Expert and Novice Performance in an Industrial Engineering Virtual World Simulation

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Boca Raton, Florida
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ISBN: 1-58112- 355-8

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ABSTRACT

Expert and novice problem solving has been a subject of research for many years. Problem solving of textbook problems and case studies in various domains such as math, physics, chess, music, system design, medical diagnosis, and business sub-domains have been the norm as the subject of this type of research. Few if any research efforts have undertaken the study of real world problem solving that occurs over an extended time such as those solved by industrial engineers in a manufacturing setting. This research studies the expert and novice problem solving performance in a scaled-world simulation of a manufacturing company experiencing a high backlog of customer orders. Research time consists of eight hours of problem solving behavior for teams of two as they diagnose the problem and make decisions to meet the problem goal. Participants can advance simulation time forward for weeks to get feedback on their decisions. The seven research hypotheses are: 1) experts will generate a better outcome for the primary problem goal in the test situation in the given time period than novices; 2) experts will make more correct decisions in solving the problem in the test situation than novices; 3) experts will understand the system dynamics of the problem in the test situation better than novices; 4) experts will search for data and situation information better than novices in solving the problem in the test situation; 5) experts will recognize and use data and situation information better than novices in solving the problem in the test situation; 6) experts will use more domain knowledge than novices in solving the problem in the test situation; and, 7) experts will use a forward or top-down problem solving method and novices will use a backward or bottom-up problem solving method. The experimental results support all seven research hypotheses. Discussion ensues about the unexpected results such as fixation on scheduling. The conclusions are that the research simulation discriminates between novice and expert performance which indicates its potential for measuring levels of industrial engineering expertise. Suggestions for future research with the scaled-world simulation and its use in the classroom are given.

ACKNOWLEDGMENTS

I wish to thank my advisor, Clark Mount-Campbell, for his patient mentoring through this process. His suggestions and insights have been invaluable.

I also thank Al Miller and David Woods for their patience and support, especially during the final stages of completing the process.

I thank everyone associated with the Industrial and Systems Engineering Department for their unknowing support and help as they dedicatedly perform their daily jobs.

I am grateful to the management at Unext and Cardean University for their support, encouragement, and resources that were enormously helpful to completing this effort. I also wish to thank the students and professionals who participated in this research, especially Craig, Doug, Roy, and Stephen.

Finally, I thank all my family and friends who endured my ordeal, gave me encouragement and support, and believed in me. A special thanks goes to Phyllis.

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CHAPTER 1

INTRODUCTION

It is debatable whether people are born experts. When trying to think of someone who might have been, Mozart comes to mind, as well might just a few others given a little time to think. Most experts become such from a combination of inheritance and hard work. The hard work part usually comes from learning, most of which takes place outside of academia. Not everybody becomes an expert. Maybe we all should. This paper is about expertise, why it is important, how it differs from novice and competent performance, how it is learned, and how we might be able to improve the learning of it. In particular, the paper focuses on expertise in the domain of industrial engineering.

Practicing industrial engineers solve real problems in the real world. The curricula of Industrial Engineering programs are intended to prepare students to know how to solve these problems and make effective decisions. Yet, there has been and is much interest in expertise, what it is, how it is acquired, and how curricula can be augmented to accelerate the progress toward expertise. The purpose of this research is to investigate real world problem solving and decision-making in the domain of Industrial Engineering. This research is preliminary and investigative in nature as part of a larger effort towards developing methods for accelerating acquisition of expertise in Industrial Engineers.

Two driving forces, both of which stem from my personal experience, motivate the proposed research. The first motivating factor is my personal interest in and twenty-five year work experience with problem solving and decision making as an industrial engineer and business and systems manager in the real world.

The second motivating factor is my personal experience as an instructor in undergraduate industrial engineering courses at The Ohio State University (OSU) including system simulation, optimization in problem solving, quality control, and the senior capstone course of real problem solving. The industrial engineering curriculum at OSU is accredited by ABET, and the instructors are dedicated and there are many good students. During the several times I co-taught the course, I observed many of the senior students struggle with the real world problem. I personally believe that students would have benefited from the experience had they acquired a higher level of expertise at real problem solving. Student surveys confirm this. Some engineering educators have indicated concern for improving engineering education. Colburn (1995) conducted research in using TQM principles combined with adult learning theory for the Engineering Economics course at OSU. Maul (1994) states that engineers believed that they were not well prepared for actual job demands, as summarized from a survey of practicing engineers. They indicated that courses were not integrated and did not provide adequate application and practice. Maul says, "The first and most critical [complaint] was that engineering curriculum was geared more to producing potential graduate students and not 'real world or practicing' engineers. Their feeling was that there was not enough practical hands-on engineering in their undergraduate programs."

Effort to introduce integrating course methodology is not new. Instructors have attempted to use such techniques as case-studies, simulations, and microworlds for years. MBA programs use case studies liberally. Harvard Business Press has a large inventory of business cases. Forrester (1994), professor emeritus at MIT's Sloan School of Management, says "case studies have served for decades in analyzing business systems. The case-study approach has remained popular because it couples directly to the real world and addresses critical corporate issues." Researchers have been interested in determining how to use these methods effectively. For example, Ertmer and Stepick (1999) explored changes in students' problem-solving skills as they analyzed instructional design case studies during a semester-long course.

Yet Forrester (1994) believes there are drawbacks to using case studies. He believes their static nature obscures the dynamic nature of the situation causing incorrect conclusions to be drawn. He describes a particular incident that occurred at a celebration at Harvard Business School.

> The program included a demonstration of the case-study method for which participants divided into classrooms of some 50 people each. The written description of the case had been distributed in advance. The group that I observed correctly identified the issues, structure, and relevant policies in the situation. The discussion progressed to recommendations for improvement. As it happened, the case was one for which we had done a system dynamics model and had tested alternative policies. The policy recommendations of the case-study group were wrong and entirely inconsistent with the system description as formulated at the beginning of the case discussion. Most misbehavior of corporate, social, and governmental systems arises from just this dependence on erroneous intuitive solutions to complex behavior.

For this reason, some have started to use simulated micro-worlds as support for case studies. Graham, et al. (1992) present two examples of such simulated supported case studies (People Express Airlines and the Intercom PBX) and discuss learning issues such as teaching effective inquiry and conceptualization skills and how to enhance the transfer of insight to new situations. Bakken, et al. (1992) conducted research on transfer of knowledge from one microworld simulation to another similar microworld. They found that transfer did occur and students had a higher rate of transfer than did professionals. Isaacs and Senge (1992) provide the learning theory underlying microworld simulations, and discuss limits to learning and some implications that apply for both individual and team applications. Senge and Sterman (1992) also discuss learning theory in terms of microworlds and present a case study about improving costs and quality in an insurance company which illustrates how such a microworld can be used. Software has recently become available for creating microworlds which increases the ease of development and use of these types of simulations. Diehl (1992) provides information about one such product, MicroWorld Creator. He reports on the design aspects that facilitate the input-output interface with the participants.

I hypothesize that using micro-world, or scaled-world, simulations in industrial engineering curricula would provide a degree of integration between course content and real-world context. Colburn (1995) proposes that there are five flaws in engineering education, two of which are the absence of context and the absence of integration. Properly developed scaled-world simulations of realistic, dynamic systems could be used in multiple courses of a curriculum to provide a consistent representation of a real-world environment for context and situated learning as well as the integration of industrial engineering concepts.

Developing and testing these simulations would be required to ensure they were representative of the target situation and that they were usable as instructional devices.

Also important is how these simulations would assist learners, mostly novices, in acquiring knowledge on the way to becoming experts. One way to determine this is to create such a scaled-world simulation and study the behavior of both experts and novices as they interact with it to make decisions and solve problems. The focus of this research is to study the differences of expert and novice decision making in a scaled-world simulation of an industrial engineering problem.

Background discussion

Expertise has been studied for a long time since it is recognized as a quality that is often sought and revered in most societies. How it relates to problem solving and decision making would be useful to know as well as the types of problems and decisions that occur in the domain of industrial engineering. Knowledge is the key to expertise and it seems to be a special kind of knowledge. I will discuss how knowledge relates to problem solving, expertise, and the domain of industrial engineering. I will also provide a brief background on simulations and how they relate to decision making.

Problem Solving and decision making**.** Why is problem solving a topic of interest? Obviously, it is what we humans do all our life, from getting that very first breath to surviving till the last. “Making decisions is a fundamental life skill”(Hammond, et al. 1999, p.2). So why study it? That as well is obvious – so we can get better at it. And we can, as Hammond, et al. (1999) purport. It is also obvious that there are big or important problems and small or insignificant ones. Either way, they do get solved. It is a question of how many resources will get devoted to the effort. Expert knowledge is one of these resources.

There is no absolutely agreed upon definition of problem solving, and the definition depends on the definition of the term problem. Wagner (1993) (as well as others, e.g., Benaroch and Tanniru 1996) provides a widely accepted definition of a problem as a gap between the current or initial state and the desired or goal state, where some process or operations will change the initial state to match the goal state. If the perceiver knows all three elements, then there is no problem. What makes the situation a problem is if one or two of the elements are not in (partially or wholly) the knowledge base of the perceiver. If all three elements are unknown to the perceiver, then there is no problem, at least as far as the perceiver is concerned. And by this definition, problems are based on the perception of the beholder. One person's problem may be another's bliss. Wagner goes on to categorize problems in terms of which state is unknown. If the initial state is unknown or at least partially so, this is a diagnosis problem. If the goal state is unknown, this is a design problem. If the process of transformation is unknown, this is rule discovery problem.

There are other ways to categorize and classify problems. Brightman (1980) distinguishes three dimensions of problems: degree of structure, level within an organization, and method of awareness. Ill structured problems are novel, complex, and confounded, where information is unavailable or requires search. Repeated ill-structured problems may become well structured over time as standard procedures are developed for solving them. Crisis problem solving is reactive while opportunity problem solving is proactive.

Smith (1988) and Benaroch and Tanniru(1996) go farther in discussing the classification of problems according to the level of structure the task presents –

structured, structurable, or unstructured. A structured task is one in which the deep structure is apparent, allowing it to be easily solved. A structurable (also called ill-structured) task has a deep structure which is partially known. The structure can be decomposed into both structured and unstructured subtasks. The unstructured subtasks require special domain knowledge or heuristics. An unstructured task is one in which there is little or no knowledge available about its deep structure. Experts may be able to solve it, but may also be unaware of just how they do it, as in these cases their knowledge may be tacit or hidden.

Problem solving is the process of closing the gap and eliminating the problem. This process is commonly referred to as the phase model of problem solving. There is no agreed upon number of phases among the researchers and scholars in academia. Textbook authors on problem solving have their own version of the problem solving phases. The text by Winston, et al. (2001) presents a method they call the seven-step modeling process. Ragsdale's (2001) text covers nearly the same topics. He says, "...we have said that the ultimate goal in building models is to assist managers in making decisions that solve problems." (p. 5) He presents a five-step problem-solving process. The bigger question and debate is whether the phase model is accurate in reality (Lipshitz and Bar-Ilan 1996). We will discuss this research in more detail later.

Another aspect of problem solving is decision-making. This section started off with a quote about decision-making. I posit that decision-making is a subtype of problem solving. There is nothing in the state definition of problem-solving regarding choice, which is what a decision is. Yet decisions are problems, as they have the three ingredients – an initial state, a goal state, and a method to close the gap. They are problems that have alternatives as part of the process, from which the problem solver must choose (usually) one. Part of the problem is searching for alternatives, either in specifying a goal state, or finding alternate paths to the goal state. Additionally, choice criteria must be developed that will determine which alternative to choose. In Winston (2001) the chapter titles all use the term “models” except the last two mentioned, which use the term “decision making.” Step 1 of the problem solving process is “define the problem.” The book discusses situations in general as problems. Yet step 5 indicates that there are alternatives to be selected from - a choice. Hence the process is one of decision-making. From this discussion, one can conclude that decision-making is problem solving.

Yet in general, problem solving is not necessarily decision making. In heuristic problem solving, one may only see a single move and take it to accomplish a subgoal. It is possible that this is repeated step by step with no cognition of any choice in the matter. It only specifies that there are operations on the problem state that transform it into the goal state.

Research in the area of naturalistic decision making (Klein 1998) indicates that much of the time, solutions to a problem are sought and reviewed in a serial fashion, and when one is found that meets the minimum requirements of closing the problem gap, it is implemented, or at least attempted. If it works, problem solved; if it doesn’t work, then the problem solver begins the search again hopefully learning from what didn’t work. Simon (1956) called this type of decision making “satisficing” as opposed to optimizing which is the rational normative model theorized by economics. Simon coined this term when he was discussing his theory of bounded rationality which says that humans do not optimize in their decision making process due to cognitive limitations or lack of computational ability and time, yet they still make rational decisions within these limitations by using the structure of the environment to provide adequate cues for using simplified choice mechanisms.

Payne, et al. (1993) present results of their studies of how decision makers adapt their strategy to the situation at hand based on an accuracy-effort tradeoff. They claim that people are adaptive decision makers and use a variety of heuristic strategies most of which are non-optimizing. Gigerenzer and Todd (1999) has expanded upon this line of research, developing and studying what he calls fast and frugal methods, a set of heuristics which he claims makes up the adaptive tool box of decision techniques.

Industrial Engineering**.** We have been discussing the general topic of problem solving. It is important to narrow the focus and look at the type of problems that are encountered in the domain of interest, industrial engineering. The Institute of Industrial Engineers defines industrial engineering in this way: *Industrial Engineering is concerned with the design, improvement, and installation of integrated systems, people, materials, information, equipment, and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems.*

Industrial engineering is focused on integrated systems. The types of problems and decisions encountered are those of design, improvement, and implementation, to obtain desired system performance. Turner, et al. (1993) provide additional distinctions for industrial engineering. They distinguish between two types of systems – human activity systems and management control systems, and specify that industrial engineers work at both the operations level and the corporate or strategic level. Their text indicates that industrial engineers work in many sub-domains: manufacturing engineering; facilities location and layout; material handling, distribution, and routing; work measurement; operations planning and control; quality control; job and wage analysis; CAD/CAM, robotics, and automation; human factors; resource management; engineering economics; optimization and operations research; and project management. The field is broad indeed. The types of problems are varied, yet they have one common theme, systems analysis and design.

It is clear that the domain of industrial engineering is broad and general, even though it has subdomains. With “system” as its focus, IE’s are sometimes considered generalists. An expert industrial engineer could be considered a “general expert” as Bereiter and Scardamalia (1993) believe is possible.

One more item worth briefly mentioning here is the similarity of concepts between industrial engineering and system dynamics. System dynamics models are designed to specify, predict, and evaluate the results of systems (Forrester 1961) which are comprised of the same elements as in the IE definition - people, material, information, equipment, and energy. The function of the IE is system improvement and design. The techniques that IE’s are taught and use are all directed at the rates and levels as characterized by system dynamics. Creating ways to change production and other operating rates and affecting levels such as work-in-process and capital equipment are the prime tasks of IE’s. Changing the system structure by process flow analysis, plant layout, TQM methods and OR modeling techniques is the domain of the Industrial Engineer.

It is clear that the role of the IE profession closely parallels that of system dynamics. However, there seems to be a disconnect between industrial engineering curricula and system dynamics, the language of systems. System dynamics is not taught in the industrial engineering program at OSU nor is it taught at many IE programs across the US. And research shows that dynamic systems are difficult to understand in terms of delays in the information feedback mechanisms. Including system dynamics in IE programs would provide the novice industrial engineer with some degree of knowledge of this difficult aspect of systems. An interesting area studied by this research is the comparison of the results by those with knowledge in system dynamics with those without the knowledge. Will expert industrial engineers have a better understanding of the dynamics of a system than novices based on their knowledge acquired through practice? Will someone with knowledge and experience of system dynamic modeling do better at solving a manufacturing system problem than an experienced industrial engineer without any formal training in system dynamics? These questions will be discussed in later chapters.

<u>Expertise and experts</u>**.** It is commonly considered that experts perform at superior levels and achieve at the high end in many and various domains. Before taking a closer look at expertise, let's ask why we are interested in it and why study it? The intuitive answer is that there are benefits to both the expert and the organizations that employ them as well as to society at large. Kuchinke (1996) says "Expertise is of importance to individuals, organizations, and society at large, and its development is at the core of the