASTING APPEARS TO HAVE SMALL HOLES DISTRIBUTED THROUGHOUT, OFTEN CONTAINING BLACK SPECKS (NOT SAND)

THEN:

THE METAL WAS POURED TOO HOT
Probability = 6/10

and THERE WAS EXCESSIVE TURBULENCE WHILE POURING
Probability = 7/10

and THE METAL WAS NOT DEGASSED PROPERLY
Probability = 8/10

NOTE: PINHOLE POROSITY IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 6. SEE PINHOLE POROSITY.

RULE NUMBER: 31

IF:

THE CASTING APPEARS TO HAVE NO SMALL HOLES IN THE SURFACE OR THROUGHOUT

THEN:

THERE WERE LOOSE SAND GRAINS IN THE CAVITY OR RUNNERS
Probability = 4/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 4/10

and THERE WAS EXCESSIVE TURBULENCE WHILE POURING
Probability = 3/10

and THE METAL WAS NOT DEGASSED PROPERLY
Probability = 4/10

NOTE: SAND HOLES AND PINHOLE POROSITY ARE NOT A PROBLEM.

REFERENCE: LAB MANUAL, PAGES 2 AND 6. SEE SAND HOLES AND PINHOLE POROSITY.

RULE NUMBER: 32

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE A FAINT CRACK OR A WEAKNESS THAT MIGHT LEAD TO A CRACK

and MONITORING OF THE POURING TEMPERATURE WAS PERFORMED WITH A PYROMETER AND CLOSELY CONTROLLED

and THE ALLOY USED FOR THE CASTING WAS ENTIRELY DERIVED FROM SCRAP -- PROBABLY POOR QUALITY

THEN:

THE METAL LACKED FLUIDITY
Probability = 7/10

NOTE: A COLD SHUT IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 2. SEE COLD SHUT.

RULE NUMBER: 33

IF:

THE CASTING APPEARS TO BE INCOMPLETE, AS IF THE CAVITY FAILED TO FULLY FILL THE CAVITY WITH METAL

and THE ALLOY USED FOR THE CASTING WAS OF UNKNOWN ORIGIN AND QUALITY

THEN:

THE METAL LACKED FLUIDITY
Probability = 7/10

NOTE: A MISRUN IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 34

IF:

THE CASTING APPEARS TO BE INCOMPLETE, AS IF THE CAVITY FAILED TO FULLY FILL WITH METAL

and THE ALLOY USED FOR THE CASTING WAS ENTIRELY DERIVED FROM SCRAP -- PROBABLY OF POOR QUALITY

THEN:

THE METAL LACKED FLUIDITY
Probability = 8/10

NOTE: A MISRUN IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 1. SEE MISRUN.

RULE NUMBER: 35

IF:

THE SAND USED FOR THE MOLD WAS PROPERLY MULLED BEFORE MOLDING

THEN:

THE SAND WAS IN NEED OF RECONDITIONING
Probability = 2/10

NOTE: MULLING CONDITIONS THE SAND BEFORE MOLDING.

REFERENCE: LAB MANUAL, PAGES 2 AND 3. SEE SAND HOLES AND CUTS AND WASHES.

RULE NUMBER: 36

IF:

THE SAND USED FOR THE MOLD WAS NOT MULLED BEFORE MOLDING

THEN:

THE SAND WAS IN NEED OF RECONDITIONING
Probability = 8/10

NOTE: MULLING CONDITIONS THE SAND BEFORE MOLDING.

REFERENCE: LAB MANUAL, PAGES 2 AND 3. SEE SAND HOLES AND CUTS AND WASHES.

RULE NUMBER: 37

IF:

THE SURFACE OF THE CASTING IS ROUGHER THAN EXPECTED

THEN:

THE SAND WAS RAMMED TOO LOOSE
Probability = 7/10

and THE SAND WAS TOO DRY
Probability = 7/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 6/10

and EXCESSIVE PARTING COMPOUND WAS USED
Probability = 6/10

and THERE WAS A POOR FINISH ON THE PATTERN USED
Probability = 5/10

NOTE: THE ROUGH SURFACE IS A DEFECT AND CAN BE CAUSED BY THE FACTORS LISTED. A ROUGH SURFACE CAN ALSO BE ASSOCIATED WITH SAND HOLES, PINHOLE POROSITY, AND SAND PENETRATION.

REFERENCE: LAB MANUAL, PAGES 2, 3, 5, AND 6. ESPECIALLY THE SECTION ON ROUGH SURFACE.

RULE NUMBER: 38

IF:

THE CASTING APPEARS TO HAVE SMALL HOLES IN THE SURFACE, OFTEN CONTAINING SAND

THEN:

THE SAND WAS RAMMED TOO LOOSE
Probability = 8/10

and THE SAND WAS TOO DRY
Probability = 8/10

and THERE WERE LOOSE SAND GRAINS IN THE CAVITY OR RUNNERS
Probability = 8/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 6/10

NOTE: SAND HOLES ARE INDICATED.

REFERENCE: LAB MANUAL, PAGE 2. SEE SAND HOLES.

<u>RULE NUMBER: 39</u>

IF:

EVIDENCE OF SAND FALLING FROM THE TOP (COPE) PORTION TO THE BOTTOM (DRAG) PORTION OF THE CAVITY IS PRESENT

THEN:

THE SAND WAS RAMMED TOO LOOSE
Probability = 7/10

and THE SAND WAS TOO DRY
Probability = 7/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 6/10

and THE MOLD WAS HANDLED ROUGHLY
Probability = 8/10

NOTE: A DROP OR A BROKEN MOLD IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 4. SEE DROPS OR BROKEN MOLDS.

RULE NUMBER: 40

IF:

EVIDENCE OF SAND FALLING FROM THE TOP (COPE) TO THE BOTTOM (DRAG) PORTION OF THE CAVITY IS ABSENT

THEN:

THE SAND WAS RAMMED TOO LOOSE
Probability = 4/10

and THE SAND WAS TOO DRY
Probability = 4/10

and THE SAND WAS IN NEED OF RECONDITIONING
Probability = 4/10

and THE MOLD WAS HANDLED ROUGHLY
Probability = 1/10

NOTE: A DROP IS NOT INDICATED.

REFERENCE: LAB MANUAL, PAGE 4. SEE DROPS OR BROKEN MOLDS.

RULE NUMBER: 41

IF:

THE MOLDING SAND SEEMED TO BE POSSIBLY TOO DRY

THEN:

THE MOLDING SAND WAS TOO DRY
Probability = 6/10

NOTE: INSUFFICIENT MOISTURE CAN CAUSE SEVERAL PROBLEMS.

REFERENCE: LAB MANUAL, PAGES 2, 3, 4, AND 5. SEE SAND HOLES, ROUGH SURFACE, CUTS AND WASHES, DROPS OR BROKEN MOLDS, AND PENETRATION.

RULE NUMBER: 42

IF:

THE SURFACE OF THE CASTING IS SMOOTH AS ONE WOULD EXPECT

THEN:

THE SAND WAS RAMMED TOO LOOSE
Probability = 3/10

and THE SAND WAS TOO DRY
Probability = 3/10

and EXCESSIVE PARTING COMPOUND WAS USED
Probability = 1/10

and THERE WAS A POOR FINISH ON THE PATTERN USED
Probability = 1/10

NOTE: ROUGH SURFACE DEFECT IS ABSENT.

REFERENCE: LAB MANUAL, PAGE 3. SEE ROUGH SURFACE.

RULE NUMBER: 43

IF:

THE CASTING'S SURFACE APPEARS VERY ROUGH AND SANDY, AS IF THE METAL FILLED VOIDS BETWEEN THE SAND GRAINS

THEN:

THE METAL WAS POURED TOO HOT
Probability = 8/10

and THE SAND WAS TOO DRY
Probability = 6/10

and THE SAND WAS RAMMED TOO LOOSE
Probability = 7/10

and THE METAL HAD EXCESSIVE FLUIDITY
Probability = 6/10

NOTE: SAND PENETRATION IS INDICATED, A CONDITION MORE SEVERE IN APPEARANCE THAN SAND HOLES OR SIMPLY ROUGH SURFACE.

REFERENCE: LAB MANUAL, PAGE 5. SEE PENETRATION.

RULE NUMBER: 44

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT

and THE DEPRESSION HAS AN EXCESSIVELY SMOOTH SURFACE APPEARANCE

and THE DEPRESSION IN THE CASTING APPEARS TO BE IN A CORED CAVITY

THEN:

THE CORE WAS NOT SUFFICIENTLY CURED.
Probability = 9/10

NOTE: A CORE BLOW IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 4. SEE BLOWS.

RULE NUMBER: 45

IF:

THE CASTING IS FORMED WITH NO HOLLOW PORTION MADE WITH A SAND CORE

THEN:

THE CORE WAS NOT SUFFICIENTLY CURED
Probability = 0/10

NOTE: A CORE BLOW IS NOT A CONSIDERATION.

REFERENCE: LAB MANUAL, PAGE 4. SEE BLOWS.

RULE NUMBER: 46

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS ABSENT

THEN:

THERE WAS NO RISER WHEN THERE SHOULD HAVE BEEN
Probability = 0/10

and THE RISER USED WAS TOO SMALL
Probability = 0/10

and THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 0/10

and THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 0/10

and THE METAL WAS POURED TOO HOT
Probability = 4/10

and THE CORE WAS NOT SUFFICIENTLY CURED
Probability = 0/10

NOTE: RISERS AND GATES SHOULD FEED THICK SECTIONS OF THE CASTING RATHER THAN THIN SECTIONS. POURING AT EXCESSIVELY HIGH TEMPERATURES CAN CONTRIBUTE TO SHRINKAGE.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 47

IF:

A RISER WAS INCORPORATED IN THE GATING SYSTEM

THEN:

THERE WAS NO RISER WHEN THERE SHOULD HAVE BEEN
Probability = 0/10

NOTE: RISERS ARE OFTEN NEEDED TO FEED HEAVY SECTIONS.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 48

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT
and THE DEPRESSION IN THE CASTING HAS A SLIGHTLY TEXTURED APPEARANCE
and A RISER WAS NOT INCORPORATED IN THE GATING SYSTEM

THEN:

THERE WAS NO RISER WHEN THERE SHOULD HAVE BEEN
Probability = 9/10
and THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 7/10
and THE METAL WAS POURED TOO HOT
Probability = 7/10

NOTE: A RISER IS OFTEN NEEDED IF THE CASTING HAS HEAVY SECTIONS.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 49

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT

and THE DEPRESSION IN THE CASTING HAS A SLIGHTLY TEXTURED APPEARANCE

and THE GATING SYSTEM HAD A RISER OF UNKNOWN SIZE OR NO RISER AT ALL

THEN:

THERE WAS NO RISER WHEN THERE SHOULD HAVE BEEN
Probability = 8/10

and THE RISER USED WAS TOO SMALL
Probability = 7/10

and THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 6/10

NOTE: RISERS ARE OFTEN NEEDED TO FEED HEAVY SECTIONS.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 50

IF:

THE GATING SYSTEM HAD A RISER LARGER THAN THE PORTION OF THE CASTING IT FED

THEN:

THERE WAS NO RISER WHEN THERE SHOULD HAVE BEEN
Probability = 0/10

and THE RISER USED WAS TOO SMALL
Probability = 1/10

NOTE: RISERS SHOULD BE LARGE TO KEEP THEM FROM FREEZING BEFORE THE CASTING.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 51

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT

and THE DEPRESSION IN THE CASTING HAS A SLIGHTLY TEXTURED SURFACE APPEARANCE

and THE GATING SYSTEM HAD A RISER SMALLER THAN THE PORTION OF THE CASTING IT FED

THEN:

THE RISER USED WAS TOO SMALL
Probability = 9/10

and THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 6/10

and THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 6/10

and THE METAL WAS POURED TOO HOT
Probability = 6/10

NOTE: SHRINKAGE IS DEFINITELY INDICATED, PROBABLY BECAUSE THE RISER FROZE PREMATURELY. THE OTHER FACTORS CAN ALSO CONTRIBUTE TO SHRINKAGE.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 52

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT

and THE DEPRESSION IN THE CASTING HAS A SURFACE THAT COULD POSSIBLY BE DESCRIBED AS SLIGHTLY TEXTURED OR AS SMOOTH -- NOT SURE

and THE GATING SYSTEM HAD A RISER OF UNKNOWN SIZE OR NO RISER AT ALL

THEN:

THE RISER USED WAS TOO SMALL
Probability = 7/10

and THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 6/10

and THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)

and THE METAL WAS POURED TOO HOT
Probability = 6/10

NOTE: SHRINKAGE IS THE MOST LIKELY DEFECT INDICATED.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 53

IF:

A RISER WAS NOT INCORPORATED IN THE GATING SYSTEM

THEN:

THE RISER USED WAS TOO SMALL
Probability = 0/10

and THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 0/10

NOTE: RISERS ARE OFTEN NEEDED TO FEED HEAVY SECTIONS.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

<u>RULE NUMBER: 54</u>

IF:

THE GATING SYSTEM HAD A RISER OF UNKNOWN SIZE OR NO RISER AT ALL

THEN:

THE RISER USED WAS TOO SMALL
Probability = 5/10

and THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 5/10

NOTE: RISERS SHOULD BE HEAVIER THAN THE SECTION THEY FEED. THEY SHOULD FEED THICK PORTIONS OF THE CASTING.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 55

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT

and THE DEPRESSION IN THE CASTING HAS A SURFACE THAT COULD POSSIBLY BE DESCRIBED AS SLIGHTLY TEXTURED OR AS SMOOTH -- NOT SURE

and THE GATING SYSTEM HAD A RISER LARGER THAN THE PORTION OF THE CASTING IT FED

THEN:

THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 6/10

and THE METAL WAS POURED TOO HOT
Probability = 6/10

and THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 6/10

NOTE: SHRINKAGE IS THE MOST LIKELY DEFECT INDICATED.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 56

IF:

AN UNDESIRED DEPRESSION IN THE CASTING IS PRESENT

and THE DEPRESSION IN THE CASTING HAS A SLIGHTLY TEXTURED APPEARANCE

and THE GATING SYSTEM HAD A RISER LARGER THAN THE PORTION OF THE CASTING IT FED

THEN:

THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 7/10

and THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 7/10

and THE METAL WAS POURED TOO HOT
Probability = 7/10

NOTE: SHRINKAGE IS PRESENT, BUT SHOULD NOT OCCUR WITH A LARGE RISER UNLESS ONE OF THE OTHER FACTORS LISTED IS RESPONSIBLE.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 57

IF:

THE GATING SYSTEM WAS DESIGNED TO FEED UNDETERMINED PORTIONS OF THE CASTING

THEN:

THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 5/10

NOTE: GATES SHOULD FEED THICK SECTIONS.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 58

IF:

THE GATING SYSTEM WAS DESIGNED TO FEED THIN SECTIONS OF THE CASTING WITH A RISER

THEN:

THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 9/10

NOTE: RISERS SHOULD FEED HEAVY PORTIONS OF THE CASTING TO PREVENT SHRINKAGE.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 59

IF:

THE GATING SYSTEM WAS DESIGNED TO FEED THIN SECTIONS OF THE CASTING ONLY

THEN:

THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 9/10

NOTE: GATES SHOULD FEED THICK SECTIONS OF THE CASTING TO PREVENT SHRINKAGE.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 60

IF:

THE GATING SYSTEM WAS DESIGNED TO FEED THICK SECTIONS OF THE CASTING

THEN:

THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)
Probability = 9/10

NOTE: GATES SHOULD FEED THICK SECTIONS OF THE CASTING TO PREVENT SHRINKAGE.

REFERENCE: LAB MANUAL, PAGE 3. SEE SHRINK.

RULE NUMBER: 61

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE NO APPARENT CRACKS OR TEARS IN THE SURFACE

THEN:

THE CASTING WAS SHAKEN OUT TOO SOON
Probability = 0/10

NOTE: A HOT TEAR IS NOT INDICATED.

REFERENCE: LAB MANUAL, PAGE 4. SEE HOT TEARS.

RULE NUMBER: 62

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE TORN METAL, OR AT LEAST THE BEGINNING OF A TEAR

and THE CASTING WAS REMOVED FROM THE SAND MOLD WHILE IT WAS STILL VERY HOT

THEN:

THE CASTING WAS SHAKEN OUT TOO SOON
Probability = 9/10

NOTE: A HOT TEAR IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 4. SEE HOT TEARS.

RULE NUMBER: 63

IF:

THE SURFACE OF THE CASTING APPEARS TO HAVE TORN METAL, OR AT LEAST THE BEGINNING OF A TEAR

and THE CASTING WAS REMOVED FROM THE SAND MOLD AFTER AN UNKNOWN AMOUNT OF TIME

THEN:

THE CASTING WAS SHAKEN OUT TOO SOON
Probability = 6/10

NOTE: A HOT TEAR IS A POSSIBILITY.

REFERENCE: LAB MANUAL, PAGE 4. SEE HOT TEARS.

RULE NUMBER: 64

IF:

THE CASTING WAS REMOVED FROM THE SAND MOLD AFTER IT HAD COOLED OFF CONSIDERABLY

THEN:

THE CASTING WAS SHAKEN OUT TOO SOON
Probability = 0/10

NOTE: CASTINGS SHOULD BE ALLOWED TO COOL ENOUGH BEFORE SHAKEOUT TO PREVENT HOT TEARS.

REFERENCE: LAB MANUAL, PAGE 4. SEE HOT TEARS.

RULE NUMBER: 65

IF:

THE CASTING'S SURFACE APPEARS VERY ROUGH AND SANDY, AS IF THE METAL FILLED VOIDS BETWEEN THE SAND GRAINS

and THE ALLOY USED FOR THE CASTING WAS OF UNKNOWN ORIGIN AND QUALITY

and MONITORING OF THE POURING TEMPERATURE WAS PERFORMED WITH A PYROMETER AND CLOSELY CONTROLLED

and THE SAND USED FOR THE MOLD WAS PROPERLY TEMPERED -- NOT TOO MOIST AND NOT TOO DRY

THEN:

THE METAL HAD EXCESSIVE FLUIDITY
Probability = 7/10

NOTE: PENETRATION IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 5. SEE PENETRATION.

RULE NUMBER: 66

IF:

THE CASTING'S SURFACE APPEARS VERY ROUGH AND SANDY, AS IF THE METAL FILLED VOIDS BETWEEN THE SAND GRAINS

and THE ALLOY USED FOR THE CASTING WAS ENTIRELY DERIVED FROM SCRAP -- PROBABLY OF POOR QUALITY

and MONITORING OF THE POURING TEMPERATURE WAS PERFORMED WITH A PYROMETER AND CLOSELY CONTROLLED

and THE SAND USED FOR THE MOLD WAS PROPERLY MULLED BEFORE POURING

THEN:

THE METAL HAD EXCESSIVE FLUIDITY
Probability = 8/10

NOTE: PENETRATION IS INDICATED.

REFERENCE: LAB MANUAL, PAGE 5. SEE PENETRATION.

RULE NUMBER: 67

IF:

THE PATTERN USED TO PRODUCE THE CASTING HAD A SMOOTH, PROPERLY FINISHED SURFACE

THEN:

THERE WAS A POOR FINISH ON THE PATTERN USED
PROBABILITY = 0/10

NOTE: THE PATTERN SHOULD NOT HAVE CONTRIBUTED TO A ROUGH SURFACE.

REFERENCE: LAB MANUAL, PAGE 3. SEE ROUGH SURFACE.

RULE NUMBER: 68

IF:

THE SURFACE OF THE CASTING IS ROUGHER THAN EXPECTED

and THE PATTERN USED TO PRODUCE THE CASTING HAD AN UNKNOWN SURFACE FINISH

THEN:

THERE WAS A POOR FINISH ON THE PATTERN USED
Probability = 6/10

NOTE: THE ROUGH SURFACE IS POSSIBLY IMPARTED FROM THE SURFACE OF THE PATTERN.

REFERENCE: LAB MANUAL, PAGE 3. SEE ROUGH SURFACE.

RULE NUMBER: 69

IF:

THE SURFACE OF THE CASTING IS ROUGHER THAN EXPECTED

and THE PATTERN USED TO PRODUCE THE CASTING HAD A RATHER ROUGH SURFACE FINISH

THEN:

THERE WAS A POOR FINISH ON THE PATTERN USED
Probability = 9/10

NOTE: THE ROUGH SURFACE IS PROBABLY IMPARTED FROM THE SURFACE OF THE PATTERN.

REFERENCE: LAB MANUAL, PAGE 3. SEE ROUGH SURFACE.

RULE NUMBER: 70

IF:

THE ALLOY USED FOR THE CASTING WAS OF GOOD QUALITY WITH ADEQUATE SILICON OR ZINC CONTENT

THEN:

THE METAL LACKED FLUIDITY
Probability = 2/10

NOTE: PROPER FLUIDITY IS NEEDED, ESPECIALLY FOR THIN CASTINGS.

REFERENCE: LAB MANUAL, PAGES 1 AND 2. SEE MISRUN AND COLD SHUT.

Appendix B:

TELECAST Qualifiers

1. AN UNDESIRED DEPRESSION IN THE CASTING IS

PRESENT
ABSENT
POSSIBLY PRESENT -- BUT NOT REALLY SURE

Used in rules: 5; 44; 45; 46; 48; 49; 51; 52; 55; 56

2. THE SURFACE OF THE CASTING IS

ROUGHER THAN EXPECTED
SMOOTH AS ONE WOULD EXPECT
POSSIBLY ROUGHER THAN EXPECTED -- NOT SURE

Used in rules: 37; 42;68;69

3. THE CASTING APPEARS TO HAVE

SMALL HOLES IN THE SURFACE, OFTEN CONTAINING SAND
SMALL HOLES DISTRIBUTED THROUGHOUT, OFTEN CONTAINING BLACK SPECKS (NOT SAND)
NO SMALL HOLES IN THE SURFACE OR THROUGHOUT
POSSIBLY SOME SMALL HOLES -- NOT SURE
SMALL HOLES CONTAINING SAND AND SMALL HOLES CONTAINING BLACK SPECKS (NOT SAND)

Used in rules: 29; 30; 31; 38

4. THE SHAPE OF THE CASTING APPEARS TO BE

ALTERED BY SAND EROSION
NOT ALTERED BY SAND EROSION
POSSIBLY ALTERED -- NOT SURE

Used in rules: 18; 19

5. EVIDENCE OF SAND FALLING FROM THE TOP (COPE) PORTION TO THE BOTTOM (DRAG) PORTION OF THE CAVITY IS

PRESENT
ABSENT
POSSIBLY PRESENT -- NOT SURE

Used in rules: 39, 40

6. THE CASTING WAS REMOVED FROM THE SAND MOLD

WHILE IT WAS STILL VERY HOT
AFTER IT HAD COOLED OFF CONSIDERABLY
AFTER AN UNKNOWN AMOUNT OF TIME

Used in rules: 62; 63; 64

7. THE DEPRESSION IN THE CASTING HAS

A SLIGHTLY TEXTURED APPEARANCE
AN EXCESSIVELY SMOOTH SURFACE APPEARANCE
A SURFACE THAT COULD POSSIBLY BE DESCRIBED AS SLIGHTLY TEXTURED OR A SMOOTH -- NOT SURE

Used in rules: 5; 44; 45; 48; 49; 51; 52; 55; 56

8. THE CASTING APPEARS TO BE

INCOMPLETE, AS IT THE CAVITY FAILED TO FULLY FILL WITH METAL
COMPLETE -- NO MISSING PORTIONS
POSSIBLY PARTIALLY INCOMPLETE -- NOT SURE

Used in rules: 1; 6; 7; 9; 13; 15; 22; 33; 34

9. THE SURFACE OF THE CASTING APPEARS TO HAVE

TORN METAL, OR AT LEAST THE BEGINNING OF A TEAR
A FAINT CRACK OR A WEAKNESS THAT MIGHT LEAD TO A CRACK
NO APPARENT CRACKS OR TEARS IN THE SURFACE

Used in rules: 7; 8; 10; 23; 24; 32; 61; 62; 63

10. THE GATING SYSTEM HAD

A RISER LARGER THAN THE PORTION OF THE CASTING IT FED
A RISER SMALLER THAN THE PORTION OF THE CASTING IT FED
A RISER OF UNKNOWN SIZE OR NO RISER AT ALL

Used in rules: 49; 50; 51; 52; 54; 55; 56

11. THE GATING SYSTEM WAS DESIGNED TO

FEED THICK SECTIONS OF THE CASTING
FEED THIN SECTIONS OF THE CASTING
FEED UNDETERMINED PORTIONS OF THE CASTING
FEED THIN SECTIONS OF THE CASTING WITH A RISER

Used in rules: 57; 58; 59; 60

12. MONITORING OF THE TEMPERATURE WAS

PERFORMED WITH A PYROMETER AND CLOSELY CONTROLLED
PERFORMED BY "EYE" SO THE TEMPERATURE WAS NOT KNOWN EXACTLY
NOT ATTEMPTED AT ALL -- SO THERE WAS NOT CLUE AS TO THE POURING TEMPERATURE
POSSIBLY PERFORMED -- NOT SURE

Used in rules: 9; 10; 23; 24; 25; 26; 27; 28; 32; 65; 66

13. THE SAND USED FOR THE MOLD WAS

PROPERLY MULLED BEFORE MOLDING
NOT MULLED BEFORE MOLDING
POSSIBLY MULLED -- NOT SURE

Used in rules: 35; 36; 65; 66

14. THE MOLDING SAND

WAS PROPERLY TEMPERED -- NOT TOO MOIST AND NOT TOO DRY
SEEMED TO BE POSSIBLY TOO MOIST
SEEMED TO BE POSSIBLY TOO DRY
WAS OF UNDETERMINED TEMPER -- NOT SURE

Used in rules: 11; 12; 13; 14; 41; 65

15. A RISER WAS

INCORPORATED IN THE GATING SYSTEM
NOT INCORPORATED IN THE GATING SYSTEM
POSSIBLY USED -- NOT SURE

Used in rules: 47; 48; 53

16. THE CASTING'S SURFACE APPEARS

VERY ROUGH AND SANDY, AS IF THE METAL FILLED VOIDS
BETWEEN THE SAND GRAINS
NORMAL -- NOT ROUGH AND SANDY
POSSIBLY A BIT ROUGH AND SANDY -- NOT SURE

Used in rules: 43; 65; 66

17. THE SPRUE CHOKE WAS

AT LEAST .5-INCH DIAMETER
LESS THAN .5-INCH DIAMETER
OF UNKNOWN DIAMETER

Used in rules: 20; 21; 22

18. THE COMBINED CROSS-SECTIONAL AREA OF THE GATES WAS

LESS THAN THE SPRUE CHOKE
GREATER THAN THE SPRUE CHOKE
OF UNKNOWN CROSS-SECTIONAL AREA

Used in rules: 15; 16; 17

19. THE ALLOY USED FOR THE CASTING WAS

OF GOOD QUALITY WITH ADEQUATE SILICON OR ZINC CONTENT
ENTIRELY DERIVED FROM SCRAP -- PROBABLY OF POOR QUALITY
OF UNKNOWN ORIGIN AND QUALITY

Used in rules: 15; 16; 17; 70

20. VENTING OF THE CAVITY WAS

PRESENT
ABSENT
POSSIBLY PRESENT -- NOT SURE

Used in rules: 1; 2; 3; 4

21. THE CASTING IS FORMED WITH

A HOLLOW PORTION MADE WITH A SAND CORE
NO HOLLOW PORTION MADE WITH A SAND CORE
POSSIBLY A CORED PORTION -- NOT SURE

Used in rule: 45

22. THE PATTERN USED TO PRODUCE THE CASTING HAD

A SMOOTH, PROPERLY FINISHED SURFACE
A RATHER ROUGH SURFACE FINISH
AN UNKNOWN SURFACE FINISH

Used in rules: 67; 68; 69

23. THE DEPRESSION IN THE CASTING APPEARS TO BE

IN A CORED CAVITY
NOT IN A CORED CAVITY
POSSIBLY IN A CORED CAVITY -- NOT SURE

Used in rule: 44

Appendix C:

TELECAST Choices

1. THERE WAS NO RISER WHEN THERE SHOULD HAVE BEEN

   Used in rules: 46; 47; 48; 49; 50

2. THE RISER USED WAS TOO SMALL

   Used in rules: 46; 49; 50; 51; 52; 53; 54

3. THE RISER WAS IMPROPERLY PLACED (FEEDING THIN SECTIONS)

   Used in rules: 46; 49; 51; 52; 53; 54; 55; 56; 58

4. THE GATES WERE IMPROPERLY PLACED (FEEDING THIN SECTIONS)

   Used in rules: 46; 48; 51; 52; 55; 56; 57; 59; 60

5. THE METAL WAS POURED TOO HOT

   Used in rules: 25; 26; 27; 28; 29; 30; 43; 46; 48; 51; 52; 55; 56

6. THE SAND WAS RAMMED TOO LOOSE

   Used in rules: 18; 19; 37; 38; 39; 40; 42; 43

7. THE SAND WAS TOO DRY

   Used in rules: 11; 12; 18; 19; 37; 38; 39; 40; 41; 42; 43

8. EXCESSIVE PARTING COMPOUND WAS USED

   Used in rules: 37; 42

9. THERE WERE LOOSE SAND GRAINS IN THE CAVITY OR RUNNERS

   Used in rules: 29; 31; 39

10. THE SAND WAS IN NEED OF RECONDITIONING

Used in rules: 11; 12; 18; 19; 31; 35; 36; 37; 38; 39; 40

11. THERE WAS EXCESSIVE TURBULENCE WHILE POURING

Used in rules: 18; 19; 31; 35; 36; 37; 38; 39; 40

12. THE MOLD WAS HANDLED ROUGHLY

Used in rules: 39; 40

13. THE CASTING WAS SHAKEN OUT TOO SOON

Used in rules: 61; 62; 63; 64

14. THE METAL WAS NOT DEGASSED PROPERLY

Used in rules: 29; 30; 31

15. THE METAL WAS POURED TOO COLD

Used in rules: 6; 7; 8; 9; 23; 24; 25; 26; 27; 28

16. THE METAL WAS POURED TOO SLOWLY

Used in rules: 6; 7; 8; 9; 10

17. THE SPRUE CHOKE WAS TOO SMALL

Used in rules: 6; 7; 8; 10; 20; 21; 22

18. THE GATES WERE TOO SMALL

Used in rules: 6; 7; 8; 10; 15; 16; 17; 18; 19

19. THE SAND WAS TOO MOIST

Used in rules: 5; 6; 7; 11; 12; 13; 14

20. THE HEIGHT OF THE SPRUE WAS INSUFFICIENT

Used in rules: 6; 7; 8; 9; 10

21. THE SAND WAS IMPERMEABLE

Used in rules: 1; 2; 3; 4; 5; 6; 7; 8

22. THE SAND WAS RAMMED TOO TIGHT

Used in rules: 5; 6; 7; 8

23. THE CORE WAS NOT SUFFICIENTLY CURED

Used in rules: 44; 45; 46

24. THE METAL LACKED SUFFICIENT FLUIDITY

Used in rules: 7; 8; 10; 32; 33; 34

25. THE POUR WAS INTERRUPTED

Used in rule: 8

26. THE METAL HAD EXCESSIVE FLUIDITY

Used in rules: 43; 65; 66

27. THERE WAS A POOR FINISH ON THE PATTERN USED

Used in rules: 37; 42; 67; 68; 69

Appendix D:

Auxiliary Computer Program

```
10    CLS
20    REM***WRITTEN BY KEN KENT***
30    PRINT:PRINT:PRINT
40    PRINT"THIS EXCERCISE IS DESIGNED TO TEACH YOU HOW TO
      DIAGNOSE DEFECTIVE"
45    PRINT"ALUMINUM CASTINGS THAT HAVE BEEN CAST IN SAND
      MOLDS.  YOU WILL BE"
50    PRINT"WORKING IN SMALL GROUPS AND EACH GROUP WILL BE
      PROVIDED A LAB MANUAL."
55    PRINT
60    PRINT"THE LAB MANUAL MAY BE USED FREELY TO ASSIST YOU
      IN DIAGNOSING THE"
65    PRINT"DEFECT AND IN ADDITION, AN INSTRUCTOR WHO IS AN
      EXPERT IN CASTING"
70    PRINT"IS PRESENT TO ANSWER YOUR QUESTIONS."
75    PRINT
80    PRINT"YOU WILL BE ASKED TO SELECT ONE OF THE ALUMINUM
      CASTINGS AND CHOOSE"
85    PRINT"ONE OF THE NUMBERED DEFECTS ON THE CASTING.
      CHECK ANY EXTRA INFORMATION"
90    PRINT"THAT MAY BE PROVIDED ON A 3 BY 5 CARD FOR THAT
      CASTING"
95    PRINT
100   PRINT"FOLLOW THE INSTRUCTIONS ON THE COMPUTER AND
      RECORD THE RESULTS OF EACH"
105   PRINT"ANALYSIS AS REQUESTED ON THE FORM PROVIDED"
110   PRINT
115   PRINT"GOOD LUCK"
120   PRINT"TO BEGIN:"
125   PRINT
160   PRINT"SELECT ONE OF THE DEFECTIVE CASTINGS PROVIDED
FOR   THE EXERCISE AND ENTER"
170   PRINT"THE NUMBER OF THE CASTING DEFECT INTO THE
      COMPUTER."
200   PRINT"ENTER DEFECT NUMBER."
202   INPUT BE
210   IF BE<10 THEN 1000 ELSE 220
220   IF BE<20 THEN 2000 ELSE 230
230   IF BE<30 THEN 3000 ELSE 240
240   IF BE<40 THEN 4000 ELSE 250
250   IF BE<50 THEN 5000 ELSE 260
260   IF BE<60 THEN 6000 ELSE 270
270   IF BE<70 THEN 7000 ELSE 280
280   IF BE<80 THEN 8000 ELSE 290
290   IF BE<90 THEN 9000 ELSE 295
295   IF BE>89 THEN GOTO 160 ELSE 160
1000  CLS
1005  PRINT"POSSIBLE CAUSES"
1006  PRINT
1010  PRINT"1.  NO RISER"
1012  PRINT"2.  RISER TOO SMALL"
```

```
1014  PRINT"3.  RISER IMPROPERLY PLACED"
1016  PRINT"4.  GATING INTO THIN SECTIONS"
1018  PRINT"5.  THE METAL WAS POURED TOO HOT"
1020  PRINT"6.  THE SAND WAS RAMMED TOO LOOSE"
1022  PRINT"7.  THE SAND WAS TOO DRY"
1024  PRINT"8.  EXCESSIVE PARTING COMPOUND IN MOLD"
1026  PRINT"9.  LOOSE SAND GRAINS IN MOLD"
1028  PRINT"10. THE SAND NEEDED RECONDITIONING"
1030  PRINT"11. THERE WAS TURBULENCE WHILE POURING"
1032  PRINT"12. THE MOLDS WERE HANDLED ROUGHLY"
1060  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THIS DEFECT."
1075  PRINT "EXAMPLE: 3 6 8 2 4"
1080  REM STUDENT INPUT
1085  PRINT
1090  INPUT AA$
1095  PRINT
1100  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
1500  PRINT"2 1 5 3 4"
1505  PRINT
1510  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES "
1511  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
1515  PRINT"PRESS RETURN"
1520  INPUT AB$:CLS:GOTO 160
2000  CLS
2005  PRINT"POSSIBLE CAUSES"
2006  PRINT
2010  PRINT"1.  NO RISER
2012  PRINT"2.  RISER IMPROPERLY PLACED"
2014  PRINT"3.  RISER TOO SMALL
2016  PRINT"4.  GATING INTO THIN SECTIONS"
2018  PRINT"5.  THE METAL WAS POURED TOO HOT"
2020  PRINT"6.  THE SAND WAS RAMMED TOO LOOSE"
2022  PRINT"7.  THE SAND WAS TOO DRY"
2024  PRINT"8.  EXCESSIVE PARTING COMPOUND IN MOLD"
2026  PRINT"9.  LOOSE SAND GRAINS IN MOLD"
2028  PRINT"10. THE SAND NEEDED RECONDITIONING"
2030  PRINT"11. THE MOLDS WERE HANDLED ROUGHLY"
2033  PRINT
2035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
2036  PRINT"EXAMPLE: 2 3 6 1
2038  INPUT AC$
2040  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
2050  PRINT"6 7 8"
2080  REM STUDENT INPUT
2120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
2121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
2135  INPUT AD$:CLS:GOTO 160
```

```
3000  CLS
3005  PRINT"POSSIBLE CAUSES"
3006  PRINT
3010  PRINT"1.  NO RISER
3012  PRINT"2.  RISER IMPROPERLY PLACED"
3014  PRINT"3.  RISER TOO SMALL
3016  PRINT"4.  SAND WAS TOO DRY"
3018  PRINT"5.  THE METAL WAS POURED TOO HOT"
3020  PRINT"6.  THE SAND WAS RAMMED TOO LOOSE"
3022  PRINT"7.  THE SAND WAS TOO DRY"
3024  PRINT"8.  EXCESSIVE PARTING COMPOUND IN MOLD"
3026  PRINT"9.  LOOSE SAND GRAINS IN MOLD"
3028  PRINT"10. THE SAND NEEDED RECONDITIONING"
3029  PRINT"11. THERE WAS TURBULENCE WHILE POURING"
3030  PRINT"12. THE MOLDS WERE HANDLED ROUGHLY"
3033  PRINT
3035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
3036  PRINT"EXAMPLE: 3 6 4 12
3038  INPUT AE$
3040  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
3050  PRINT"6 2 9 10"
3080  REM STUDENT INPUT
3120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
3121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
3135  INPUT AF$:CLS:GOTO 160
4000  CLS
4005  PRINT"POSSIBLE CAUSES"
4006  PRINT
4010  PRINT"1.  NO RISER
4012  PRINT"2.  RISER TOO SMALL"
4014  PRINT"3.  RISER IMPROPERLY PLACED
4016  PRINT"4.  GATING INTO THIN SECTIONS"
4018  PRINT"5.  THE METAL WAS POURED TOO HOT"
4020  PRINT"6.  THE SAND WAS RAMMED TOO LOOSE"
4022  PRINT"7.  THE SAND WAS TOO DRY"
4024  PRINT"8.  EXCESSIVE PARTING COMPOUND IN MOLD"
4026  PRINT"9.  LOOSE SAND GRAINS IN MOLD"
4028  PRINT"10. THE SAND NEEDED RECONDITIONING"
4030  PRINT"11. THERE WAS TURBULENCE WHILE POURING"
4032  PRINT"12. THE MOLDS WERE HANDLED TOO ROUGHLY"
4033  PRINT
4035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
4036  PRINT"EXAMPLE: 3 4 7 1
4038  INPUT AG$
4040  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
4050  PRINT"6 7 10 11"
4080  REM STUDENT INPUT
4120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
```

```
4121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
4135  INPUT AH$:CLS:GOTO 160
5000  CLS
5005  PRINT"POSSIBLE CAUSES"
5006  PRINT
5010  PRINT"1.  THE METAL WAS POURED TOO HOT
5012  PRINT"2.  THE SAND WAS RAMMED TOO LOOSE"
5014  PRINT"3.  THE SAND WAS TOO DRY
5016  PRINT"4.  EXCESSIVE PARTING COMPOUND IN MOLD"
5018  PRINT"5.  LOOSE SAND GRAINS IN MOLD"
5020  PRINT"6.  SAND NEEDS RECONDITIONING"
5022  PRINT"7.  SAND RAMMED TOO TIGHT"
5024  PRINT"8.  THE MOLD WAS HANDLED TOO ROUGHLY"
5026  PRINT"9.  THE METAL WAS NOT DEGASSED PROPERLY"
5028  PRINT"10. THE METAL WAS POURED TOO COLD"
5033  PRINT
5035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
5036  PRINT"EXAMPLE: 4 2 8 6
5038  INPUT AI$
5040  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
5050  PRINT"2 3 8 6"
5080  REM STUDENT INPUT
5120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
5121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
5135  INPUT AJ$:CLS:GOTO 160
6000  CLS
6005  PRINT"POSSIBLE CAUSES"
6006  PRINT
6010  PRINT"1.  LOOSE SAND GRAINS IN MOLD
6012  PRINT"2.  THE METAL WAS NOT DEGASSED PROPERLY"
6014  PRINT"3.  THE SAND WAS TOO WET
6016  PRINT"4.  THE MOLD WAS HANDLED TOO ROUGHLY"
6018  PRINT"5.  THE SAND WAS RAMMED TOO TIGHTLY"
6020  PRINT"6.  THE CASTING WAS SHAKEN OUT TOO SOON"
6022  PRINT"7.  GATING INTO THIN SECTIONS"
6024  PRINT"8.  THE MOLD WAS POURED TOO HOT"
6026  PRINT"9.  THE SAND WAS TOO DRY"
6028  PRINT"10. THE GATES WERE TOO SMALL"
6033  PRINT
6035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
6036  PRINT"EXAMPLE: 6 3 8 2
6038  INPUT AK$
6040  PRINT"THE AUTHOR FEELS THE CAUSE WAS..."
6050  PRINT"6"
6080  REM STUDENT INPUT
6120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
6121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
6135  INPUT AL$:CLS:GOTO 160
```

```
7000  CLS
7005  PRINT"POSSIBLE CAUSES"
7006  PRINT
7010  PRINT"1.  THE RISER WAS TOO SMALL
7012  PRINT"2.  THE METAL WAS POURED TOO COLD"
7014  PRINT"3.  THE METAL WAS NOT PROPERLY DEGASSED
7016  PRINT"4.  THE METAL WAS POURED TOO HOT"
7018  PRINT"5.  THE CASTING WAS SHAKEN OUT TOO SOON"
7020  PRINT"6.  THE METAL WAS POURED TOO SLOWLY"
7022  PRINT"7.  THE SAND WAS TOO DRY"
7024  PRINT"8.  THE SAND WAS IMPERMEABLE"
7026  PRINT"9.  THE MOLD WAS HANDLED TOO ROUGHLY"
7028  PRINT"10. THERE WAS NO RISER IN THE MOLD"
7033  PRINT
7035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
7036  PRINT"EXAMPLE: 3 7 5 9
7038  INPUT AM$
7040  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
7050  PRINT"4 7"
7080  REM STUDENT INPUT
7120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
7121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
7135  INPUT AN$:CLS:GOTO 160
8000  CLS
8005  PRINT"POSSIBLE CAUSES"
8006  PRINT
8010  PRINT"1.  THERE WAS INSUFFICIENT SPRUE HEIGHT
8012  PRINT"2.  THE SAND NEEDED RECONDITIONING"
8014  PRINT"3.  THE METAL WAS NOT PROPERLY DEGASSED
8016  PRINT"4.  THE CHOKE WAS TOO SMALL"
8018  PRINT"5.  THERE WAS TURBULENCE WHILE POURING"
8020  PRINT"6.  THE SAND WAS RAMMED TOO TIGHT"
8022  PRINT"7.  THE RISER WAS IMPROPERLY PLACED"
8024  PRINT"8.  THE METAL WAS POURED TOO HOT"
8026  PRINT"9.  THE MOLD WAS POURED TOO COLD"
8028  PRINT"10. THE METAL WAS POURED TOO SLOWLY"
8033  PRINT
8035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
8036  PRINT"EXAMPLE: 5 7 2 9
8038  INPUT AO$
8040  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
8050  PRINT"3 8 5"
8080  REM STUDENT INPUT
8120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
8121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
8135  INPUT AP$:CLS:GOTO 160
```

```
9000  CLS
9005  PRINT"POSSIBLE CAUSES"
9006  PRINT
9010  PRINT"1.  THE CASTING WAS SHAKEN OUT TOO SOON
9012  PRINT"2.  THE SAND WAS RAMMED TOO TIGHT"
9014  PRINT"3.  THE SAND WAS TOO DRY
9016  PRINT"4.  THE SAND WAS TOO WET"
9018  PRINT"5.  THE CHOKE WAS TOO SMALL"
9020  PRINT"6.  THE GATES WERE TOO SMALL"
9022  PRINT"7.  THE SAND WAS IMPERMEABLE"
9024  PRINT"8.  THERE WAS INSUFFICIENT SPRUE HEIGHT"
9026  PRINT"9.  THE METAL WAS POURED TOO COLD"
9028  PRINT"10. THE METAL WAS POURED TOO SLOWLY"
9030  PRINT"11. THERE WAS EXCESSIVE PARTING COMPOUND"
9032  PRINT"12. THE SAND NEEDED RECONDITIONING"
9033  PRINT
9035  PRINT"IN ORDER OF IMPORTANCE, LIST WHAT YOU THINK WAS
      THE CAUSE OF THE DEFECT"
9036  PRINT"EXAMPLE: 4 8 12 3
9038  INPUT AQ$
9040  PRINT"THE AUTHOR FEELS THE CAUSES WERE..."
9050  PRINT"9 10 5 6 7 2 4 8"
9080  REM STUDENT INPUT
9120  PRINT"WHEN YOU HAVE RECORDED YOUR CHOICES AND THE
      AUTHOR'S CHOICES"
9121  PRINT"ON THE ANALYSIS FORM PROVIDED, PRESS RETURN"
9135  INPUT AR$:CLS:GOTO 160
```

Appendix E:

Evaluation Instrument

ALUMINUM CASTINGS:
DEFECT ANALYSIS

Directions: This test is to evaluate your knowledge of the causes of defects in aluminum castings that have been poured in green sand molds. Defects are numbered and are followed by five possible causes. For each defect listed, place the letter of the one most likely cause of the defect on your answer sheet. DO NOT WRITE ON THIS TEST!

1. MISRUN

A. There was excessive venting of the cavity
B. The metal was poured too cold
C. There was no riser when there should have been
D. The metal was poured too hot
E. The core was too dry

2. SHRINK

A. The pour was interrupted
B. There were loose sand grains in the cavity or runners
C. The gates were improperly placed (feeding thin sections)
D. The sprue choke was too large
E. The sand was too moist

3. PENETRATION

A. The metal was poured too hot
B. The riser was improperly placed (feeding thin sections)
C. The metal was poured too slowly
D. The sprue choke was too small
E. The riser used was too large

4. COLD SHUT

A. The riser used was too small
B. The sprue choke was too large
C. There was excessive venting of the cavity
D. The sand was in need of reconditioning
E. The sand was too moist

5. PINHOLE POROSITY

A. The metal lacked fluidity
B. The gates were improperly placed (feeding thin sections)
C. There was excessive turbulence while pouring
D. The metal was poured too cold
E. The height of the sprue was insufficient

6. SAND HOLES

A. The sand was rammed too tight
B. The height of the sprue was insufficient
C. The core was not sufficiently cured
D. The sand was in need of reconditioning
E. The sand was impermeable (not vented)

7. MISRUN

A. The sand was rammed too loose
B. The metal was poured too slowly
C. There was excessive turbulence while pouring
D. The sand was too dry
E. The casting was shaken out too soon

8. ROUGH SURFACE

A. The riser was improperly placed (feeding thin sections)
B. The gates were too large
C. The height of the sprue was insufficient
D. The sand was impermeable (not vented)
E. The sand was rammed too loose

9. BLOWS

A. The sand was impermeable (not vented)
B. The pour was interrupted
C. There were loose sand grains in the cavity or runners
D. The mold was handled roughly
E. The casting was shaken out too soon

10. COLD SHUT

A. There was no riser when there should have been
B. The metal was poured too hot
C. The core was too dry
D. There was a poor finish on the pattern used
E. The height of the sprue was insufficient

11. DROPS

A. The metal was poured too slowly
B. The sprue choke was too small
C. The metal was not degassed properly
D. The riser used was too large
E. The mold was handled roughly

12. MISRUN

A. The gates were too large
B. The sprue choke was too small
C. The riser used was too small
D. Excessive parting compound was used
E. The metal had excessive fluidity

13. SHRINK

A. The riser was improperly placed (feeding thin sections)
B. The sand was in need of reconditioning
C. The metal lacked fluidity
D. The casting was shaken out too soon
E. The metal was not degassed properly

14. COLD SHUT

A. The sand was impermeable (not vented)
B. There was excessive venting of the cavity
C. The gates were too large
D. There were loose sand grains in the cavity or runners
E. Excessive parting compound was used

15. CUTS AND WASHES

A. The metal was poured too cold
B. The sand was too moist
C. The sand was rammed too loose
D. The core was too dry
E. The sand was rammed too tight

16. MISRUN

A. The sprue choke was too large
B. There was excessive venting of the cavity
C. The gates were too small
D. There was no riser when there should have been
E. The mold was handled roughly

17. PINHOLE POROSITY

A. The riser used was too small
B. The metal was poured too hot
C. The pour was interrupted
D. The gates were improperly placed (feeding thin sections)
E. The metal was poured too slowly

18. SAND HOLES

A. The sand was impermeable (not vented)
B. Excessive parting compound was used
C. The riser was improperly placed (feeding thin sections)
D. There were loose sand grains in the mold or runners
E. The core was not sufficiently cured

19. PENETRATION

A. The gates were improperly placed (feeding thin sections)
B. The sprue choke was too small
C. The sand was rammed too loose
D. Excessive parting compound was used
E. The sand was too moist

20. COLD SHUT

A. The metal was not degassed properly
B. The core was too dry
C. The riser used was too small
D. The metal was poured too cold
E. There was excessive venting of the cavity

21. ROUGH SURFACE

A. The metal lacked fluidity
B. The sand was rammed too tight
C. The sand was impermeable (not vented)
D. There was a poor finish on the pattern
E. The gates were too large

22. SHRINK

A. The metal was poured too hot
B. The sand was rammed too loose
C. The sand was rammed too tight
D. The metal had excessive fluidity
E. There was excessive turbulence while pouring

23. MISRUN

A. The sand was in need of reconditioning
B. There was a poor finish on the pattern used
C. The sand was too moist
D. Excessive parting compound was used
E. The metal was poured too hot

24. DROPS

A. The metal lacked fluidity
B. The sand was in need of reconditioning
C. The metal was poured too slowly
D. The metal was poured too cold
E. The sprue choke was too large

25. ROUGH SURFACE

A. The core was not sufficiently cured
B. The sand was too dry
C. The casting was shaken out too soon
D. The pour was interrupted
E. The height of the sprue was insufficient

26. COLD SHUT

A. There was a poor finish on the pattern used
B. There was not riser when there should have been
C. The sand was too dry
D. The metal had excessive fluidity
E. The sand was rammed too tight

27. CUTS AND WASHES

A. The sand was in need of reconditioning
B. The riser used was too large
C. The height of the sprue was insufficient
D. The sand was too moist
E. The core was not sufficiently cured

28. BLOWS

A. The gates were too large
B. The metal lacked fluidity
C. The gates were too small
D. There was excessive venting of the cavity
E. The core was not sufficiently cured

29. HOT TEAR

A. The gates were improperly placed (feeding thin sections)
B. The riser was improperly placed (feeding thin sections)
C. The casting was shaken out too soon
D. The sand was too dry
E. The gates were too small

30. MISRUN

A. The core was too dry
B. There was excessive turbulence while pouring
C. There were loose sand grains in the cavity or runners
D. The riser used was too small
E. The height of the sprue was insufficient

31. SAND HOLES

A. The gates were improperly placed (feeding thin sections)
B. The metal was poured too cold
C. The sand was rammed too tight
D. The sand was too dry
E. The pour was interrupted

32. CUTS AND WASHES

A. The metal was not degassed properly
B. There was excessive turbulence while pouring
C. The metal was poured too cold
D. The metal was poured too slowly
E. Excessive parting compound was used

33. COLD SHUT

A. The sprue choke was too small
B. The mold was handled roughly
C. The metal had excessive fluidity
D. The riser used was too large
E. The metal was not degassed properly

34. SHRINK

A. The pour was interrupted
B. The metal had excessive fluidity
C. The riser used was too small
D. There were loose sand grains in the cavity or runners
E. The sand was in need of reconditioning

35. MISRUN

A. The metal was poured too hot
B. The casting was shaken out too soon
C. There was excessive venting of the cavity
D. There was no riser when there should have been
E. The sand was impermeable (not vented)

36. PENETRATION

A. The sprue choke was too small
B. The gates were too small
C. The core was not sufficiently cured
D. The sand was too dry
E. The metal was not degassed properly

37. DROPS

A. The gates were too small
B. The sand was rammed too loose
C. The metal lacked fluidity
D. The sprue choke was too small
E. The gates were improperly placed (feeding thin sections)

38. COLD SHUT

A. There was a poor finish on the pattern used
B. There was excessive turbulence while pouring
C. The riser used was too small
D. There were loose sand grains in the cavity or runners
E. The metal lacked fluidity

39. CUTS AND WASHES

A. The sand was rammed too tight
B. The sand was impermeable (not vented)
C. The core was not sufficiently cured
D. The sand was too dry
E. The casting was shaken out too soon

40. ROUGH SURFACE

A. Excessive parting compound was used
B. The sprue choke was too small
C. The gates were too large
D. The riser used was too large
E. The riser was improperly placed (feeding thin sections)

41. MISRUN

A. The metal was not degassed properly
B. The sand was rammed too tight
C. The metal was poured too hot
D. The sand was in need of reconditioning
E. There was a poor finish on the pattern used

42. PINHOLE POROSITY

A. The metal was poured too slowly
B. The mold was handled roughly
C. The metal was not degassed properly
D. The gates were too small
E. The metal was poured too cold

43. BLOWS

A. The riser used was too large
B. The mold was handled roughly
C. The riser was improperly placed (feeding thin sections)
D. The sand was too moist
E. The metal had excessive fluidity

44. COLD SHUT

A. The core was too dry
B. There was no riser when there should have been
C. The riser used was too large
D. The gates were too small
E. The sand was rammed too loose

45. DROPS

A. The metal had excessive permeability
B. The sand was too dry
C. The sprue choke was too large
D. The sand was rammed too tight
E. The riser was improperly placed feeding thin sections

46. MISRUN

A. The riser used was too small
B. The metal had excessive fluidity
C. The metal lacked fluidity
D. There was excessive venting of the cavity
E. The core was too dry

47. PENETRATION

A. The metal had excessive fluidity
B. The gates were too small
C. The gates were improperly placed (feeding thin sections)
D. The pour was interrupted
E. The metal was poured too slowly

48. SHRINK

A. There was a poor finish on the pattern used
B. The gates were too large
C. There was excessive turbulence while pouring
D. The sprue choke was too large
E. There was no riser when there should have been

49. SAND HOLES

A. The height of the sprue was insufficient
B. The sand was too moist
C. The casting was shaken out too soon
D. The sand was rammed too loose
E. The core was not sufficiently cured

50. COLD SHUT

A. The pour was interrupted
B. There was no riser when there should have been
C. There were loose sand grains in the cavity or runners
D. There was a poor finish on the pattern used
E. The riser used was too small

Appendix F:

Lab Answer Sheets

Group members ______________________________

Directions: For each defect record an ID number, the terminology used to describe the defect and your diagnosis. Then compare your diagnosis with the computer's and discuss any variances.

Identification # of the defect: __________

Terminology used to describe this defect: __________

List/rank the factors you believe caused this defect:

Identification # of the defect: __________

Terminology used to describe this defect: __________

List/rank the factors you believe caused this defect:

Identification # of the defect: __________

Terminology used to describe this defect: __________

List/rank the factors you believe caused this defect:

Group members ____

Directions: For each defect record an ID number, terminology used to describe the defect and the computer's diagnosis. Discuss the diagnosis. Does your group concur?

Identification # of the defect: ______________

Terminology used to describe the defect: ____________

List the computer's diagnosis:

Identification # of the defect: ____________

Terminology used to describe the defect:

____

List the computer's diagnosis:

Identification # of the defect: ______________

Terminology used to describe the defect: ____________

List the computer's diagnosis:

Appendix G:

Definitions of Casting Defects

Definitions given on the board for the pretest:

MISRUN:
"A casting not fully formed" (Sylvia, 1972, p. 320).

SHRINK:
A cavity formed in a casting by contraction of the metal during freezing (Sylvia, 1972).

PENETRATION:
Rough sandy appearance of surface of casting with some sand embedded in surface (LaRue, 1980).

COLD SHUT:
"Where two streams of metal do not unite thoroughly in a casting" (Sylvia, 1972, p. 309).

PINHOLE POROSITY:
Spherical gas holes usually near surface of casting (Cowles, 1964).

SAND HOLES:
"Cavities of irregular shape and size whose inner surfaces plainly show the imprint of granular material" (Sylvia, 1972, p. 326).

ROUGH SURFACE:
Rougher than expected surfaces "with no apparent sand, ash or crush" (Cowles, 1964, p. 22).

BLOWS:
"A casting defect due to trapping of gas in molten or partially molten metal" (Sylvia, 1972, p. 304).

DROPS:
"Sand falling from the cope of a mold" (Sylvia, 1972, p. 312).

CUTS AND WASHES:
Defects resulting from erosion of the sand by the molten metal stream (LaRue, 1980).

HOT TEAR:
"Cracks in castings formed at elevated temperatures" (Sylvia, 1972, p. 317).

Appendix H:

Randomization Techniques

The following computer program was used to generate a list of random numbers to divide the student population into two groups:

```
10   RANDOMIZE TIMER
20   FOR I = 1 TO 100
30        PRINT INT(RND*84)+1;  ;
40   NEXT I
50   END
```

The first 42 different numbers generated by the program were used to place students into Group 1. These numbers, listed in rank order, are listed below:

1 3 5 6 7 9 13 15 16 18 21 23 25 26 27 29
32 36 37 38 41 42 44 46 47 49 50 51 52 56 57
59 61 64 65 69 70 75 77 80 81 82

Appendix I:

Defective Casting Samples

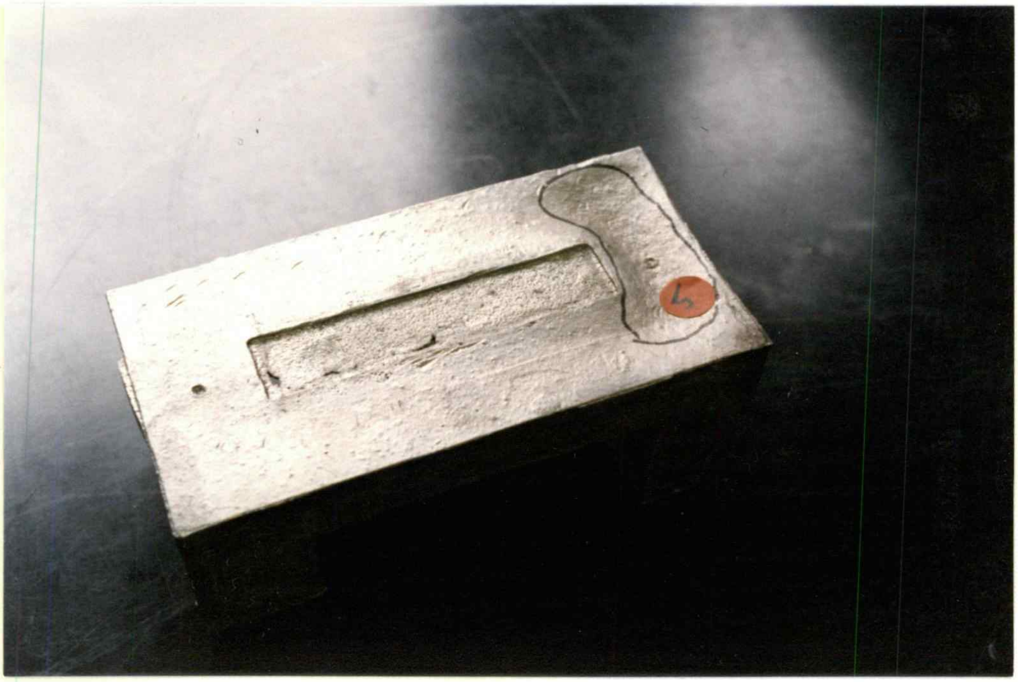

Figure 2: Example of Shrink

Figure 2: Example of Misrun

Figure 3: Example of a Drop

Figure 5: Example of Cuts and Washes

Figure 6: Example of a Hot Tear

Figure 7: Example of Sand Penetration

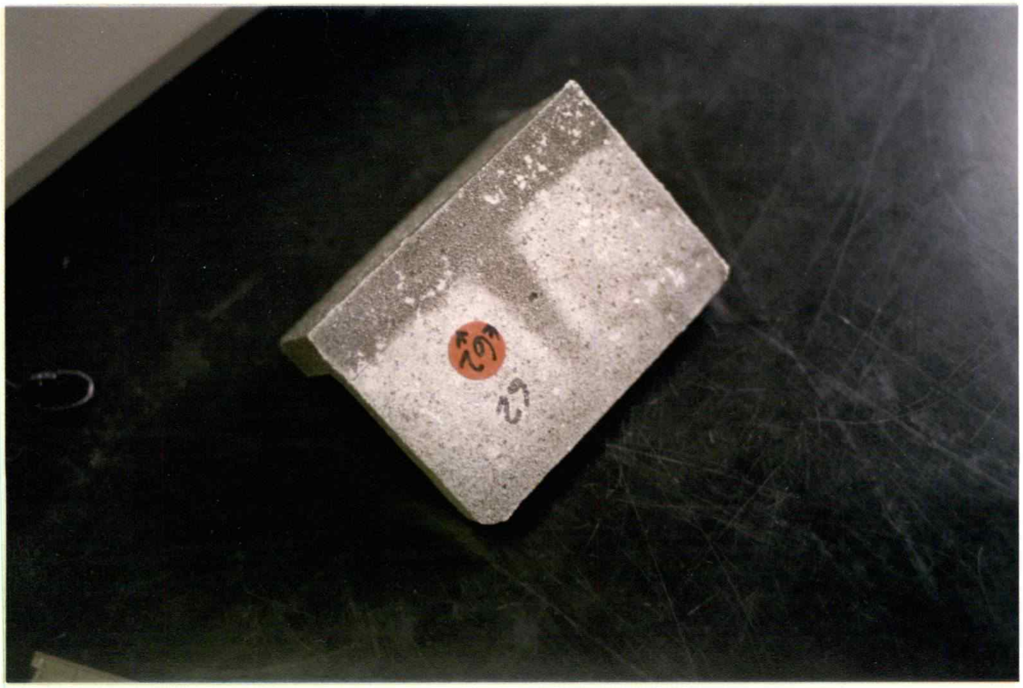

Figure 8: Example of Rough Surface

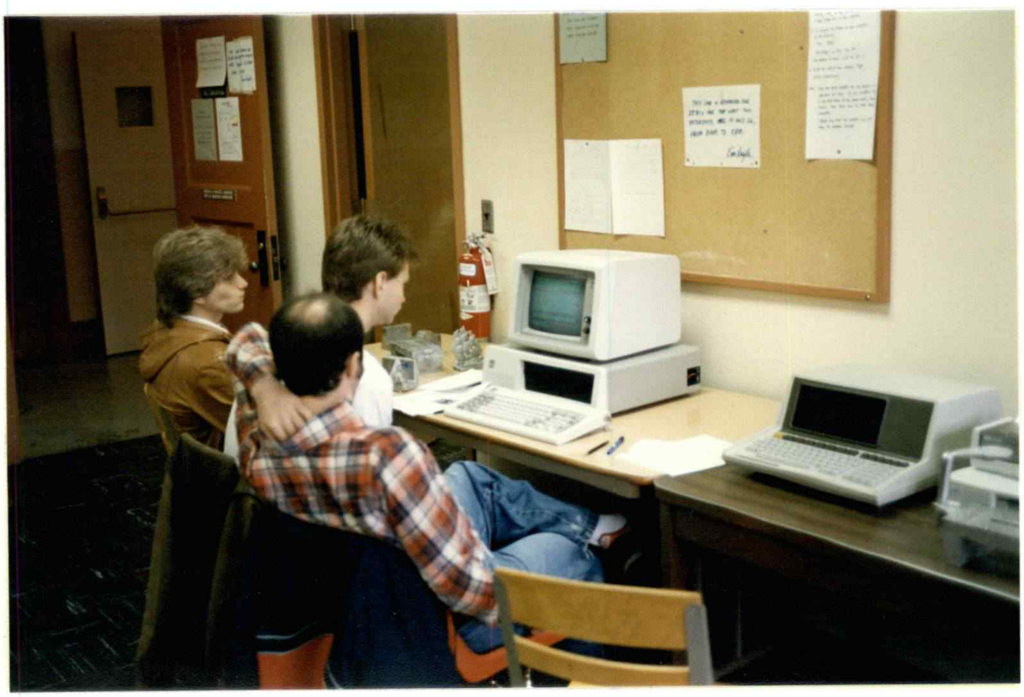

Figure 9: View of Typical Work Station

Appendix J:

Subjective Student Comments

The comments recorded below are representative samples from evaluations completed by all students who participated in this study. Students were asked to comment on the effectiveness of TELECAST and their perceived value of expert systems as a tool to facilitate learning. They were also asked to state whether they felt it was an advantage to have the rules displayed automatically when the system was used or if it was preferable to allow the user to call out the rules as desired. Suggestions for improvement of the system and ideas for implementation in an educational setting were solicited.

No attempt has been made to in any way categorize or group these comments. The comments are quotes, but liberty was taken to correct spelling and minor grammatical errors and in some instances slightly alter the wording without changing the meaning to make the material readable.

****

I think that this system works well for a complement to lab work or a complement to lecture. If the system is to be used only once or twice in a row, the rules are an advantage. If a large number of runs are done, the rules are a hindrance.

One thing that might be useful at the end of the program is that at the time of the evaluation, the program should output some of the possible problems (i.e. misrun, blows, hot tears) in addition to the possible causes of these problems. This would help the student to learn what causes each problem. When the rules appear on the screen (which I think is very valuable) they should say something like "In this case, it <u>appears</u> that a misrun is indicated" rather then "A misrun is indicated." Most of the questions seem to be worded okay, as is the entirety of text. However, the format of the display of the rules is somewhat confusing, because it's hard to tell if the computer is keeping the criteria or eliminating it. I realize that this tool would be much more valuable if the student had a hands-on lab experience at the same time so that he would know all of the conditions surrounding the casting, which would eliminate the need for answering "maybe." I think that this program would be most effective if used with a casting expert working side by side with the student so that the student can actually see what different defects are and what they are caused by. If you give it accurate info, it will diagnose accurately.

Should be able to go back to a question if you make a mistake. I think this is a good learning tool for this application. Yes it is good to display the rules, but then it's good to have the option to not display it after you've played with it for a while. Generally, the system does seem to diagnose well. But if you don't know much about the "conditions" of how the casting was made, it often doesn't give a diagnosis above 5.

The diagnosis depends heavily (entirely) on how we view the casting. Due to ignorance or oversight we may overlook something or misrepresent it. It is therefore as fallible as the user. It also seemed to be pretty noncommittal on certain diagnoses when we felt pretty positive. The wording used is generally fairly good, but there seems to be a general problem of extremism of the answers; it's either all or nothing or not sure. What about the option of being positively somewhere in between the extremes? As a teaching tool, it seemed fairly effective. However, a little follow-up would have been helpful. The last part of the lab should have been used by you describing some of the castings and what you feel went wrong. As it was, we weren't sure how effective our analysis or the computer's analysis was in actuality. A higher level of sophistication would be nice to give it more flexibility, but that would be difficult. Overall, it was good for familiarizing us with defects and getting us used to observing and diagnosing. The display of rules the first time through is useful but is tiresome after a while. I would say the current system of rules is good. Some of the wording is not well defined in my own mind. It may help to have some explanation or example of the choices.

The program seems to diagnose defects fairly well, especially the obvious ones. Some of the questions don't allow the user enough choices to really specify the condition. This probably leads to some poor diagnoses. I believe with a little more refinement the program could be a valuable learning tool for students. I especially liked the rules, where it told you what the program is attempting to do.

The program seems to function very accurately, but there are still some things that must be fixed. The questions are somehow not as clear as they're supposed to be, and there are not enough or wrong choices for the questions. The rules and the reasons of defects were well organized and explained.

The diagnosis seems to be accurate. Some of the questions could use another choice. For instance, the question about small holes with sand or holes throughout with black specks does not consider small holes without any sand or black specks. The question concerning the texture of depression asks for either granular or excessively smooth, but most of the depressions we saw were rough (wrinkly) but not granular. This system would be good as a learning tool. The first lab we ran the program without listing the rules so we did not learn the causes of the certain defects. During the second lab we ran the rules and frequently asked why; this helped enormously.

In general, the system diagnoses the defects correctly. The expert system is good, but I have learned more asking the experts in the room. You can't get as detailed answers from the system as you can from a human expert.

For the most part, the computer does find the casting defects, but it really depends on how well the questions are answered. If it's easy to make the correct choices and there's not too many "not sure" answers, it (the computer) is pretty close. Try and reword the questions so there's not so many "not sure" answers. It's easier to learn if we would have spent more time reading some of the rules. It's easier for me to learn because it's fun and not as monotonous as reading through a book to find your answers.

Overall, I feel the program has been effective in teaching me to diagnose defects in castings. It is user friendly, the questions are clear, and there are ways to determine the cause for asking the question. I liked being able to use "why," and it helped us to give a more accurate response.

The system seems to diagnose castings very well and the ranking of the faults given helps to give an idea of which defects to check first. The question concerning small holes in the casting could use some more options. There is also a problem when hitting return at the wrong times -- it will kick it out of the program. The program works very well as a teaching system if the rules are used. The ability to ask why the computer is asking certain questions is good because only rules that there is uncertainty about need be seen. The only disadvantage as a learning system is that it requires very little input from the person running the program but to notice the defects. One can learn with the system but they're not forced to.

The system in general is actually very good. The rules are very helpful. It seems that having the rules shown and helpful lab assistants would be the ideal learning situation.

This is a good teaching tool. The program does an effective job of forcing the user to evaluate the casting systematically. After approaching many different defects in the same systematic way many times, the user develops a knack for what kinds of things to look for.

Sometimes it gives the correct answers, but sometimes it doesn't. But I think when it gets the wrong answer we have input something wrong. The system, I think, will be very useful for someone with relative amount of background, but is not for beginners. It would be better if small letters are used also instead of <u>all</u> capital letters. It makes it a bit hard to read. The system does help and is a lot better than looking into books. although the system doesn't give the exact answers, it guides us to the right direction for the exact correct answer. But I don't think it should replace books. It is good for getting us to get started.

I think that using the computer expert system is a good way to learn. It gives you hands-on experience and it makes learning easier because the pace at which learning is accomplished is controlled by the student. It is a good idea to have the option of not having the rules displayed. Once you get going, "Why" can always bring them back. A great option.

Most of the time the diagnosis is similar to what we thought was wrong to begin with. But every once in a while we would get answers we knew were wrong. Most of this I think was due to a misinterpretation of the questions. One aspect that was good was the final evaluation printed all possible errors; therefore you would be reminded of any possible problems you did not consider.

The system works. I like the way that you can run the program and ask why only where needed. The problem I found with this system is that once you enter your number in the diagnosis, you can't go back if you pushed the wrong number. You first have to run the whole program and can later correct it. Some form of graphics would be nice to look at and may be helpful.

The questions could be more specific. They should explain themselves more. Also, the answers should somehow be more specific so that they won't be misinterpreted.

All in all, it is a good learning tool because you are using the computer and really seeing the part instead of using just pictures.

Good program. It will probably be useful in helping to diagnose casting defects in a school shop. However, to get the most out of the program, the user should know: 1) how to operate the system thoroughly (this might take some time); 2) terminology used in the questions (like sand holes, pinhole porosity) and what they look like. Pictures of the defects will be very helpful with the program.

The diagnosis is dependent upon the amount of information we have on each casting. Castings with no information about the sand condition, metal condition, or mold structure were diagnosed with small probabilities and an occasional cause apparently coming from left field. The precision of the system is restricted by the background data. Its process of elimination seems to work great. We tried to screw it up and couldn't succeed. We input a perfect cast with no flaws and all of the probabilities were four or below, as it should be. The rules were good to have for reference and first time usage. They take up a lot of time. We did not use them until we tried to mess up the program.

For my point of view, I think this is a great way to help diagnose casting defects. It would be better if graphics, color, and a bigger screen were provided.

Since the system goes by the book and all I know is from the book, I would have to say yes, it diagnoses accurately. Overall, for a quick diagnosis, this is an excellent system.

I think the program is easy to follow except when you get to the end of the problem. It doesn't really tell you the proper name of the problem.

I believe this system is helpful in teaching. But I do believe more information should be given about the reasoning of the system's conclusions.

It diagnoses defects with a good degree of accuracy provided that the data is sufficient. The more "unknowns" or "not sures" entered will result in a less definite analysis of the casting. One should be aware of the principle "garbage in, garbage out" when using this program. This program would probably be beneficial for educational purposes in a vocational type situation where the analyst will have experience in making an actual casting.

Distinguishing between rough, very rough, and smooth is difficult because we have nothing to compare to. Why not set up some standard test pieces to have on hand while doing the diagnosis. Overall, I felt the program was very helpful. But it should be combined with actual lab work to be truly beneficial. I can foresee this being very useful in a situation where a student is trying to perfect a certain casting. He could try one, keeping track of the procedure, and use the computer to analyze it. Then he could alter one factor and see the actual results on the product.

It seems to diagnose quite well except when there are several "unknown" answers. The computer then diagnoses a bunch of causes that you know are not the cause. The option of not having the rules is great once you have run the program for some time. But for educational use, you should require the rules to be printed with an explanation for each question the first time it is presented. But in industry, having it just whip through the questions saves time, and you always have the option of asking "Why."

Most of the notes included with the rule display are clear and helpful, but would be more useful in the learning process if the defect noted were <u>defined</u>. Grouping the final causes under the respective defect in the final analysis would by useful. The system's diagnosis usually matched our own, but there is always the error of the operator entering the wrong information and getting the wrong diagnosis. If the operator cast the part, then the system would not only accurately diagnose the defect, but would serve as a learning tool as well. The expert system is a good learning tool, but would be even more effective if used in conjunction with a human expert.

The expert system is something you can work with because the computer won't get tired. But it's only good for preliminary evaluations. Overall, I think this is a good system if there's no instructor. I would prefer having someone to discuss with rather than rely on a computer. It's so boring.

This could be a useful tool if more were known about the conditions at the pouring time. I don't believe the tool could ever replace human evaluation. The program would be best used to eliminate the gross or obvious reasons for defects. But the subtle or unusual defects should still be handled by human analysis. The rules display should remain optional. It is useful while the user is unfamiliar with the program, but it's nice to be able to turn it off when you have it most of the rules memorized.

This program diagnoses castings fairly accurately. Many times we did not have adequate information to answer some of the questions. If that information was known, the diagnosis would be more accurate. This program would be a very good educational tool for courses in casting. I went to a technical high school, and something like this would be beneficial in the pattern and foundry shops. To really understand (learn) and benefit from this program, you should have extra time to "fiddle" with the different answers to see the different diagnosis. Reading the rules and asking "why" was helpful also.

From what I know about casting, the expert system does a fairly comprehensive job in diagnosing the problem. The use of a scale from 1 to 10 for the final diagnosis was clear in terms of understanding. The only real problem that I can see which may make the diagnosis defective is human error (subjective) in selecting options. The system does help me learn about castings because it enables me to diagnose a casting while actually holding it in my hand. Sometimes, I think the rules could be more condensed for the user. I personally think that I would learn more if I had an actual teacher to help me along as I enter my responses. The computer can't teach me everything.

Most of the questions seem to be clear and understandable. I think that anyone with a little knowledge of casting could understand the questions. Seems like a very good system overall. Should be a good teaching device.