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The PACE System: An Expert Consulting System for Nursing
Steven Evans

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The PACE System

An Expert Consulting System for Nursing

With 30 Illustrations

Springer

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Dedicated to my father and my mother

Foreword

In this volume, Steven Evans reports on a quarter century of work—work that resulted in a commercial product known as the PACE System. An advanced clinical management system, PACE links all care delivery settings and reaches across multiple episodes. It offers capabilities critical to managed care, including care planning and clinical pathways, the critical pathway analyzer and clinical repository central to outcomes-based care, and more.

The pages that follow describe the PACE project, focusing on its knowledge base and semantic network. They offer insights into system implementation and address the synthesis of principles within the PACE System. From this project in nursing informatics, Steven Evans relates both successes and failures, sharing the strategies and techniques to adopt and pitfalls to avoid in a project that followed five years of preliminary theoretical work.

With clarity and candor, he gives us the benefit of two decades of project development, first in academia and then in the commercial sector. Over the course of the project, many tens of millions of dollars and close to 500 person-years of effort were invested. Building on the strong conceptual base developed at Creigton University's School of Nursing, the project has seen exponential growth in its clinical capabilities since entering the commercial sector in 1989.

As an advocate of nursing informatics, I have had the great good luck to follow Steven Evans' work on this project from early on. Despite the frustrations and complications that inevitably surround a large-scale group effort, he held true to his concept, building on each success and learning from every failure.

Like other visionary health informaticians, including Larry Weed, he has been proven right by time. Steven Evans was among the first to recognize the contribution that cognitive science could make to healthcare computing. Today we are seeing this discipline gain recognition as informaticians seek to understand information-seeking behaviors in a changing information environment.

Through his intellectual boldness and professional dedication, Steven Evans has succeeded. What was 25 years ago difficult, if not impossible for many of us to conceptualize, is now a reality we can see for ourselves—and that we can use to improve patient care.

I join with Steven Evans in thanking those many professionals who helped move his theories into practice. He has counted mightily on their support. Yet I know the one central truth: without Steven Evans, there would be no PACE System. He has been its true believer, the one who held true to his vision when it would have been easier to relinquish it.

For this commitment, we owe him our admiration and our attention to the pages that follow. Let us read and learn. Today more than ever, our world needs the benefits visions made real can bring.

Marion J. Ball

Series Preface

This monograph series intends to provide medical information scientists, health care administrators, physicians, nurses, other health care providers, and computer science professionals with successful examples and experiences of computer applications in health care settings. Through the exposition of these computer applications, we attempt to show what is effective and efficient and hope to provide some guidance on the acquisition or design of medical information systems so that costly mistakes can be avoided.

The health care industry is currently being pushed and pulled from all directions—from clinicians, to increase quality of care; from business, to lower cost and improve financial stability; from legal and regulatory agencies, to provide detailed documentation; and from academe, to provide data for research and improved opportunities for education. Medical information systems sit in the middle of all these demands. The generally accepted (popular) notion is that these systems can satisfy all demands and solve all the problems. Obviously, this notion is naive and is an overstatement of the capabilities of current information technology. Eventually, however, medical information systems will have sufficient functionality to satisfy most information needs of health care providers.

We realize that computer-based information systems can provide more timely and legible information than traditional paper-based systems. Most of us know that automated information systems provide, on average, more accurate information because data capture is more complete and automatic (e.g., directly from devices). Medical information systems can monitor the process of health care and improve quality of patient care by providing decision support for diagnosis or therapy, clinical reminders for follow-up care, warnings about adverse drug interactions, alerts to questionable treatment or deviations from clinical protocols, and more. Because medical information systems are functionally very rich, must respond quickly to user interactions and queries, and require a high level of security, these systems can be classified as very complex and, from a developer's perspective, also as "risky."

Information technology is advancing at an accelerated pace. Instead of waiting for 3 years for a new generation of computer hardware, we are now confronted with new computing hardware every 18 months. The forthcoming changes in the telecommunications industry will be revolutionary. Certainly before the end of this century new digital communications technologies, such as the Integrated Services Digital Network (ISDN) and very high-speed local area networks using efficient cell switching protocols (e.g., ATM) will not only change the architecture of our information systems but also the way we work and manage health care institutions.

The software industry constantly tries to provide tools and productive development environments for the design, implementation, and maintenance of information systems. Still, the development of information systems in medicine is, to a large extent, an art, and the tools we use are often self-made and crude. One area that needs desperate attention is the interaction of health care providers with the computer. Although the user interface needs improvement and the emerging graphical user interfaces may form the basis for such improvements, the most important criterion is to provide relevant and accurate information without drowning the physician in too much (irrelevant) data.

To develop an effective clinical system requires an understanding of what is to be done and how to do it and an understanding of how to integrate information systems into an operational health care environment. Such knowledge is rarely found in any one individual; all systems described in this monograph series are the work of teams. The size of these teams is usually small, and the composition is heterogeneous (i.e., health professionals, computer and communications scientists and engineers, biostatisticians, epidemiologists, etc). The team members are usually dedicated to working together over long periods of time, sometimes spanning decades. Clinical information systems are dynamic systems; their functionality constantly changes because of external pressures and administrative changes in health care institutions. Good clinical information systems will and should change the operational mode of patient care, which, in turn, should affect the functional requirements of the information systems. This interplay requires that medical information systems be based on architectures that allow them to be adapted rapidly and with minimal expense. It also requires a willingness by management of the health care institution to adjust its operational procedures and most of all, to provide end-user education in the use of information technology. Although medical information systems should be functionally integrated, these systems should be modular so that incremental upgrades, additions, and deletions of modules can be done to match the pattern of capital resources and investments available to an institution.

We are building medical information systems just as automobiles were built early in this century (1910s) (i.e., in an ad hoc manner that disregarded even existing standards). Although technical standards addressing computer and communications technologies are necessary, they are insufficient.

We still need to develop conventions and agreements, and perhaps a few regulations, that address the principal use of medical information in computer and communication systems. Standardization allows the mass production of low-cost parts that can be used to build more complex structures. What are these parts exactly in medical information systems? We need to identify them, classify them, describe them, publish their specifications, and, most important, use them in real health care settings. We must be sure that these parts are useful and cost-effective even before we standardize them.

Clinical research, health services research, and medical education will benefit greatly when controlled vocabularies are used more widely in the practice of medicine. For practical reasons, the medical profession has developed numerous classifications, nomenclatures, dictionary codes, and thesauri (e.g., ICD, CPT, DSM-III, SNOMED, COSTAR dictionary codes, BAIK thesaurus terms, and MESH terms). The collection of these terms represents a considerable amount of clinical activity, a large portion of the health care business, and access to our recorded knowledge. These terms and codes form the glue that links the practice of medicine with the business of medicine. They also link the practice of medicine with the literature of medicine, with further links to medical research and education. Because information systems are more efficient in retrieving information when controlled vocabularies are used in large databases, the attempt to unify and build bridges between these coding systems is a great example of unifying the field of medicine and health care by providing and using medical informatics tools. The Unified Medical Language System (UMLS) project of the National Library of Medicine, NIH, in Bethesda, Maryland, is an example of such effort.

The purpose of this series is to capture the experience of medical informatics teams that have successfully implemented and operated medical information systems. We hope the individual books in this series will contribute to the evolution of medical informatics as a recognized professional discipline. We are at the threshold where there is not just the need but already the momentum and interest in the health care and computer science communities to identify and recognize the new discipline called Medical Informatics.

Salt Lake City, Utah HELMUTH F. ORTHNER

Acknowledgments

Like PACE, this book was possible through the support in part by a grant from the W.K. Kellogg Foundation of Battle Creek, Michigan. The author is also greatly indebted to Dr. Helmut Orthner, Springer series editor, for his invaluable recommendations and encouragement, without which this book would never have survived. What clarity of expression there is owes its debt to both the Springer-Verlag and Chernow editors. Finally, both PACE and this volume owe their existence to the family support every contributor needs; just as this author is indebted to his Evans family, Deirdre, Bette, Micah, Jeremy, and Frances, too.

Contents

* Coauthored with Patricia L. Tikkanen, RN, MSN

CHAPTER 1

Introduction to the PACE Project

Purpose and Organization of the Book

First Goal: Requirements for Project Survival

The first goal of this book is to utilize the case study of the development of the PACE (*Pa*tient *C*are *E*xpert) system to describe and explain fundamental requirements that enabled a 20-year, large-scale project not only to survive but also to achieve its overall mission in the face of significant challenges (Evans, 1988b). The challenges facing a major initiative differ crucially from those confronting a focused and cohesive limited project. Contrast the task of obtaining lunch for oneself with the goal of preparing lunch for several battalions of an army. For yourself, you can find a convenience store, buy a ready-made sandwich and a drink, eat the lunch, and discard the packaging as you leave. Feeding several battalions requires obtaining massive amounts of ingredients, storing them, identifying recipes commensurate with huge quantities, preparing the different components of the meal in parallel with numerous personnel, distributing the food in a short time to large numbers, deploying support facilities to pick up (and store) the leftovers, completing the cleanup, and so on.

Clearly there are challenges in the latter case that do not arise in the former. Such are the issues in a large-scale project like the one we shall describe in this volume. Readers involved in such larger efforts will find this volume helpful in the planning, initiation, and ongoing management of these enterprises. From the first goal presented above, it may be somewhat apparent why this book is applicable not only to nursing but to many other similar domains as well. Although some of the challenges facing the project were to a degree unique to nursing, most are endemic to any undertaking that is extensive and substantial in scope. Major efforts usually entail large groups, a large scale, and the long term.

If the project requires a group effort, then inherent in this need is the division of knowledge and effort among the members of the group. From this division arises the need for integration and communication to mitigate the effects of division and separate activities. A large-scale project calls for the allocation of significant resources. Inherent in such resource allocation is the need for ongoing support and the continuous management of resources. In a long-term project, changes are likely to occur in the technology, the philosophy, and the environment in which the project is immersed. With a longer term come changes in personnel, the need to renew focus and project continuity, and normal loss of momentum, which can impede any effort.

Since the foregoing attributes apply to any domain, whether nursing or another, this book has widespread applicability. There is great potential in gaining insights into the approaches that were successful, understanding the pitfalls and mistakes from which lessons may be extracted, and recognizing solutions that may be applicable in the future. Since this specific undertaking did achieve worthwhile results in nursing, those with a special interest in nursing will also have particular interest in the details of this effort (Evans, 1988a).

Second Goal: PACE Strategies and Approaches

The second major goal of this book is to more fully elaborate on the specific approaches and solutions we devised to successfully accomplish the project. We describe the strategies that worked and those that did not, explaining why success was or was not achieved and giving our reasons for choosing one path over another. Thus others may benefit from the enormous experience acquired and lessons learned over two decades. We shall discuss in greater depth the various specific problems confronted, the selection and use of methodological approaches, the challenge of massive knowledge acquisition, codification, and maintenance, and the distribution of a practical system applicable to the working professional.

These issues and underlying solution strategies remain as active and applicable today as they were during the 20 years needed to fashion them, although informatics tools and techniques to tackle the problems have changed markedly (Prokosch et al., 1995; Rasmussen, 1993; Soda, 1995). It is anticipated that our focus on the underlying strategy rather than just on the technicalities of our solutions will provide a wealth of useful problem-solving strategies for readers.

Third Goal: Historical Perspective and Context

The third major goal of this book is to describe to the next generations of informatics workers some of the historical events of one of the largest, longest surviving, and most massive informatics efforts (whether in nursing or medicine). It is hoped this record will help instill an appreciation of the work that has gone on before, enable us to learn from it, and through the lessons, to be better guided in the future. In addition, more than just a historical reflection, the specifics regarding the evolution of the project helped to deepen the understanding of the barriers that can and must be overcome, the challenges that can arise, and the value of certain methodologies and strategies. These are more fully understood when context and historical perspective are provided. Given that to some degree history repeats itself, albeit in new ways, this presentation should be of real value to those who will find their working environments not at all dissimilar to the ones encountered throughout the PACE system history. For the reasons given above, and for continuity of presentation of the total 20-year history of this undertaking, the Section 2 of Chapter 1 begins with the historical context.

Organization of the Chapters

In Chapter 2, we set the stage for the remaining chapters by contrasting the original system and its capabilities with the current version to give the reader a concrete understanding of PACE's evolution over the past 20 years. In Chapter 3, we discuss issues in the initial development of a knowledge base and our approach to the challenges identified. In Chapter 4, we turn to the specific activities and efforts needed to acquire, maintain, and manage the knowledge base itself. In Chapter 5, we review the implementation, distribution, and subsequent validation of the entire clinical system. In Chapter 6, we consider specific issues in the development as well as the maintenance (and its automation) of the semantic network that is a hallmark of this effort. In Chapter 7, we analyze some of the principles and lessons that may be gleaned from this effort which may be useful for researchers and developers in the future.

Project History

The Research Environment for Conceptual Underpinnings

The PACE system, an expert consulting system for nursing, involves an enterprise that actually spans fully 25 years, counting the development of the theoretical underpinnings. The initial efforts were based on research undertaken by the author as a member of the faculty of the Graduate School of Industrial Administration at Carnegie-Mellon University in Pittsburgh, Pennsylvania, beginning in 1971 (Evans, 1974a; Evans, 1974b). This research addressed innovative ways to capture and utilize knowledge, using the then-new field of artificial intelligence (AI), a subfield of computer science and cognitive psychology (Evans & Newell, 1972). During this period, other active research efforts were under way in AI to look at new ways to organize knowledge, to capture knowledge, and to utilize rules about the use of knowledge to mimic and model cognitive behavior, particularly complex problem-solving behavior (Newell & Simon, 1972; Quillian, 1966; Shapiro, 1971).

Of specific interest to researchers were professionals in a wide field of endeavors who solve complex problems by manipulating and utilizing knowledge in apparently highly effective ways (Buchanan et al., 1983; Buchanan & Shortliffe, 1984; Hayes-Roth, 1984; Harmon & King, 1985). Of particular note were two other large-scale AI expert systems begun within this approximate time frame, INTERNIST and HELP (Miller et al., 1982; Kupermann et al., 1991; Johnson et al., 1984). Both applications-oriented efforts were similar in nature to the PACE effort in that they attempted to create a usable, powerful tool for health care providers. These efforts in modeling experts evolved into what has become known as "expert medical informatics systems" (Miller, 1994; Miller & Masarie, 1990).

At the very onset, many researchers began to work with and utilize new organizational schemas that were devised to assemble and represent knowledge, as well as the relationships among knowledge elements, to describe how humans apparently used this information (Davis et al., 1977; Biachoff et al., 1983; Masarie et al., 1985; Warner et al., 1988; Jones, 1986). The work by Quillian heralded one of the new approaches and introduced semantic networks (Quillian, 1966). These and other efforts, particularly by Minsky and Pappert, defined and described cognitive models which seemed to reflect those processes apparently used in organizing and applying knowledge (Newell & Simon, 1972; Minsky, 1966).

During this time, many other advances were initiated that were later to affect numerous applications in medical and industrial settings alike. (Feigenbaum & McCorduck, 1983). Much of the focus of this work resided not only at Carnegie-Mellon University but also at several other universities such as the Massachusetts Institute of Technology, Stanford University, and Rutgers. Researchers introduced new list processing languages and new uses for formal methods such as automatic theorem proving, and they rediscovered earlier cognitive psychology research and theories (Bobrow, 1994). These were exhilarating times, and the research drew as much from the area of cognitive psychology as it did from computer science and the representation of data elements.

As the research at these institutions unfolded, investigators gravitated toward questions involving data structure development with a very strong engineering and systems science focus, compared to the cognitive psychology orientation more prevalent at the onset. Many years later, essentially a schism between the two cultures would erupt, and the spin-off area of cognitive science would move to capture more of what the original areas of artificial intelligence were about (Pollack, 1995; Holyoak & Thagard, 1995).

The research developments in the early 1970s initiated a number of very large-scale applications projects that were to continue for many years. Remarkably, some of the longest continuing developments had their origins during this time frame. Three of the most prominent projects originating during this period, which continue to be active and consistent with the original goals and still involve at least some of the original researchers, include the INTERNIST, the HELP system, and the PACE project (although all three have undergone some name changes) (Miller et al., 1982; Kupermann et al. 1991; Evans, 1981). The first project (INTERNIST) was an effort in medical diagnosis that originated at the University of Pittsburgh and is active there today with some of the original participants (Miller, 1986; Miller, 1994). The HELP system, developed at the University of Utah in conjunction with Latter-Day Saints Hospital, remains very active (Kupermann et al., 1991). The third project, originally called COMMES (Creighton On-Line Multiple Modular Expert System), is an effort that ultimately unfolded into what is now called the PACE system (Evans, 1993).

The concepts and ideas germinal to the PACE system were created, applied, and tested during 1971 to 1974 in the specific areas of knowledge capture and knowledge reorganization in the industrial administration context. As originally spearheaded by Herbert Simon and then-dean Richard Cyert at Carnegie-Mellon University's business school, the position was advanced that there is great value in capturing knowledge of experts in the fields of business and management science and making this knowledge efficiently and effectively available to busy high-level executives, who could access the kinds of information they required (Evans, 1976; Evans, 1974a). Although Carnegie-Mellon was the home of cofounders of artificial intelligence, this application was originally envisioned as an application of formal management science methods and optimization techniques with traditional data processing methods applied to the structured business school curriculum, somewhat akin to an inventory control approach. Preserving the underlying goals of the project, this author underscored the limitations of the original approach and conceived and then redefined the design and implementation strategy as an overall artificial intelligence application project (Evans, 1971). This first management science application effort reflected many core principles that were later applied or adapted and extended to the PACE system.

The Health Sciences Application Domain

The next major step in the evolution of the PACE enterprise occurred when the entire application of the ideas of knowledge capture, knowledge storage, and knowledge retrieval (in an expert systems sense) was undertaken at Creighton University, in the health sciences schools (Evans, 1975). Following the first effort at Carnegie-Mellon University, a multi–million dollar project was begun by the author within the health sciences schools of medicine, nursing, pharmacy, dentistry, and allied health at Creighton University, funded by a grant of approximately one million dollars from the W.K. Kellogg Foundation of Battle Creek, Michigan (Evans, 1977). This funding sponsored a health sciences application drawing on many of the methods and approaches the author had formulated at Carnegie-Mellon University.

Some Presumptions Underlying Initial Goals

The primary goals were the capture and effective organization or reorganization of all health sciences knowledge of all five health sciences schools. In concert, it was planned to redistribute to off-site locations updated knowledge that would be appropriate and useful to health care professionals in their pursuit of patient care. These two very broad goals implied the need for a vast amount of directed effort and extensive resources in combination with a great deal of cooperation and dedication. It was anticipated that knowledge aggregation and unification would include all the clinical and basic sciences across all the health sciences and that this material could be marshaled because Creighton University is a strongly teaching-oriented institution. It was anticipated that the faculty's expert knowledge could be captured, continually maintained, and disseminated nationally and even internationally on an efficient and effective basis.

Another basic assumption made at Creighton was that an effort of this scope would represent a significant change in the future operation of the health science schools: in essence, all their information would be effectively organized and electronically interrelated (Tate, 1975). Recognizing the pressures and forces unleashed from such a change, the project from the very onset identified this undertaking as a fundamental reorganization in the conduct of everyday curricular business. Hence change theory was applied at every step of the enterprise to attempt to properly handle the forces unleashed. It was assumed that not only would change unfold, but that the changes themselves, once recognized, would represent difficulties and pressures that would have to be accommodated to enable the project to go forward (Thurkettle & Sones, 1978; New & Couillard, 1981; Barry & Gibbons, 1990).

It was also assumed that the project would span all the health science programs and would affect most of the health science practitioners associated with each program. Thus there would be correlations, associations, and interplay that heretofore had proceeded with only a modest degree of success. Although a great deal of commentary had often been elicited about the value of interdisciplinary efforts in health sciences and about the appropriateness of an interdisciplinary team, it was assumed that this particular interdisciplinary activity would represent yet new forces of change and some difficulties.

It was also assumed that if such clinical information were to be collected, it would have to undergo continuous change (upgrading and updating), and thus would represent a whole new effort of information organization on the part of faculty and other researchers (Giuse et al., 1993; Giuse et al., 1993; Giuse et al., 1989; Giuse et al., 1988; Giuse et al., 1990). As a result, this vast project not only was reviewed by the deans of the health science schools whose explicit approval was both requested and obtained, but in fact the entire effort was presented to the board of directors of Creighton University, as well as to the other vice presidents of the university. It was recognized that a university-wide undertaking would unfold, even within the apparently limited health sciences focus that was articulated and proposed. Thus the project ultimately would need to have university-wide acceptance. Over several months, all these review boards provided their approval. Many years later, the wisdom of this approval mechanism was validated when counterforces came into play, attacking the legitimacy of the effort. One could point to the initial legitimization of the project across the main domains on which it had an impact; this approval process was a genuine mitigating factor for many subsequent newcomers who questioned the obligations they inherited.

Learning from Other Projects

Although this health sciences application started at Creighton University in 1975 four years after theory construction at Carnegie-Mellon, the W.K. Kellogg Foundation funding mentioned above started in 1977. At that time, the state of the art of computer technology at Creighton was woefully behind the requirements of this project. More broadly, even medical informatics in general was in a far more formative stage than the current environment reflects (Davis et al., 1977; Duda & Shortliffe, 1983; Shortliffe, 1982). There had been relatively few such enterprises undertaken on a similarly targeted size and scale. Project leaders had been aware of selected large-scale, university-based efforts elsewhere (Weed, 1969; Weed, 1970). However, learning from these efforts and applying the lessons to this project were formidable challenges.

One such enterprise was a University of Washington project, only a few years before, in which a massive organization of all clinical information had been attempted. The goals included the achievement of a uniform, efficient, and nonredundant presentation of health sciences information to obtain curricula efficiencies and even reduce the total curricula length. The efforts had ended in disarray, however, with disillusionment for the entire enterprise.

The experience in Washington was studied very carefully by the researchers at Creighton University, since a great deal might be learned from what went wrong. Curiously, not many footprints or even remaining tracks could be discerned to suggest the difficulties encountered. Clearly, however vast changes had been undertaken and initiated, creating enormous pressures that ultimately led to the abandonment of the effort.

Within this overall time frame, several additional large-scale projects were under way, facing challenges and hurdles often quite similar if not identical to PACE challenges. The massive work by Dr. Lawrence Weed on the PROMISE project and the accomplishments of Dr. Edward Shortliffe and his colleagues on the MYCIN project were representative of such efforts (Weed, 1982; Buchanan & Shortliffe, 1984). Not surprising, project results and conceptual advances are more easily published (and even more gratifying to publish) than accounts of barriers, pitfalls, or failures. The PROMISE effort faced among other challenges the need for substantial capital for enormous lengths of time, in concert with a need for deep changes in the underlying pattern of clinical care behavior by physicians (Weed, 1969). MYCIN and its analogs (e.g., ONCOCIN) faced a similar need to remain relevant, supported within a university environment, updated, and so on (Biachoff et al., 1983; Shortliffe et al., 1981). However, information about the disparate strengths and weaknesses and lessons learned from these projects was not available to this project's leadership in a timely fashion. Thus PACE did not benefit substantially from analogous medical informatics project initiatives operative in the same years. Such lack of communication did not go unnoticed by other medical informatics leaders, and there were repeated calls for improvements. Even now, widely disseminated in-depth project discussions have been very infrequently undertaken, although the HELP system is a notable exception. This volume is an effort to address such a need for future projects.

Original Goals and Expectations

Creating a Knowledge Industry

It may be clear from the discussion so far why our million-dollar grant proposal to the W.K. Kellogg Foundation was initially entitled "Institutionalizing Change" (Evans, 1975). This title, nearly an oxymoron, attempted in effect to change the university system itself into an orchestrated knowledge industry that would capture and systematically maintain the vast up-to-date knowledge that the professionals actually held. The project would then relay that knowledge "from the few to the many." These key ideas were at the very heart of the original project. The goal was to capture, maintain, and ultimately disseminate up-to-date patient care information, specifically the faculty's clinical wisdom, which previously had been provided only by lecture, internship, or through personal interactions in the context of ongoing patient care. This codification process represented a fundamental alteration in the organization of the knowledge at the university and in the health care center as a whole. The plan for information dissemination was initiated at the very beginning and guided much of the design (Evans, 1977).

Forces of Change

The results of the projected information dissemination would produce feedback to the information providers about the appropriateness, the accuracy, and the timeliness of the information, as well as its relevance to patient care. This feedback closed the loop between the provider and the consumer of clinical information, representing a significantly new element in the total instructional equation. The feedback loop could then provide a force for change, which was envisioned to be both beneficial and advantageous overall to the institution (Thurkettle & Jones, 1978; New & Couillard, 1981; Barry & Gibbons, 1990). It was always recognized that such a feedback loop would also be contentious and a great source of stress, since it was in effect both a verification and a validation component in the development of patient care information.

The Entire Health Care Team

It was originally expected that the entire model would be used by all the university's educators of physicians, nurses, pharmacists, dentists, and the allied health professionals. Thus planners envisioned from the outset a cross-correlated integrated universe of knowledge, formally designated the Total-System Design of Instruction. Although the global goal which the system was organized to accommodate was restricted in later project phases, as we discuss later, the appropriateness of the concept of the health care team was apparent at the earliest project phases. Thus the design for this concept was fortunately in place all along.

As the project unfolded, an entire knowledge base definition was completed across every domain of health care identified above. In each health sciences school, hundreds of pages detailing definitions for each program were drafted, describing in elaborate detail every learning objective of every component of every program, including the clinical experiences. The School of Dentistry achieved the high baroque form of the definition with six volumes covering several thousand pages, sometimes dividing lecture or clinical learning objectives into minute-by-minute accomplishments in completely formal, behaviorally measurable learning objectives (as defined by the project leadership team). For some schools (such as the School of Medicine), this was the first articulation of the explicit and detailed content that had ever been formulated by many of the clinicians in the school. Some expositions of clinical goals created explications of clinical assessment and differential diagnosis that the practitioners indicated had not existed to their knowledge anywhere else in the published literature. For example, the renown Creighton clinician Dr. James Sullivan began with the comment that he articulated only one goal during his decades of clinical rotation supervision in gastroenterology. A man of very few words, his goal was "Seek excellence." At the end of the definition phase, Dr. Sullivan had provided 40 pages of detailed objectives that amounted to a treatise of his 30 years of clinical wisdom, formulated as an organized body of correlated learning objectives.

Focusing on Nursing

The size and scope of the effort needed to continue the full development across all these areas (including knowledge updates, revision, and complete electronic entry into the computer systems) far exceeded the financial resources obtained (from the W.K. Kellogg Foundation), already consuming several millions of dollars (in direct and indirect dollar allocations). With several hundred faculty participating, the original full extent of the focus far exceeded the project management team's capacity to handle the logistical requirements in all the domains, given the limits on financial resources, and available office space and personnel. Project review led to the decision to take a specific, single focus, namely, a flagship to demonstrate the legitimacy of the complete effort and, hopefully, to later provide the impetus to permit all the other health sciences programs to proceed in a similar fashion. After much review and discussion by project leadership, the author decided that nursing would be the flagship (Ryan, 1983). Several of the reasons for this decision are discussed below.

Beginning Pressures

The School of Nursing represented one of the most positive and optimistic subgroups among the health care team that undertook the developmental efforts. However, as alpha site users and other evaluators worked with the nursing knowledge base and the computer-based delivery system, the project's requirements expanded to meet identified needs for even more detailed information and more flexible searching capabilities. As a consequence, nursing faculty orchestrated and organized their knowledge to a more definitive level and then codified it with more specificity for future searching purposes, to ensure that it could be entered into the knowledge base as needed. Additional codification was needed not only for the content in the knowledge base but also for the computer-based semantic network of descriptors. Given the pressing demands in an academic setting that incorporates a strong and extensive clinical component, we underestimated the time needed for the project, and thus many faculty shouldered an overload of project requirements on top of an already demanding environment. Hence, this effort became an ever-increasing challenge for the faculty as a whole.

Project Challenges in Nursing

The project continued its active development under the strong leadership of the former dean of nursing, Sheila A. Ryan, who spearheaded the project efforts both before her sabbatical departure and again later after her return (Ryan, 1983). Several individual faculty members also became champions, and with their enthusiasm, permitted the project to continue. At the same time, the faculty as a whole worked even harder to main enthusiasm, which certainly was a challenge in light of the relative absence of formalized corresponding reward structure or professional peer reinforcement. As will be noted below, this discontinuity between tasks and rewards was not adequately addressed by the project management in the planning stages.

Hence over time, slowly the idea of "flagship" gave way to the view of "hardship" that only nursing among the health sciences schools had to bear. As new faculty joined the school, more and more members of the instructional staff preferred to support their historical roles and activities in lieu of any unrewarded change, much as change theory and organizational development theory predict.

Limited Reward System

The response by faculty was not surprising in light of change theory and the university's reward system, which provided no particular incentive to participate in such a project. Although the project recognized that the feedback loop of reward *within* the university (e.g., the actions of the Rank and Tenure Promotion Committee) needed to be modified to reinforce the role-changes constructed, only modest success was achieved. At the same time, in all schools and universities nationwide there was an ever-greater emphasis on publications and grants. Federal cutbacks in funding support had escalated, and all schools were conveying heightened needs to faculty to accelerate their pursuit of grant funds, in conjunction with publications (which can significantly help support grant proposals). Thus, given the added stress and the perception of change that increased anxiety, a much greater shift in the reward system of the university would have helped to positively affect faculty attitudes and subsequent project performance.

Confronted with these pressures, the project was able to continue within the School of Nursing, even in the face of the diminishing impact of the dean's efforts. In conjunction with the dean's ongoing leadership "pull," there was the "push" from a small dedicated contingent of key faculty members on whose shoulders more and more work fell to pursue the entire effort.

Although PACE represents a monumental credit and noteworthy achievement of the faculty as a whole, in the final years much of the actual initiative was borne by a very small group of faculty members who saw the vision and continued to drive the effort forward, sometimes to their own career detriment (Cuddigan et al., 1988; Cuddigan et al., 1987). From a broad of point of view, this result is not unusual, and many research efforts have followed such a pathway of evolution.

Continued Progress

In spite of all difficulties and pressures, the project continued to create and maintain an active knowledge base that would slowly grow to subsume large portions of the known clinical and structured knowledge of the domain of nursing care. The systems part of the project evolved to provide this knowledge in an effective delivery system that could be utilized in hospitals nationally and even internationally. A number of national sites were excellent role models both before and after the commercialization of the service, and a limited number of international possibilities arose. One major hospital in Canada experimented with the system for a number of years, and the presentation and response to the system in India was extremely favorable, although lack of funding prevented implementation there.

The knowledge base update process enabled the knowledge to be maintained by the School of Nursing, which then could begin receiving financial gain from the sale of the system (at the price of its ongoing maintenance). Fulfilling original goals, the project would permit the School of Nursing to role-model the dissemination of its expert knowledge "from the few to the many" and lead the other health care educational programs forward as a flagship. Project expectations included the presumption that such an enterprise could continue within an academic setting, albeit fundamentally a commercial enterprise, which would provide clinical care information to hospitals and other health care centers. We envisioned the existence of such an enterprise within an academic/teaching hospital setting in a compatible fashion. It was hoped that significant financial reimbursement through the distribution of the system would provide the needed reinforcement that would keep the faculty's interest and the school's goals tied to the enterprise.

An Academic Management Information System

Not only did the project's original computer-based system represent a clinical application, but built into this framework was a curricula management system for academia itself (Evans, 1984). For example, all the information in the computer system was cross-indexed to every course which taught that piece of information, indicating when and where it was taught, the kinds of mastery expected on the part of the course, and other instructional requirements. Textbook materials and other learning resources and references were indexed to each module of knowledge, giving an auxiliary learning resource for each objective or information unit. Individual faculty were correlated to every piece of knowledge also. One could search the information database using learning resource types as part of the search inquiry. One could search all the learning resources by name or date (or any combination), or one could find all information taught in each specific course, or all the material for which each faculty member was responsible.

During one academic accreditation visit to the School of Nursing, the system listed all learning objectives for all courses as a simple, single computer inquiry. With the cross-indexing that had been completed, all the behavioral objectives for every knowledge domain could be shown to be correlated to one or more of the faculty to whom the respective modules were assigned. This academic management system for all the stored information represented a phenomenal information resource and existed within the PACE system. The School of Nursing found this cross-indexing very useful for the accreditation review process, which was conducted once every six years. On the other hand, academic management typically did not require the systematical evaluation of activities in the arena of instruction when the accreditation process was dormant. Thus this tool was not a feature that would regularly contribute to the school's needs.

The Audiovisual Management Feature

In conjunction with the organization of knowledge of the educational programs, extensive efforts were made to similarly codify the vast holdings in the university's health sciences library, particularly in the field of audiovisual (A/V) media. Media were viewed, primarily videotapes, and encoded by experts itemizing the detailed content of the A/Vs (Evans, 1981). Every 2- to 5-minute conceptional element of the A/V unit was described with regard to its instructional goal, the degree of mastery that could be expected, the time needed to accomplish and master that particular unit, and so on. This information was also extensively cross-indexed so that the parts of the individual media components in the health sciences media library that might be utilized by students in support of their educational effort could be easily ascertained. Using the PACE inquiry capacity, managerial capability for A/V evaluation and assessment was automatically incorporated into the delivery system.

Interdisciplinary Indices

The design, as noted, anticipated and envisioned a team approach to patient care. This particular theme was articulated by the vice president for health sciences as well as by the School of Nursing well before the project began. Consistent with this perspective, the design of the PACE system included the capacity to cross-index any knowledge unit with all the health professions that might wish to address that module of knowledge. This discipline-oriented indexing produced new capabilities of analyzing and comparing curricula as well as heretofore impossible instructional approaches across disciplines.

One of the many analyses undertaken by the author focused on a comparison of the indexing terms used among different health professionals. For example, given a particular health care issue, such as adult-onset diabetes, one could look at the frequency different health professionals selected indexing terms that referenced various preventive care issues appropriate to that domain. One study compared the number of times preventive care issues were referenced by physician experts as they coded and described medical knowledge in that area compared to the nurses working in the same particular area. This author found identification and correlation of preventive care issues on the part of nursing instructional experts to be 20 times more frequent than was the case by their physician counterparts. Other knowledge areas, however, showed close correlation, such as the similar identification of specific complications for typical medical problems. A great deal of interesting cognitive research can be achieved in this way, by comparing the tens of thousands of indexing terms employed among different health professionals. Unfortunately this research and the availability of this reservoir of information in the very early 1980s was not easily disseminated to other nursing researchers in the field, integrated as it was within a huge system on the Creighton mainframe computer system and therefore not easily ported. It was also difficult to compare and contrast our results from this unique source with those of anyone else. Thus, this particular capacity has yet to achieve its potential, and the extensive results are still ripe for future assessment, evaluation, and possible dissemination.

Pitfalls and Lessons Learned

A number of pitfalls that arose during project development are more easily seen by hindsight. One pitfall was the failure to connect project contributions in a significant and substantial way with the reward system the (nursing) faculty enjoyed within the university. When faculty efforts are not seen as explicitly addressing their own interests and their professional contributions over a 10-year project period, and when project labor is not tied to compensation, it is not hard to predict that nursing faculty interest will wane over time. In addition, leadership within the health sciences continued to evolve and change, as would normally be expected. Both these issues will be explored further.

Continuity of Administrative Support

The project took quite a number of years longer to begin to bear fruit than had originally been contemplated (Evans 1979; Evans, 1993). As a result, PACE development extended beyond a number of important tenures of office, including those of the vice president who had helped support the project initiation and of key senior administrators in the health sciences. As a result, administrative support changed over time (sometimes several times). The ability for the university to remain focused on such an extensive and far-reaching effort slowly diminished as the years passed. Tangible rewards and benefits to the university were simply not adequate to overcome the length of time (almost two decades) needed to achieve such potential gains.

In addition, as leadership in the School of Nursing evolved from one dean to another, understanding of the project waned. Faculty changed, and new members were unaware of the enterprise and its goals. As new faculty filled the roster, their aggregate interest in maintaining such an effort markedly declined. Ultimately as "new faces" among faculty came to outnumber original participants, the question arose as to when and where the faculty had "bought into this." Thus the problem of maintaining continuity over many years grew larger and larger.

Commercial Activity in a University Setting

The creation of a commercial enterprise within the health care setting itself represented a new stress factor. There was the need to write contracts with external users of the system. There had to be marketing and sales to disseminate the product, including the development of marketing materials and descriptions that used the university name and logo. Finally, there was the need to address customer needs and customer satisfaction in a virtually immediate and responsive way. All these requirements were appreciated by the school, but the activities and behaviors necessary to implement them were not among those typical in an academic setting.

During all the project years at the Creighton School of Nursing, the primary academic setting operated to an important measure on a nine-month year. Although there were ongoing programming efforts during the summer months, the academic programming simply did not lend itself to a twelve-month enterprise, as required by the commercial enterprise. Thus, there was ultimately a fatal flaw in attempting to maintain a year-round, ongoing business enterprise within our particular academic setting. This was remedied after the end of the project's university period, as the project spun off from the university and became a completely independent commercial enterprise.

Originally, project directors had unequivocally envisioned a commercial enterprise within the university. In retrospect, it is perhaps important that this miscalculation was part of the design because without the presumption of a university-based commercial success (and at least financial rewards), the project might not have gone forward. The subsequent requirement to spin off from the university setting and achieve in a commercial environment new levels of investment, marketing, and sales ultimately provided the basis for the successes that have unfolded. In short, the project may have needed this internal miscalculation to survive and then a correction to the incorrect assumption (a commercial spin-off) to achieve its successes.

Personal Identification

Another seemingly contradictory pitfall involved the strong positive identification on the part of the faculty with the PACE product, in spite of the stress and the conflict that often surrounded it. The faculty identified their contributions to the knowledge base as a unique Creighton-related enterprise. There was an ongoing interest by faculty in providing the expertise for the knowledge base because PACE was viewed as a homegrown product. Time and again we found that many faculty strongly identified with their Section of the total knowledge base and did not eagerly support the notion that outside nursing experts might undertake the updating duties for them. Thus, the positive desire to expand and extend the basis of the knowledge expertise by and through Creighton faculty nonetheless was confounded by the burden represented by actually undertaking such efforts. This personal identification issue became a regular management challenge, which was resolved only when the entire project successfully spun off from the university setting. After the spin-off, experts were hired nationally and even internationally to support the knowledge base, and at the same time helped overcome the appearance of a single-faculty perspective that must inevitably be considered when faculty from only one school of nursing is involved.

Proof of Success

Another pitfall was related to the difficulties the "flagship" (i.e., the School of Nursing) had in demonstrating the viability of the PACE enterprise. Specifically, the other schools were watching the School of Nursing address the challenge of maintaining and advancing the knowledge base, and they were reluctant to participate and advance their own initiative until clear successes from such efforts were identified. Since the typical reward systems (publications, grants, etc.) did not substantially reinforce project activities, the other schools developed an interest in possible receipt of significant revenue from the licensing of the system in health care settings. Since the project within academia could not achieve the kind of marketing, sales, and distribution efforts that would be necessary to secure significant revenue, the project itself had a built-in, self-defeating design. A great many start-up dollars would have been needed to market and sell the product to generate revenue. On the other hand, this is not the kind of expense the School of Nursing or the university would normally undertake. Hence, once again another potential reward component did not materialize in a timely manner. Thus, the other potential school participants awaited successes before they would invest further. In a somewhat chicken-and-egg scenario, the total development could not proceed until a substantial development such as nursing had successfully gone forward. In the end, this challenge could be remedied only by a spin-off to an outside commercial enterprise.

Working with More Limited Goals

In hindsight, considering the entire project and the approaches that were taken, one might make the presumption that if

(a) a far more focused effort had been undertaken,
(b) in only a very specific knowledge area,
(c) with full resources bought to bear in one area, and
(d) successes were achieved,

this approach would have ensured a building-block strategy of success, and onto these building blocks, further successes could be built. However, it is not likely that this approach would have worked, for reasons outlined below.

First, a critical mass of clinical information was needed to interest outside commercial (e.g., hospital) users. In commercial settings, a successful product would have to provide wide clinical coverage to give care providers sufficient reason to use the system across the board. Thus, a very large effort in both depth and breadth of knowledge base development was called for. On the other hand, our experience was that no one school was willing to make such a far-reaching commitment. Each institution considered making a commitment in the context of some other school's proven success. At the onset, friendly project competition among the schools was an important catalyst driving each school, to a certain degree, to complete its initiative of fully defining a comprehensive knowledge base domain. However, this positive, reinforcing rivalry was insufficient to keep all the programs going to completion.

Project Cycle Length

It is helpful to understand the implication of a project's life cycle in most organizational settings. The PACE effort achieved success only after many years of development, verification, validation, and ultimately wide dissemination. This process requires a great deal of commitment and leadership that is ongoing and unbroken for a great length of time. It would be extraordinary, however, to find that much leadership and continuity for the required period of time in any organizational setting. In this particular project, only one individual, the author, maintained continuity throughout the entire enterprise. Such continuity—even if there is but a single person—is necessary simply to keep the project alive, to ensure the replenishment of resources and personnel, to spark the renewal of interest, and to spearhead the rearticulation of goals to new people, new faculty, and new leadership. Such projects require a great length of time, and it is clear that if all the principal leaders happen to leave, transfer, or even worse, die, the project is not likely to succeed. One is caught between the need for long-term developmental continuity and the likely contingencies and vicissitudes of life that work against such longer term project cycles. If at all possible, efforts should be made to expand regularly the core leadership in an effort to gain added continuity.

The problem of a protracted project life cycle has been identified in industrial settings and research organizations. Often it is a criticism of American businesses that their focus on quarter-to-quarter profits precludes this kind of long-term development. American businesses are sometimes contrasted with Japanese efforts in particular, as well as those of other industrial societies, that are prepared to make much longer investments over a much greater length of time before success is anticipated. The emphasis of other cultures (e.g., Japan) on a team approach and team management more likely ensures continuity, which is necessary to keep a project alive.

The foregoing criticisms should be contrasted, however, with a balanced analysis of American long-range planning. We need only identify the Bell Labs of AT&T or the defense department's funding agency, ARPA (Advanced Research Projects Agency), as two examples of funding sources with very long-range goals. This country's efforts to put a man on the moon and to cure cancer represent vast and sustained expenditures of time and money. Even within medical informatics, the elusive unified, national electronic medical record is pursued with the vigor one might have thought reserved for the holy grail. One lesson to draw is that to traverse successfully a lengthy project life cycle, there must be either determined tenacity of leadership, excitement of the goal accomplished, reward recognition if the goal is achieved, or some other powerful driving force.

As another factor in this discussion, the individualism and variations in personal style that are typical of American research culture operate against such long-term project efforts. Fortunately this particular project *did* achieve and maintain a consensus among numerous faculty regarding a conceptual paradigm for the knowledge, without which the project would have failed. Thus, a consensus was built in this particular project, albeit this remarkable success was not widely recognized as such in the completion of this effort. Indeed it is a credit to all participants that this project was able to succeed as it has. The issue of differing styles suggests that when we attempt to recruit new blood into a long-term project, compatibility of perspective and approach is an important attribute to help ensure project continuity.

Roles and Recognition

We end this chapter by identifying some of the major contributors without whose help this project would have failed. Most readers will not recognize the personalities named; rather, the value of this Section is its focus on the *role* of each individual identified. These responsibilities as we shall briefly note them convey what organizational support was most instrumental in the success of the project.

Top-Level Administration

With this Section's goal in mind, perhaps it comes as no surprise that first and foremost the leadership of the vice president for health sciences, Robert P. Heaney, provided the most crucial, instrumental role, without which the project would have been completely impossible. Although the project transcended the length of his vice presidential tenure at Creighton University's Health Sciences Center, it was Dr. Heaney's dynamic leadership and commitment that permitted this project to both begin and proceed in a positive fashion. Later the project enjoyed the support of other top-level administrators who became convinced over time of its values. A key example of new-found support was provided by the associate vice president for health sciences, Raymond Shaddy. Dr. Shaddy brought a second rung of high-level support at the most crucial times.

Computer Operations

Second and also most instrumental was the support of the director of the Computer Center, James T. Ault III, without whose help the technical side would never have unfolded, as was minimally required to achieve success. With the transitions and the change of interests on the part of the university, Ault's ongoing commitment and support helped rally the systems support personnel, particularly technical services director Chuck Ruch and senior systems analyst Deborah Kirwan, so that we could maintain programming operations over 20 years. In fact, his deep personal commitment even ensured Computer Center support when the university itself did not wish to officially provide such support any longer. This project would not likely have succeeded without his personal dedication to the project goals. Years later, as crucial needs arose that required the extensive expertise of Ruch and Kirwan, the wisdom of Ault's extension of commitment to the next administrative level down became apparent. Only through a renewed commitment by this then-second level (which in the latter years of the project had become the system's top level) did the systems side of the project continue its survival until the corporate handoff was complete.

Project Office

The ongoing support of key people on the research and development staff of the office that directed this project represented monumental personal commitments, which were also required to permit the project to go forward. Such commitment was displayed by our knowledge base managers, such as Carolyn Deters, Ruth Graham, Stephanie Scinta, and Kay Wise, whose work demonstrated extraordinary insight, dedication, and unrelenting attention to detail, as well as by all the secretaries, such as Pam Karbowksi and Pam Pickenpaugh, whose tenacious commitment was remarkable. All contributed to the continuity of efforts needed to produce success. Equally strong was the programming staff within the project office, who worked tirelessly, ignoring the lure of higher paying positions to pursue the project goals. Timothy Hillis worked quite literally to his dying day to ensure the success of this effort.

Nursing

Without key nursing support, the flagship would never have sailed from port. Individuals who shouldered a major portion of the work included the dean, Dr. Sheila A. Ryan, in conjunction with one foremost nursing faculty supporter and developer of the system for all of nursing, Professor Dorothy Vossen, who single-handedly rallied other nursing faculty over and over again. A second missionary in nursing, Janet Cuddigan, combined her efforts with those of other major nursing supporters to do the work necessary to have a whole product. Without these few key people, success would not have been possible.

The Nursing Research Milieu

Research and development do not operate in a vacuum. The interactions with other colleagues, even on the infrequent basis of yearly meetings at national conferences (particularly the former Symposiums on Computer Applications in Medical Care; now called the American Medical Informatics Association Symposiums) provide intellectual stimulation and new insights. In addition, the encouragement and enthusiasm from colleagues reinvigorates investigators in their determination to address that ever-present next challenge. This project benefited from a number of nursing professionals who served this informal advisory and supportive role. We are particularly indebted to Marion Ball, Virginia Saba, Sue Grobe, Patricia Brennen, Diane Skiba, Gary Hales, Rita Zielstorff, Judith Ozbolt, Kathryn Hannah, Roy Simpson, Judith Graves, Kathleen McCormick, Helen Hoesing, Sue Logan, Fotine O'Connor, Jack Yensen, and Carol Romano.

Similarly, landmarks in nursing informatics contributions have helped both to improve the understanding of nursing informatics and to accelerate its acceptance in mainstream nursing (Ball & Hannah, 1984; Ball et al., 1994; Hannah et al., 1994; Saba & McCormick, 1986).

Commercial Spin-Off

The spin-off to the commercial sector needed a strong and tenacious commitment to an investment whose payoff would be postponed for many years. Officers of the commercial firm disseminating PACE—the (past) president, Michael Vasquez, the vice president, Simon Casidy, and particularly the firms chief financial adviser, John Pappajohn—provided just such a long-term involvement. Underscoring the recognition of the need to build professional leadership continuity within the commercial sector as well, a new level of long-term leadership commitment has begun within the firm, beginning with the new president, Mark Emkjer.

The Importance of a Few True Believers

As one can see, a relatively small number of individuals have been most crucial to the success of PACE during this initial 20-year period. Even among the individuals listed, several represent the substitution of one person for another upon someone's departure. At the beginning, the core research group entailed three primary individuals plus two to three administrative support people. Even at the largest, latter project stages, there were approximately five primary people and an equal number of support people. This size has been typical of other projects of similar scope as well.

As this Section indicates, one of the most important lessons learned was the critical need to discover and later expand a small core of "true believers" to address project challenges as well as to accommodate the difficulties and changes in personnel that accrue over a long project life cycle. The project outlived almost every major player present at the project's onset, as a result of untimely death, retirement, and departure, or the shift of focus of the project itself and its basis of operation (i.e., from university to a commercial enterprise).

Loss or change of such crucial personnel inevitably contributed to slow deterioration in the basis of the core support for the project as a whole. It was fortunate that there were successful transitions among members of this small, core team, so that another ture believer could pick up where someone else left off. In the end, the most significant project resource consisted of totally committed people who would strongly articulate the need for the vision and the gains the project goals provided. This experience demonstrates that the more such very strong commitment is obtained by project leadership, even among just a few key people, the more likely is a large-scale project's successful outcome.

The Financial Impetus

Interestingly, we also discovered after many years that although substantial funding was in fact obtained, it was not the money itself that entered significantly into the equation. In present-value dollars, the grant money represented many millions of dollars. Such a sum had of course the potential for significant impact on the budgetary considerations of the various schools, and indeed did have such an effect. Nonetheless, as we later recognized, money per se was one of the more insignificant variables in our capacity to achieve the project. The *receipt* of the money, the *prestige* of the award, and the concomitant *commitment* to undertake the project (because the funding was accepted) were in fact the more significant factors. Thus, although we could not have accomplished the project without the grants, the grants seen as *catalysts* were far more significant than the actual money received through the grants themselves.

Although recognizing the importance of the funding, one would still conclude that the more significant project factor was the continuity of leadership. As administrative leadership thinned and finally nearly disappeared, it always required a contingent of at least two or three to continue the project. Over the total of fourteen years at Creighton, and six commercial years of development, project leadership began with two individuals (Evans and Heaney) and at times held on to a bare existence with just the author. Ideally, the initial leadership basis as well as sources of funding would be expanded for future enterprises of this magnitude.

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Chapter 2

PACE—Then and Now*

The extensive transformation of the PACE delivery system is a pertinent issue in the developmental history of this particular product. Over its 20-year history, the various evolutionary stages were fairly well anticipated as part of the natural growth path of the services and product. As a consequence, a reasonably smooth evolution has unfolded from the origins of the first system to the current status of the product.

Underlying Development Principles

Part of the continuity in the natural growth of PACE occurred as a result of the original expectations that were explicitly perceived when the project was first conceived (Evans, 1975; Evans, 1977). The fundamental observation (in our research published before the present PACE initiative was begun) underscored a fundamental recognition: the health professional faces a glut of changing information (Evans, 1976). The challenge is to make intelligent selections from this universe of information and to organize them for particular patient care purposes (Evans, 1974a; Evans, 1974b). Even in recent marketing literature, the same core observation is reprinted and underscored as the driving force. This underlining principle has remained throughout the product history, although the generational differences nonetheless are worth distinguishing. Using Figure 2.1 as a road map, we will review key aspects about the generational differences below.

First Generation: The Educational Advisor

As originally envisioned, the first generation (1977–1979) of the project was to be a focused educational advisor (Evans, 1979). This product was planned as a combination of the structure and definition of the entire health care domain (medicine, nursing, dentistry, pharmacy, plus allied health

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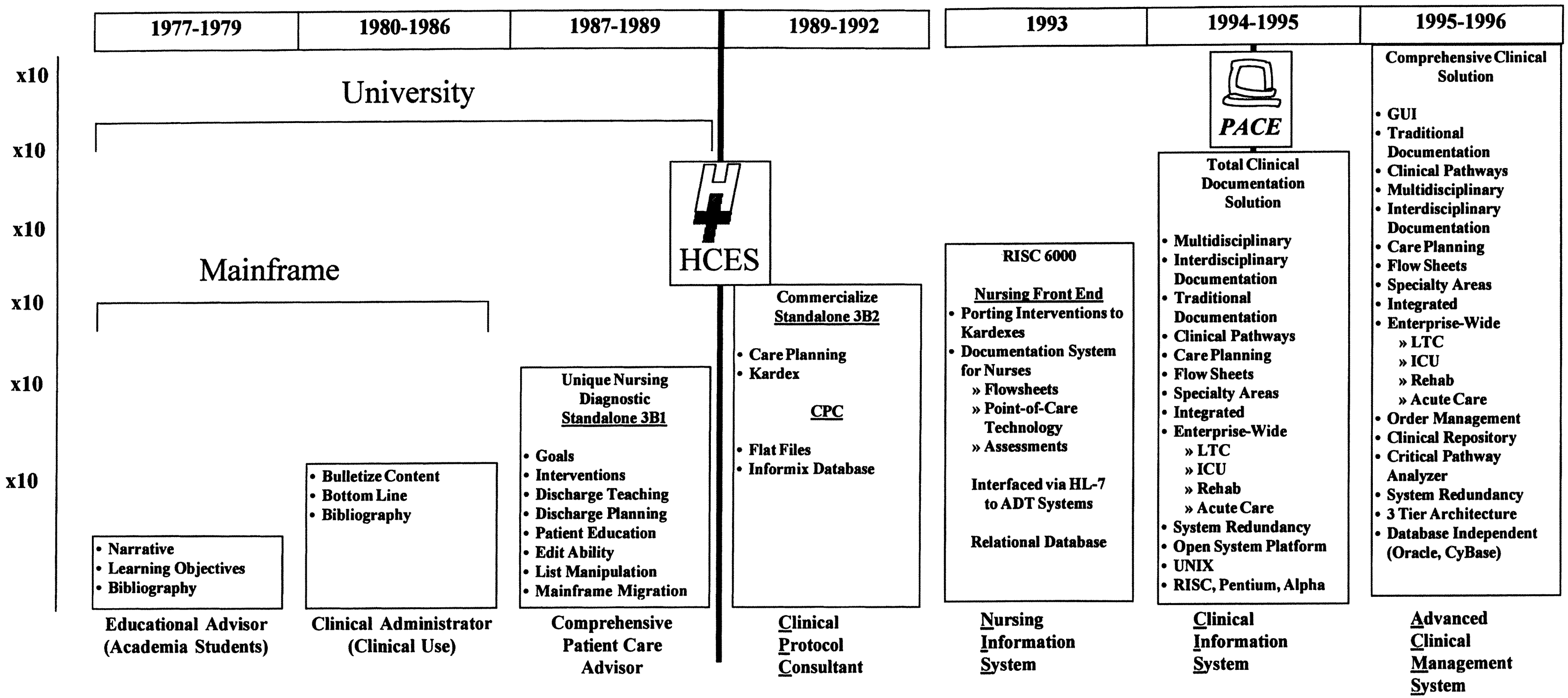


FIGURE 2.1. The generational differences in the development of the PACE delivery system.

areas such as medical technology, nurse anesthetist, and respiratory therapy) within the knowledge base. Correlated to each program was all the basic sciences information (e.g., biochemistry, anatomy, physiology, microbiology, pathology) on which each and every knowledge module was dependent. Finally, for every single module of information, there were associated bibliographic materials and other learning resources (slides, videos, etc.) that supported or provided the module of knowledge involved. This first stage of program definition was actually completed, yielding a printout of information at one point over 15 feet tall.

The primary content of the first-generation system structured the knowledge needs about a health care issue for the health care provider so that, if these needs were fulfilled, the patient would in fact be assured of proper care. Thus, for an inquiry about a given patient problem, specific educational goals were enumerated that explained precisely the kind of informational status the health care provider should have achieved to ensure proper care subsequently. For example, for a target goal of "rehabilitation for the patient with emphysema," the nursing system would address the requirements for health care delivery by the practitioner with the following guidance:

1. Explain the need for incorporating relief of airway obstruction, breathing retraining, and exercise tolerance in providing emphysema care.
2. Understand the need for and be able to develop a teaching plan.
3. Address environmental physiological and physical factors to promote rehabilitation.
4. Understand the elements of a proper rehabilitation plan.

The output was specific informational needs, which an educational advisor would identify in terms of the intellectual, constituent elements of the topic. To ensure that the health care provider could in fact accomplish these individual goals, the system explicitly identified the appropriate specific learning resources. Thus, as a result of following the educational advice with the learning resources specified, the health care provider would likely acquire a proper understanding of what patient care should follow. Such a system and its capacity to address a range of issues were described and defined over the first three-year period from 1977 to 1979. At the end of 1979, initial utilization of the system began at various external sites (Evans, 1982).

Second Generation: The Clinical Administrator

The first generational shift occurred as the system attempted to provide not just educational recommendations but actual clinical care recommendations as well. During this five-year development effort, the system itemized specific patient care protocols that included clinical advice (Evans, 1984). A care advisor had always been intended to be part of the product. Thus, although the Clinical Advisor represented a major system advancement, the capacity to deliver this capability was resident within the original system. Between 1980 and 1986, the knowledge base expanded at least tenfold to accommodate this particular move from educational advisor to clinical care advisor.

Third Generation: The Comprehensive Patient Care Advisor

Over the next three years, between 1987 and 1989, the next generational advance represented an undertaking to permit the user to actually develop a comprehensive clinical patient care plan (Evans, 1988). This was accomplished by expanding the application beyond specific patient care protocols (Cuddigan et al., 1987; Cuddigan et al., 1988). This version was enhanced with the practicing clinician in mind: not only were specific protocols of care available, but they contained many additional categories germane to clinical practice (e.g., extensive enumeration of goals, interventions, discharge teaching and planning, patient education). There was yet again approximately a near tenfold increase in the size and scope of the knowledge base, as well as in the complexity of the system. The system was envisioned as being of most benefit within a clinical setting, and it was at this time that Creighton University sought help in marketing the application and delivering the system to users (Evans, 1985). Thus began the relationship with Health Care Expert Systems, Inc. (HCES: the forerunner of the PACE Health Management Systems Corporation).

Fourth Generation: Clinical Protocol Consultant

The fourth generation (1990–1992) moved from providing a somewhat static patient care picture to the provision of a time-series description of all the patient care nursing documentation activities from admission to discharge. This type of development required a move to a fourth-generation language, full-screen editing, far more complex programming capacities, and a much more elaborate support system to cover the entire patient care record (Evans, 1993). For example, at the end of discharge, the entire record had to be put into an archive; consequently storage and retrieval issues arose, and so on. This fourth generation created another tenfold increase in both information and complexity and represented a major generational shift.

Fifth Generation: Nursing Information System

The fifth generation (1993) was specifically noteworthy for the move from the more narrow focus of a nursing patient care documentation system to a completely integrated, hospital-wide nursing patient care documentation system. In this context, the system interacted with admissions, discharge, and transfer, and could address and interact with order entry and other parameters. A wide variety of different care delivery models could be accommodated, and the documentation would reflect these styles (e.g., Orem's or Rogers's nursing theory or operational models such as primary care or team nursing). The system was integrated into the entire hospital complex and was envisioned as both inpatient-based and facility-wide. Each of the different hospital areas carried its own ID and protocols, and specialty information could be resident for each work center. Thus this generation represented yet another order-of-magnitude increase in both the complexity and the size and scope of the PACE product. By the time the fifth generation was complete and installed and smoothly operative, a 10,000-fold increase from the original knowledge had been accomplished. The concomitant increase in system complexity was five orders of magnitude.

Sixth Generation: Clinical Information System

The sixth generation represents a shift from a nursing system that itself had been extracted from a universe of all health care providers to a more fully integrated interdisciplinary system within the medical care environment. This generation incorporates an integrated and expanded patient medical record documentation system. This PACE system has a fully developed clinical repository that holds a copy of the integrated documentation provided during the entire encounter with the health care system. This encounter could be either inpatient or outpatient. This clinical repository is structured and organized to facilitate search, analysis, and evaluation.

The system permits a wide range of health care professionals to address the patient care environment in the context of the individual's professional perspective. Thus, not only does the sixth generation address the tertiary care within the hospital, but also it addresses the care of the patient in different settings such as long-term or skilled-bed facilities, subacute settings, home health, and rehabilitation settings. For example, long-term care is a specific module that includes the minimum data set permitting a facility to use the PACE system to report all data as required in a variety of U.S. government formats (e.g., the OPR 87 reporting requirements, RAPS, and HICFA form 672). Moreover the system design anticipates a series of patient care records in a variety of care settings as the patient moves through the system (e.g., emergency room, intensive care unit, medical–surgical unit, long-term care). These are all stored and retrieved as part of the clinical repository of the specific patient. Thus, this system generation supports the patient record across the care spectrum. As a consequence of this expansion of application, there is yet another tenfold increase in the complexity of the system.

Seventh Generation: Advanced Clinical Management System

In the current generation (as of the second quarter of 1996), most of the original vision of the project returns to the delivered product. Of particular note is the inclusion of additional multidisciplinary features of the system, with no longer the primary focus on nursing alone. Since nursing has always emphasized the health care team concept in the project's development, this version of PACE supports complete interdisciplinary documentation and expects to maintain the entire patient care record within its clinical repository. The expanded interdisciplinary focus with a full clinical repository capacity supports the basis for the distinction of this version as another generation of PACE.

As a result of the full support provided by this version, far more subtle and comprehensive analysis and evaluation of health care can be achieved. For example, as proposed by this author, the patient records (with their documentation of patient care and outcomes) permit an analysis that can correlate which care procedures are more strongly associated with favorable outcomes. Using the facility's experiences, improvements in managed care and clinical care pathways can be derived from such studies. As a formal tool, this module of analysis has successfully introduced repository analysis as an available component of the currently delivered system.

Although the knowledge base content does not expand tenfold in this generation, the information managed does in fact expand at this level. Such was the vision for the original product, since as previously described, the project began by capturing the knowledge base of all the health professionals across the entire domain available at the Creighton Medical Center (including the knowledge base of physicians, nurses, pharmacists, dentists, and a variety of allied health care professionals). Hence the evolution of the product moved from global vision, to a very, very focused application to achieve specific valued payoffs, to a comprehensive support system spanning the entire health care field.

Demand on Resources

During these several generations, substantial financial support permitted the project to succeed or at least simply to survive until its current successes could be realized. From 1979 to 1986, sales were essentially a function of word of mouth and modest marketing efforts that had been initiated while the project was completely resident within Creighton University. In the next seven years, the number of sites increased fivefold. It is conservatively estimated that within the next three years, PACE will realize at least another fivefold gain in the size of the customer base. At the same time, the support staff has necessarily increased by a factor of 50% as sales and the customer base have grown fivefold. Current projections envision that another 30% will be necessary to sustain the next threefold increase.

It is worthwhile to note that in the early commercialization of this product, a single, standard version was delivered. Virtually all the implementation and support needed were provided to the customer as part of the sale. PACE in its present state represents greater complexity in the software, added sophistication in the technology, and a much wider impact and application throughout the health care enterprise. Thus more often than not customers now must dedicate significant resources (technical and clinically-oriented expertise) to implement the system successfully.

Hardware Requirements

One of the important hardware developments that has worked in tandem with the growth just described has been the exponential increase of the availability of computer power at declining prices, which has supported product delivery. Required computing power more than doubled for each generation of the PACE product. At the same time, the cost for the commensurate computing power has dropped. Thus, the estimated need for computing power capacity more than one hundred times greater than the original system has in fact been available at a small fraction of 1977 prices. Indeed the curves are exponential both in their rise of power and in their decline for the unit price for each element of power. This shift in effect has opened up the marketplace for very small, efficient applications even though the power of the product has increased to what at the onset would have been possible only with a multi-mainframe application, costing millions of dollars.

Examples from the PACE System Generations

The current PACE system is a moving definition because R&D continues at a high rate to stay up with an extremely aggressive marketplace. Nonetheless, some examples of the systems will permit the reader to appreciate its evolution and to interpret some of the principles presented in light of the product itself.

Generation 1

Recall that at the beginning of the project, the fundamental output elements were instructional units. In effect, the initial output was a structured curriculum that defined the capabilities of an expert to have the capacity to address the problem presented as input to the system. Typical of first-generation output was a goal–subgoal–sub-subgoal description of a knowledge area, as a result of which the user would understand the conceptual requirements necessary for a proper understanding of the domain. Concomitantly the system enumerated learning resources so that each concept could be mastered, thereby guiding the user to mastery of the topic. Figures 2.2A and 2.2B demonstrate how the output appeared at the first generation.

Chronic Airway Obstruction: assess data, plan interventions and evaluate treatment associated with chronic airway obstruction.

Chronic Bronchitis:	identify therapeutic implications associated with inhalation of foreign materials. See Luckman, *Medical-Surgical Nursing*, pp. 1258-62
Emphysema:	identify pathophysiological changes resulting signs and symptoms and therapeutic implications associated with croup See Luckman, *Medical-Surgical Nursing*, pp. 1262-64
Bronchiectasis:	identify pathophysiological changes, resulting signs and symptoms and therapeutic implications assoicated with croup See Luckman, *Medical-Surgical Nursing*, pp. 1264-66
Asthma:	identify pathophysiological changes, resulting signs and symptoms, and therapeutic implications associated with atelectasis See Luckman, *Medical-Surgical Nursing*, pp. 1266-68
Cystic Fibrosis:	identify pathophysiologic changes, resulting sign and symptoms, and therapeutic implications associated with atelectasis See Luckman, *Medical-Surgical Nursing*, pp. 1268-70

REHABILITATION: formulate a plan of care which promotes the rehabilitation of the patient with pulmonary disturbances.

Adjustment: illustrate the need for both physical and emotional adjustment in coping with pulmonary disease
See Luckman, *Medical-Surgical Nursing*, pp. 1270-71

Teaching: design an appropriate and comprehensive teaching plan to promote rehabilitation
See Luckman, *Medical-Surgical Nursing*, pp. 1271-72

Compliance: recognize the problem of noncompliance in patients with pulmonary disturbances

defense mechanisms: assess defense mechanisms and coping strategies employed by pulmonary patients and their families and discuss appropriate interventions
See Luckman, *Medical-Surgical Nursing*, pp. 1272-73

Support systems: locate community sources of support for the pulmonary patient and his family
See Luckman, *Medical-Surgical Nursing*, pp. 1273-74

FIGURE 2.2. Educational Advisor sample screens.

Generation 2

The second-generation output also addressed clinical aspects of a diagnosis in a more narrative format and was used more for informational purposes. The specific care needs were summarized, in extremely short and telegraphic fashion. In the second generation, the system added clinical pointers and summarized care principles that further aided the user to recognize just what issues should be addressed and what capabilities needed to be achieved. The content of the clinical advisor came from the semantic network, which required that these associated concepts be tied to each knowledge element for indexing and retrieval purposes. A typical example of the output at the second generation is provided in Figure 2.3.

NURSING PRACTICE PROTOCOL FOR THE FOLLOWING GOAL:

FORMULATE A CARE PLAN WHICH PROMOTES THE REHABILITATION OF THE PATIENT WITH PULMONARY DISTURBANCES

NURSING PRACTICE SHOULD INCORPORATE THE FOLLOWING PATIENT CARE ISSUES:

THE NEED FOR BOTH PHYSICAL AND EMOTIONAL ADJUSTMENT IN COPING WITH PULMONARY DISEASE

Specific aspects of physical adjustment might include environment, breathing pattern, hydration, activity, occupation, and no smoking.

Specific aspects of emotional adjustment might include reinforcement, motivation, reward, and family response.

PROVIDE AN APPROPRIATE AND COMPREHENSIVE TEACHING PLAN TO PROMOTE REHABILITATION OF A PATIENT WITH PULMONARY DISEASE, INCLUDING ENVIRONMENTAL, PSYCHOLOGICAL, AND PHYSICAL FACTORS

Specific aspects of teaching plan might include self care, environmental adjustment, family cooperation, and coping mechanisms.

Specific aspects of rehabilitation might include physical rehabilitation, physical adjustment, psychological rehabilitation, pulmonary rehabilitation, and environmental adjustment.

Specific aspects of environmental factors might include depression, mentation, incentive, coping mechanism, family concern, emotonal response, and self image.

Specific aspects of physical factors might include physical strength and energey.

ADDRESS DEFENSE MECHANISMS AND COPING STRATEGIES EMPLOYED BY PATIENTS WITH PULMONARY PROBLEMS AND THEIR FAMILIES AND DISCUSS APPROPRIATE INTERVENTIONS.

Specific aspects of defense mechanisms might include denial, avoidance, fantasy, and regression.

Specific aspects of coping strategies might include reality rehearsal, personal value system, attitude, problem-solving, and resource use.

Specific aspects of family include family anxiety and family support.

IDENTIFY COMMUNITY SOURCES OF SUPPORT FOR THE PATIENT WITH PULMONARY PROBLEMS AND HIS FAMILY

Specific aspects of support system might include family support and community support.

Specific aspects of community support might include community agency, health service agency, American Lung Association, and Nebraska Lung Association.

RECALL SOCIAL, CULTURAL AND DEVELOPMENTAL INFLUENCES ON THE PATIENT WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE AND RELATE THESE TO HIS RESPONSE TO ACUTE DISTURBANCES AND COMPLIANCE WITH THERAPY.

Specific aspects of chronic obstructive pulmonary disease might include chronic bronchitis, emphysema, tuberculosis, adult respiratory distress syndrome (ARDS), chronic asthma, and cystic fibrosis.

Specific aspects of acute pulmonary disturbance might include acute spasmodic laryngitis, acute airway obstruction, croup, pneumonia, atelectasis, and hemothorax.

FIGURE 2.3. Clinical Administrator sample screen.

Generation 3

In the third generation, the capacity of the system escalated to an actual care plan definition, with a rich and detailed commentary. The knowledge provided by the system would easily rival the level of detail found on any nursing care plan. In fact several studies were undertaken to compare the real-time derived and assembled care plans with those of expert nurses given the same challenge, and the system performed extremely well. There was however little capability to allow the user to incorporate the output into a patient's medical record that could be directly used in the user's health care system. The third generation remained fully within the university setting, although there was a complete contractual and integrated relationship with HCES, the commercial firm that addressed marketing, sales, and system delivery. HCES worked in partnership with the university, although most decision making remained with the university project management.

This third generation of PACE (entitled COMMES at that time) was reviewed by Ozbolt, who identified three major limitations. These were:

1. The system is designed as a stand-alone entity apart from a hospital's information system, which will prevent the hospital from accessing stored patient information.
2. Needed information easily available from nursing reference books may be retrievable from the system only after a lengthy dialogue with the system.
3. The task of keeping the highly specific knowledge base up-to-date is too expensive in terms of time.

Ozbolt was quite accurate in her identification of these three limitations, and had the system terminated at the third generation, it probably would not have survived and thrived. As we shall demonstrate, by the sixth generation, PACE had both addressed and overcome all the objections voiced by Ozbolt and others. (Ozbolt, 1983, Hannah et al., 1994).

A typical example of output from the third generation is provided in Figure 2.4.

Generation 4

The fourth generation moved the system from a consulting role to a direct-use application, intending to be the actual patient care plan for providers' use, which would become a permanent part of the medical record. Developing this application as a relational database with fourth-generation software tools such as INFORMIX laid the groundwork for a complete nursing documentation system. In this setting, with the addition of administrative issues such as admissions, discharge, transfer, and room assignments, the

NURSING DIAGNOSIS
- impaired breathing pattern for emphysema
  - goal/expected outcome:
    - effective breathing pattern including
      - respiratory rate 12-24
      - regular unlabored respiration
  - interventions:
    - monitor respiration rate/rhythm/depth
    - assess degree of dyspnea
    - breathing exercises -slow rate/abdominal-diaphragmatic/pursued lip
    - q2h day/eve, q6h nights
    - note use of accessory muscles
    - position in semi-fowler
    - monitor lung volume reports
    - cough and deep breath
    - assess lung sounds frequently
  - discharge teaching
    - avoid activity causing dyspnea
    - rest before and after activity
    - importance of progressive activity
    - need for adequate rest
    - stop smoking
    - medication regime-purpose/dose/schedule/side effect
    - use of home o2
    - caution with home o2--no smoking/open flame/electric appliances
    - name and home phone number of local supplier of o2
    - do not increase prescribed o2 dose
    - alert fire department to location/use of o2
    - breathing exercise
    - community resources--american lung association
    - eat small frequent meals
    - need for high calorie snacks

FIGURE 2.4. Comprehensive Patient Care Advisor (CPCA) sample screen.

complexity of the system increased tenfold. The system supported complete editing of the care plan and allowed for a limited amount of nursing documentation such as patient education, discharge planning, and discharge teaching. Care plans and Kardexes were the primary working documents of this system. This generation coincided with the administrative move to a commercial corporate sector (completely divorced from the university setting). Although the extent of the system can be represented only partially, since there were dozens of different screens and extensive capabilities, a sampling of the system's output and performance is provided in Figure 2.5. Note in particular that users could still access the knowledge base directly (a separate function in later generations), obtain detailed knowledge of personally tailored topics, and use the extensive network of interrelated indexing terms to initiate knowledge base searches as they desired.

Generation 5

The fifth generation of PACE permitted a wide latitude of use, allowing the nurse to meet patient care needs such as the initiation of a patient assessment, the complete elaboration of an admission interview, the building or updating of the traditional Kardex in a manner consistent with the usual practices, and the development of a complete report (including charts with fluid balance, temperature graphs, etc.). In addition, worksheets that identify various interventions could be identified and printed as full reports and as record keeping (e.g., labor flowsheets and treatment records). Not only did the system's screens support chronological patient charting such as Kardex, admissions interview, medication schedules, vital signs summary, a discharge report, and a complete elaboration of all patient education, it also permitted further report aggregation, local protocol development, and complete nursing documentation. All these components could be tailored by the site, allowing for full integration. This capability enabled a site to feel completely comfortable with its application. Point-of-care documentation was also introduced during this phase to expedite data collection activities. In Figure 2.6 we present examples from the fifth-generation system.

Generation 6

One major capability of the sixth generation is the fully integrated support of point of care using a pen-pad in which a small, portable automated pen-pad permits the capture of a wide variety of information at the point of care. The pad also permits the retrieval from the PACE record of an equally wide variety of patient care information. Thus, this approach carries the record of PACE to the bedside and carries the captured data from the bedside back to the PACE clinical record. Such straightforward tasks as the recording of vital signs and the conformation of the provision of medications are easily accomplished using a pen stylus, with natural handwriting on the pad, as well as by making selections from numerous menus.

Brown, C. **CARE PLAN SUMMARY** **Date: 06/12/91 12:09**

Room/Bed: 210LA Patient: Darwin, Charles E. Class:

Problem/Diagnosis	Status
EMPHYSEMA	CUR
Impaired breathing pattern	CUR
Impaired gas exchange	CUR

Date Entered 06/11/91 Update 06/11/91 15:16:50 By Heichert, S.
Select a blank line to add a problem; number a primary problem

F1	F2	F3 Insert	F4 Delete	F5 Goal/	F6 Teach/	F7	F8
Help		Line	Line	Intervntn	Related	Print	Exit

A

Brown, C. **NURSING DIAGNOSIS** **Date: 06/12/91 12:09**

Room/Bed: 210LA Patient: Darwin, Charles E.
Problem: EMPHYSEMA
NDX: impaired breathing pattern

Goals/Expected Outcomes	**Target**	**Stat**
EFFECTIVE BREATHING PATTERN	6/14/91	CUR
respiratory rate 22-24	6/13/91	CUR
regular unlabored respirations	6/13/91	CUR
Interventions	**Freq**	**Notes**
monitor respiratory rate/rhythm/depth	Q2H	
assess degree of dyspnea	Q2H	
breathing exercises-slow rate/abdominal-diaphragmatic/pursed lip q2h day/eve, q6h nights		
note use of accessory muscles	Q2H	
position in semi-fowlers		
monitor lung volume reports		
cough & deep breath	Q2H	
assess lung sounds frequently		

Date Entered 06/11/91 **Update** 06/12/91 10:55:24 By Brown, C.
Enter/Edit Intervention

F1	F2	F3 Insert	F4 Delete	F5	F6	F7	F8 Go To
Help		Line	Line	Goals		Print	NDX

B

FIGURE 2.5. (A) Clinical Protocol Consultant (CPC) sample screen 1. (B) CPC sample screen 2. (C) CPC sample screen 3.

Brown, C. **NURSING DIAGNOSIS** **Date: 06/12/91 12:11**

Room/Bed: 210LA Patient: Darwin, Charles E.
Problem: EMPHYSEMA

Patient/Discharge Teaching Items	**Who**	**Learning How**	**Addtl. Info**
avoid activity causing dyspnea	PT	Q&A	
rest before & after activity	PT	Q&A	
importance of progressive activity	PT	Q&A	
need for adequate rest	PT	Q&A	
stop smoking	PT	FLM	
medication regime-purpose/dose/schedule/side effect	PT	Q&A	
use of home o2	PT	DEM	
caution w/home o2 -- no smoking/open flame/electric appliances	PT	DEM	
name & home phone number of local supplier of o2			
do not increase prescribed o2 dose			
alert fire department to location /use of o2			
breathing exercises			
community resources - american lung association			
eat small frequent meals			
need for high calorie snacks			

Date Entered 06/11/91 **Update** 06/11/91 15:16:50 By Heichert, S. More Down
Enter Discharge Teaching

F1	F2	F3 Insert	F4 Delete	F5	F6	F7	F8 Go To
Help		Line	Line	Goals	Related	Print	PT Problem

C

FIGURE 2.5 *Continued*

A second significant innovation is the integration into the documentation process of the concepts of critical pathways as well as the broader sense of managed care. Pathways can be initiated, documented against, and displayed with associated documentation and variances recorded as the patient moves from admission into the hospital to discharge. Consistent with this expanded notation is the expansion of the recording of data that includes information from nurses as well as from the other care providers on the health care team that interact with the patient. Figure 2.7 show representative output from this more elaborate and extensive system.

Generation 7

Foremost of the characteristics that distinguish the seventh generation from the prior ones is its design of a clinical record as part of a clinical repository. This clinical repository contains the detailed data of all the care the patient has received during specific episodes in the hospital setting. Its capabilities include collecting a variety of specific episodic events that may occur over several different hospital or outpatient settings and integrating them into an ongoing unified care record. Input into the clinical repository goes

Date: 06/14/91 **Health Care Expert Systems** **Page:** 1
Time: 12:36:55 **Assessments** HCES, 2.03

Patient Name: Darwin, Charles E. Patient I.D. #: 329494632
Attending Physician: Dr. Doktor Date Admitted: 06/12/91
Primary Nurse: Nightengale, Flo Date Discharged:
Room/Bed: 210LA

1. Problem: EMPHYSEMA
   2. Topic: oxygenation assessment of emphysema

1. history of cigarette smoking
2. progressive exertional dyspnea
3. persistent dyspnea in late stages
4. mild hypoxemia
5. shallow 7 rapid respiration
6. prolonged exhalation
7. accessory muscle use
8. taut chest & neck muscles
9. pursed lip breathing
10. typical hands on knees positioning
11. ruddy to ruddy cyanotic
12. hyperresonant chest on percussion
13. marked overdistention of chest
14. large anteroposterior diameter of chest
15. distant breath & heart sounds
16. barrel chest
17. flattened diaphragm
18. underweight
19. cachectic
20. pulmonary hypertension
21. increased pulmonary vascular resistance in late stages
22. cor pulmonale in late stages
23. reduced forced vital capacity/increased residual lung volumes

A

FIGURE 2.6. (A) Nursing Information System (NIS) sample screen 1. (B) and (C) NIS sample screen 2.

Date: 06/14/91
Time: 12:29:02

Health Care Expert Systems
Care Plan

Page: 1
HCES, 2.03

Patient Name:	Darwin, Charles E.	Patient I.D. #:	329494632
Attending Physician:	Dr. Doktor	Date Admitted:	06/11/91
Primary Nurse:	Nightengale, Flo	Date Discharged:	
Room/Bed:	210LA		

1. Problem: EMPHYSEMA
   1. Nursing DX: impaired breathing pattern

Expected Outcomes	Stat	Target	Interventions	Freq
1. EFFECTIVE BREATHING PATTERN	REV	06/14/91	1. monitor respiratory rate/rhythm/depth	Q2H
			2. assess degree of dyspnea	Q2H
2. respiratory rate 12-24	REV	06/13/91	3. breathing exercises-slow rate/abdominal-diaphragmatic/pursed lip	Q2HW/A
				Q2H
3. regular unlabored respirations	REV	06/13/91	4. note use of accessory muscles	
			5. potision in semi-fowlers	
4. uses appropriate pursed lip breathing	REV	06/14/91	6. monitor lung volume reports	Q2H
			7. cough 7 deep breath	
5. denies dyspnea	REV	06/14/91	8. assess lung sounds frequently	

2. Nursing DX: impaired gas exchanges

Expected Outcomes	Stat	Target	Interventions	Freq
1. EFFECTIVE GAS EXCHANGE	REV	06/14/91	1. administer o2 @ 2 lpm per progns & document effect	Q8H
2. po2 at-or-slightly above baseline level value	REV	06/13/91	2. monitor abg's	Q4H
3. skin color pink			3. assess skin color/temperature & moisture	Q4H
4. alert & oriented	REV	06/14/91		
	REV	ALL TMS	4. assess level of consciousness	Q8H
			5. advise on need to stop smoking	
			6. monitor ecg for arrhythmias	

B

FIGURE 2.6 *Continued*

Date: 06/14/91
Time: 12:29:02

Health Care Expert Systems
Care Plan

Page: 2

Patient Name:	Darwin, Charles E.	Patient I.D. #:	329494632
Attending Physician:	Dr. Doktor	Date Admitted:	06/11/91
Primary Nurse:	Nightengale, Flo	Date Discharged:	
Room/Bed:	210LA		

1. Problem: EMPHYSEMA
   3. Discharge Teaching

	Taught	How
1. avoid activity causing dyspnea		
2. rest before & after activity		
3. importance of progressive activity		
4. need for adequate rest		
5. stop smoking		
6. medication regime-purpose/dose/schedule/side effect		
7. use of home o2		
8. caution with home o2 -- no smoking/open flame/electric appliances		
9. name & home phone number of local supplier of o2		
10. do not increase prescribed o2 dose		
11. alert fire department to location/use of o2		
12. breathing exercises		
13. community resources - american lung association		
14. eat small frequent meals		
15. need for high calorie snacks		
16. drink 6-8 glasses fluid per day		
17. report weight loss		
18. report increased dyspnea		
19. report decreased activity tolerance		
20. report related symptoms of upper respiratory infection		

C

FIGURE 2.6 *Continued*

beyond the walls of nursing and includes multidisciplinary documentation as well as the ability to capture data across the entire health care enterprise. The reader will see some of this in the representative screens provided in Figure 2.8.

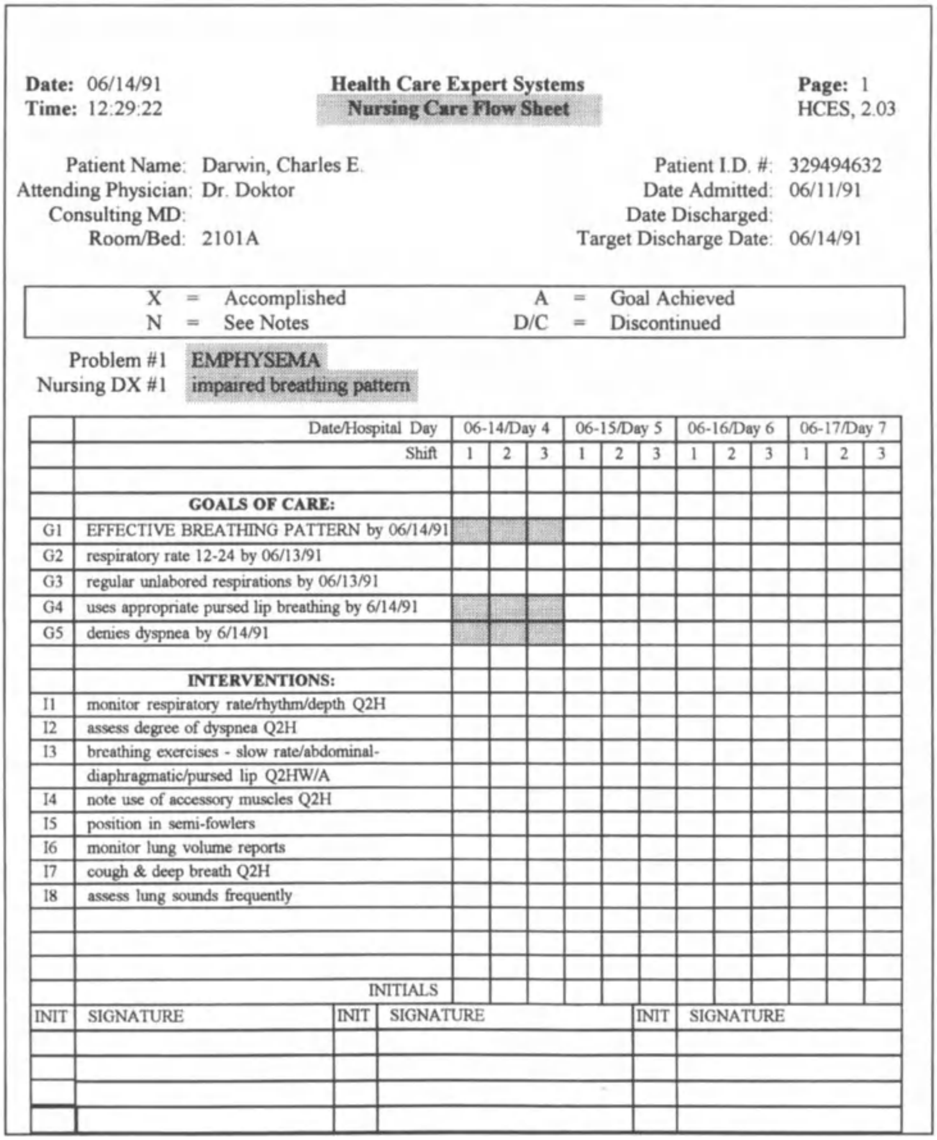
Advances in Methodological Evaluation

The seventh generation also introduces a significant methodological advance in the way the system can assist the user in evaluating patient care. This benefit arises from two capabilities, the first being the ongoing capture of continuous patient care information over time, throughout an individual's medical history. In effect a long, complex pattern of patient care along with the associated outcomes and actual historical results of that care are regularly documented. The second capability is the application by PACE of certain analysis methodologies from computer science (developed in the subarea of artificial intelligence). This analysis approach uses what are called genetic algorithms, which permit new ways to evaluate the kind of long-term care data collected by PACE (Goldberg, 1989; Hedberg, 1994; Koza, 1992). The use of this methodology has been successfully incorporated into PACE and applied to a longitudinal record of care, as part of the seventh generation of the system.

Neural Networks: Forerunner to Generic Algorithms

In the history of the development of more powerful analysis methods that could be applied to the clinical repository, the author first advanced the use of neural networks to automatically aid in the discovery of optimal clinical pathways (Anderson, 1995; Hassoun, 1995). Such optimal pathways were embedded in the data of care and associated outcomes if these patterns could be found and teased out of the data universe. Although an explication of neural networks and related methodologies such as data mining techniques and genetic algorithms is beyond the scope of this book, a brushstroke description may be usefully given.

The purpose of neural networks is to be able to detect and recognize patterns buried within a vast, complex sea of data. Typically these patterns are not apparent through other modes of formalistic analysis. An example sometimes given is the identification of a rose among a wide variety of other flowers. It is extremely difficult to build a rule-based, expert system to distinguish a rose from a carnation or another flower because it is not clear or easily articulated what the unique features are that should be identified. There is no innate language for flowers, or in particular, the language of a rose. Still humans can identify a rose from a wide range of other flowers. Although we might at first specify a characteristic, such as the color "red," together with a certain overall form, we know by common knowledge that indeed there may be a yellow rose, a pink rose, and so on, and few would think these were different specimens of flower altogether. Thus the characteristics that identify the pattern remain elusive.



Date: 06/14/91
Time: 12:29:22

Health Care Expert Systems
Nursing Care Flow Sheet

Page: 1
HCES, 2.03

Patient Name: Darwin, Charles E.
Attending Physician: Dr. Doktor
Consulting MD:
Room/Bed: 2101A

Patient I.D. #: 329494632
Date Admitted: 06/11/91
Date Discharged:
Target Discharge Date: 06/14/91

X = Accomplished
N = See Notes
A = Goal Achieved
D/C = Discontinued

Problem #1 EMPHYSEMA
Nursing DX #1 impaired breathing pattern

	Date/Hospital Day	06-14/Day 4			06-15/Day 5			06-16/Day 6			06-17/Day 7		
	Shift	1	2	3	1	2	3	1	2	3	1	2	3
	GOALS OF CARE:												
G1	EFFECTIVE BREATHING PATTERN by 06/14/91												
G2	respiratory rate 12-24 by 06/13/91												
G3	regular unlabored respirations by 06/13/91												
G4	uses appropriate pursed lip breathing by 6/14/91												
G5	denies dyspnea by 6/14/91												
	INTERVENTIONS:												
I1	monitor respiratory rate/rhythm/depth Q2H												
I2	assess degree of dyspnea Q2H												
I3	breathing exercises - slow rate/abdominal-												
	diaphragmatic/pursed lip Q2HW/A												
I4	note use of accessory muscles Q2H												
I5	position in semi-fowlers												
I6	monitor lung volume reports												
I7	cough & deep breath Q2H												
I8	assess lung sounds frequently												
	INITIALS												

INIT	SIGNATURE	INIT	SIGNATURE	INIT	SIGNATURE

A

FIGURE 2.7. (A) and (B) Clinical Information System (CIS) sample screen 1. (C) and (D) CIS sample screen 2. (E), (F), and (G), CIS sample screen 3. (H) CIS sample screen 4. (I): Clinical Pathways sample screen 1. (J) Clinical Pathways sample screen 2. (K) Clinical Pathways sample screen 3. (L) Clinical Pathways sample screen 4.

Date: 06/14/91
Time: 12:29:22

Health Care Expert Systems
Nursing Care Flow Sheet

Page: 2

Patient Name: Darwin, Charles E.
Attending Physician: Dr. Doktor
Consulting MD:
Room/Bed: 2101A

Patient I.D. #: 329494632
Date Admitted: 06/11/91
Date Discharged:
Target Discharge Date: 06/14/91

X	=	Accomplished	A	=	Goal Achieved
N	=	See Notes	D/C	=	Discontinued

Problem #1 EMPHYSEMA
Nursing DX #1 impaired gas exchange

	Date/Hospital Day	06-14/Day 4			06-15/Day 5			06-16/Day 6			06-17/Day 7		
	Shift	1	2	3	1	2	3	1	2	3	1	2	3
	GOALS OF CARE:												
G1	EFFECTIVE GAS EXCHANGE by 06/14/91												
G2	po2 at-or-slightly above baseline level value												
	by 6/13/91												
G3	skin color pink by 6/14/91												
G4	alert & oriented by ALL TMS												
	INTERVENTIONS:												
I1	administer o2 @ 2 1pm per progns & document												
	effect												
I2	monitor abg's Q8H												
I3	assess skin color/temperature & moisture Q4H												
I4	assess level of consciousness Q4H												
I5	advise on need to stop smoking												
I6	monitor ecg for arrhythmias Q8H												
	INITIALS												

INIT	SIGNATURE	INIT	SIGNATURE	INIT	SIGNATURE

B

FIGURE 2.7 *Continued*

Date: 06/14/91
Time: 12:29:39

Health Care Expert Systems
Discharge/Teaching Flow Sheet

Page: 1
HCES, 2.03

Patient Name: Darwin, Charles E.
Attending Physician: Dr. Doktor
Consulting MD:
Room/Bed: 2101A

Patient I.D. #: 329494632
Date Admitted: 06/11/91
Date Discharged:
Target Discharge Date: 06/14/91

X	=	Accomplished	A	=	Goal Achieved
N	=	See Notes	D/C	=	Discontinued

Problem #1 EMPHYSEMA

	Date/Hospital Day	06-14/Day 4			06-15/Day 5			06-16/Day 6			06-17/Day 7		
	Shift	1	2	3	1	2	3	1	2	3	1	2	3
	DISCHARGE TEACHING ITEM:												
1	avoid activity causing dyspnea												
2	rest before & after activity												
3	importance of progressive activity												
4	need for adequate rest												
5	stop smoking												
6	medication regime - purpose/dose/schedule/												
	side effect												
7	use of home o2												
8	caution w/home o2 - no smoking/open flame/												
	electric appliances												
9	name & home phone number of local supplier of o2												
10	do not increase prescribed o2 dose												
11	alert fire department to location/use of o2												
12	breathing exercises												
13	community resource - american lung association												
14	eat small frequent meals												
15	need for high calorie snacks												
16	drink 6-8 glasses fluid per day												
	INITIALS												

INIT	SIGNATURE	INIT	SIGNATURE	INIT	SIGNATURE

C

FIGURE 2.7 *Continued*

Date: 06/14/91
Time: 12:29:39

Health Care Expert Systems
Discharge/Teaching Flow Sheet

Page: 2

Patient Name: Darwin, Charles E.
Attending Physician: Dr. Doktor
Consulting MD:
Room/Bed: 2101A

Patient I.D. #: 329494632
Date Admitted: 06/11/91
Date Discharged:
Target Discharge Date: 06/14/91

X	=	Accomplished	A	=	Goal Achieved
N	=	See Notes	D/C	=	Discontinued

Problem #1 EMPHYSEMA

	Date/Hospital Day	06-14/Day 4			06-15/Day 5			06-16/Day 6			06-17/Day 7		
	Shift	1	2	3	1	2	3	1	2	3	1	2	3
17	report weight loss												
18	report increased dyspnea												
19	report decreased activity tolerance												
20	report related symptoms of upper respiratory												
	infection												
	INITIALS												

INIT	SIGNATURE	INIT	SIGNATURE	INIT	SIGNATURE

D

FIGURE 2.7 *Continued*

PACE Healthcare Enterprises

Admission Assessment Report

Admitted 04/06/95 -- 1 days
Doctor: BAILEY, JASON MD

300-2
3399998223 10/15/1950 M 44Y
Dumpty, Herman A
339999

DEMOGRAPHICS:

Date - Time:	04/06/95 7:11	Physician:	BAILEY, JASON MD
Admitted from:	Clinic	Mode:	Walk-in
Accompanied By:	Wife	Language:	English
Occupation:	Construction Worker	Religion:	None
Contact 1:	Jane Dumpty	Contact 2:	
Relation:	Spouse	Relation:	
Address:	22886 103 Ave West Des Moines	Address:	
ZIP:	50265	ZIP:	
City:		City:	
State:	IA	State:	
Phone:	(515) 223-8877	Phone:	

Smoker: No ETOH: Yes Glasses: No Hearing Aid: No

Referral to PFS: Not
Advanced Directives: "Living Will" "Copy on Chart"
Orientation to Room:
"Bathroom" "Smoking" "Visiting" "Call Light" "Meal Time" "Side Rails"
"Bed Control" "Bedside Unit" "Telephone" "TV"
ID Band on: Yes Allergy Band on: Yes
Valuables: Cash With Patient

PATIENT HISTORY:

Chief Complaint:
Pt. Reports: headaches-severe, blurred vision
Allergies:
04/06
ALLERGIC REACTION to: Penicillin
TYPE OF REACTION is: rash.
Diagnosis:
R/O Hydrocephalus
Medical History: S/p
Asthma
Surgical Procedural History: s/p
Herniorrhaphy

MEDICATION	Dose		Route	Freq	Last Date/Time
ASPIRIN	650	mgs	PO	QID	04/06/95/
VENTOLIN	1	ccs	Puffs	BID	04/06/95/

VITALS

DATE NURSE	TIME	TEMP (ROUTE)	BP HOW	BP	BP	PULSE LOCATE	RESP RATE	WEIGHT	INT
04/06 R.OUTER	8:14	99 F 0	150/90 LL	0 /0	0 /0	92 R	12	220 lbs 0 oz 99 kgs 792 gm	

E

FIGURE 2.7 *Continued*

PACE Healthcare Enterprises
Admission Assessment Report
(continued)

Admitted 04/06/95 -- 1 days
Doctor: BAILEY, JASON MD

			300-2
3399998223	10/15/1950	M	44Y
Dumpty, Herman A			
			339999

ASSESSMENTS:

Level of Comfort:
Pain Rating: 5 Location: Head
Descriptor: Dull
Pain Relief: With:
Pain Increased with:

Activity:

Ambulates on own. Steady gait. Walks frequently

Cardiovascular: HIGH SYS BP HIGH PULSE

Radial pulses strong, regular. Apical pulses strong, regular. No chest pain.

EENT:

EYES
Vision Blurred vision OU+

Gastrointestinal: ETOH

Abdomen soft.
Abdomen non tender. Bowel sounds present x4 quadrants.
Nausea/Emesis Nausea Intermittent Emesis 2X

Genitourinary:

Urine clear, yellow. No dysuria, frequency or incontinence.

Integumentary:

Skin warm, dry, pink, intact.

Musculoskeletal:

No pitting edema present. Full range of motion. Extremities pink, warm to touch. Fast blanching < 5 seconds.

Neurological:

F

FIGURE 2.7 *Continued*

PACE Healthcare Enterprises
Admission Assessment Report
(continued)

Admitted 04/06/95 -- 1 days
Doctor: BAILEY, JASON MD

			300-2
3399998223	10/15/1950	M	44Y
Dumpty, Herman A			
			339999

Oriented to person, place & time.
Eye Movements EOM's Intact
Speech Clear
Strength Hand Grasps Strong and Equal
Gait Normal:
Pain Head Temple - L Dull

Psych/Social/Hygiene:

Spontaneous interactions. Clear thoughts. Clean, well kept.
Odor free. Sleeps without difficulty. (at least 6 hours/noc)

Respiratory:

Lung Sounds Wheezes Expiratory Throughout;
Cough Dry Infrequent

G

FIGURE 2.7 *Continued*

PACE Healthcare Enterprises
Labor Flowsheet
04/05/95
Admitted 03/27/95 -- 10 days
Doctor: HAHN, DEE MD

200-1
989898 10/15/1965 F 29Y
Hill, Jill
989898

Date/Time	03/31/95 10:45 R.O'BRIAN	03/31/95 10:03 R.O'BRIAN	03/31/95 9:28 R.O'BRIAN	03/31/95 8:40 R.O'BRIAN
Vitals	EDIT	EDIT	EDIT	EDIT
Temp/Route	99.0 F O	98.8 F O	99.0 F O	99.2 F O
BP/How	138/ 78 LR	136/ 76 LR	134/ 76 LL	128/ 70 SL
Pulse/Locate	92 A	84 A	85 R	84 A
Resp/Rate	24	24	24	24
Weight	lbs oz kgs 0 gm	lbs oz kgs 0 gm	lbs oz kgs 0 gm	158 lbs oz 71 kgs 810 gm
Int				
FHR	124	138	144	137
Variability	124	138	144	137
Decelerations	124	138	144	137
Dilatation	124	138	144	137
Effacement (%)	124	138	144	137
Station	124	138	144	137
Contractions Frequency Duration Quality	 3 min 60 sec strong	 3 min 45 sec moderate	 4 min 30 sec moderate	 5 min 30 sec mild
Medications				
Oral Intake				
IV Intake				
Output				
Activity	SHOB	SHOB	BR=B	SHOB
Monitors	EFM ECM	EFM ECM	EFM ECM	EFM ECM
Notes	1	2	3	4

FIGURE 2.7 *Continued*

The Toledo Hospital

Move to 7-Up View
Admitted 09/24/94 -- 1 days
Doctor: Martin M. Alexander

33333 12/31/1945 F
Smith, Joan
560 Hout Farm Road
New Canaan, CT 06840

Day Date	1 09/24/94	2 09/25/94	3 09/26/94	4 09/27/94	
INFO	--- Patient Information / Reference ---				
Patient Diagnosis	[kidney stone]				
Procedure					
Allergies	ALLERGIC REACTION to: INHALANTS - dust, pollen.				
Patient Alerts	Body fluids precautions				
ACTIVITY	--- Activities / Interventions ---				
Activity	09/24 (Variance <1>). Bedrest with commode, as tol.	09/25 - 09/26. C&B	→	09/27 - 09/29. OOB as tolerated.	→
Diet			09/26 - 09/30. As tol., enc PO fluids unless contraindicated	→	→
Elimination	09/24 - 09/30, I&O	→	→	→	→
Safety	09/24 - 09/30. Rails x 4 @ HS	→	→	→	→
Hygiene	09/24 - 09/26. Complete.	→	→	09/27 - 09/30 Partial	→
Nursing Treatments	09/24 - 09/25 (h).T,C,DB.	→	→		
General Nursing Care					
Narrative Nursing Notes					
Respiratory Treatments	09/24 - 09/25. 02,Nebs.	→			

FIGURE 2.7 *Continued*

<u>The Toledo Hospital</u>

Move to 7-Up View
09/24/94

33333	12/31/1945	F	47Y
Smith, Joan			

Day Date	1 09/24/94	2 09/25/94	3 09/26/94	4 09/27/94	
Blood					
Subcutaneous Infusions					
Continuous Enteral Nutrition					
Lab Tests	CBC. 09/24 2:00pm, High. (<2>)				
Diagnostic Tests					
OUTCOMES				---- Expected Outcomes ---	
Impaired gas exchange		09/25. Patient will demonstrate normal respiratory pattern & rest without O2.	09/26. ABG/O2 Sat. values will improve if patient on O2.	09/27 - 09/29. Pt. will tolerate bedside commode/C&B without resp. distress.	
Ineffective airway clearance	09/24 - 09/29. Pt. will have adequate secretion management to promote optimal gas exchange.	→	→	→	→
Infection r/t pathogens in respiratory tract	09/24 - 09/25. Pt. will state s/sx pneumonia experienced.	→	09/26 - 01/29. Pt. will demonstrate decrease in sx.	→	→
	09/24 - 09/26. Measures to identify/counteract infx will be implemented.	→	→	09/27 - 09/29. Antibiotic rx re-evaluated per C&S results.	→
Hyperthermia r/t infection	09/24 - 09/25. Pt. temp will be decreased through use of antipyretics & cooling measures.	→	09/26 - 09/27. Pt. temp will be at or near normal w/o antipyretics.	→	→

FIGURE 2.7 *Continued*

The Toledo Hospital

Move to 7-Up View
09/24/94

33333 12/31/1945 F 47Y Smith, Joan

Day Date	1 09/24/94	2 09/25/94	3 09/26/94	4 09/27/94	
Special Devices			09/26. Egg crate mattress.		
Vital Signs Frequency	09/24 (q6). T/P/R- Temp: Oral: Pulse: Radial:	09/25 - 09/26 (q4). Blood pressure - with Doppler.	→		
Teaching					
Consults and Referrals	09/24 - 01/30 Team.	→	→	→	→
Social Work & Discharge Planning					
Assessments	09/24 - 09/25 (q2). Assess lung sounds & resp status	→	09/26 - 09/27 (q4). Assess lung sounds & resp status	→	
ORDERS	Orders (Meds/IVs/Labs/Diagnostics)				
Medications	Betopic 0.5% Ophtha 1.000 gtts Starts 09/24 12:00 am, 48 hours (qd	→			
	Aspirin 650.000 mg Starts 09/24 12:00 am, 72 hours (q4)	→	→		
IV Infusions	D5 1/2 NS; 1000 cc at 100 cc/hr Starts 09/24 12:00am, 48 hrs (EXPIRES 09/26)	→	→		

K →

FIGURE 2.7 *Continued*

The Toledo Hospital

Move to 7-Up View
09/24/94

33333 12/31/1945 F 47Y
Smith, Joan

Day Date	1 09/24/94	2 09/25/94	3 09/26/94	4 09/27/94	5 09/28/94	
Alteration in fluid & electrolyte bal. r/t infection or dehydration.	09/24 - 09/25. Pt's. fluid and elec. bal. will be addressed via PO & IV supplementation	→	09/26 - 09/27. Pt;s. fluid & elec. bal. will be at or near normal by QS u/o of @ least 30cc/hr & lab elec. WLN.	→	09/28. Pt. will maintain adequate fluid intake PO.	
Pain r/t pneumonia	09/24 - 09/29. Pt. will express relieve from pain w/analgesics.	→	→	→	→	→
PLAN	---- Select a View ---					
PLAN	---- Toggle Plan Options ---					

<1> Patient/Family [By P.Tikkanen, RN on 09/24 7:44pm]
Edited. Patient restless.

<2> Normal [By P. Tikkanen, RN on 09/24 5:25pm]
CBC. 09/24 2:00 pm, High.

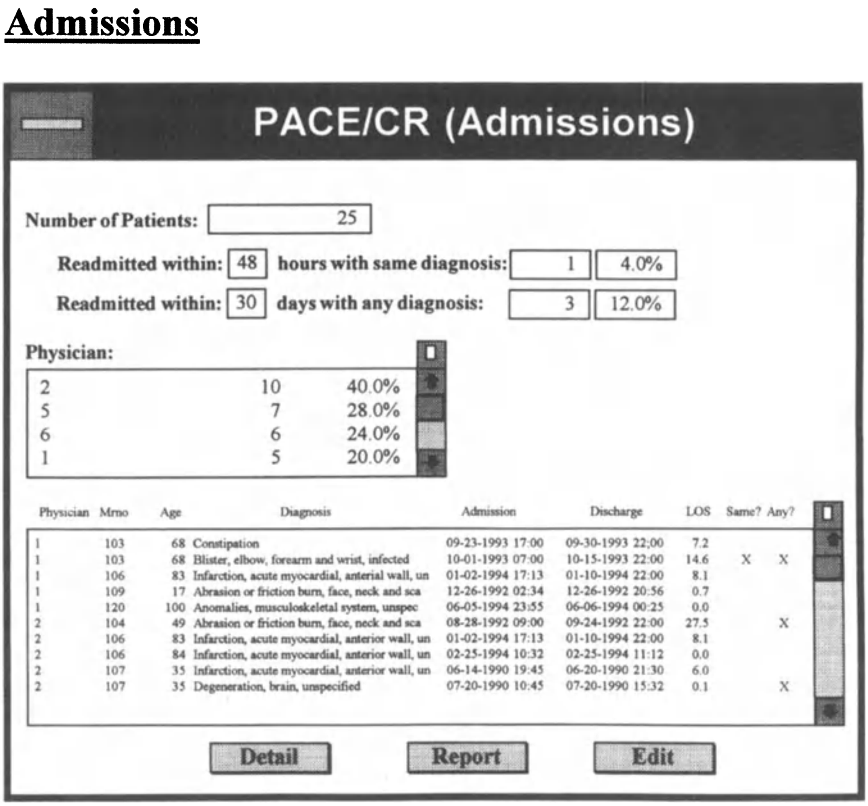
FIGURE 2.7 *Continued*

Neutral networks scan data patterns, whether they are presented as actual photographs, as numerical data, or as other kinds of captured qualitative information. This methodology is able to efficiently select a set of attributes that can be used to distinguish one pattern (e.g., a rose) from all the others buried within the data, if in fact there is a basis for differentiating that pattern from the others. Neural networks represent an array of weighted attributes whose weights the methodology can configure on its own in a self-learning environment. Each attribute adds to the outcome value, modified by the weights and the interconnections among the attributes (or "sensors"). The final output confirms or rejects a recognition of "a rose." Neural networks have been applied to configure attributes and associated weights to tease out patterns in data that otherwise might have been buried and not recognized.

Uses of Neural Networks

This methodology addresses a fundamental issue that has been posed in nursing. The argument has been advanced by some that the patterns nurses identify transcend the individuals' ability to articulate them as an explicit set of so-called IF-THEN rules. There are those who allege that the subtle pattern recognition is precisely what the expert brings to bear that transcends the rule-based models undertaken by a variety of developers in nursing informatics. Neural networks challenge the argument that all rule-based systems are doomed to failure because of their finite number of rules. Neural nets represent extremely subtle and analog assessments that need not be based on any prior model to achieve significant differentiations. Thus neural networks represent a class of methodologies that can successfully identify patterns that may be extremely subtle and buried in a sea of information.

To understand how neural networks apply productively, we can present one simple example. Imagine that for a class of patients, such as those in ICU with a myocardial infarction, we label as "roses" all those who survive at least 72 hours (a definitive class). As attributes that could describe these "roses" (i.e., the 72-hour survivors), we list all their specific assessments, medications, outcome, vitals signs, and other possibly pertinent patient interventions and outcome measures during this period. Then the neural network



A

FIGURE 2.8. (A) Partial screen from the Clinical Repository. (B)Partial screen from the Rehab Area. (C) Order Review screen.

Discharge Evaluation Physical Therapy

Motor Control/Synergy

PHYSICAL THERAPY NEUROLOGICAL EVALUATION
Field can pop up or toggle

Motor Control/Synergy KEY:
S=Synergy O=Absent IS=Isolated NT=Not Tested
S1/4=S1/4 Range S1/2-S1/2 Range S3/4=S3/4 Range

Motor Control STATUS:	Initial 09/27/95 15:13		Discharge		
	L	R	L	R	
Hip Flexion	S1/2	S1/2			
Hip Extension	S1/2	S1/2			
Knee Flexion	S1/2	S1/2			
Knee Extension	S1/2	S1/2			
Plantar Flexion	S1/2	S1/2			
Dorsi Flexion	S1/2	S1/2			

Initial Comment:

F1: Help ESC:Cancel F10:Save F2:Clear F5:ChTime TAB:Copy
END:Sav/Next ENT:NxtFld F6:SigEvent Pag:History

Fri 09/29 12:58 BETH Radio-1 Brown, Joan W.

B

VIEW SCHEDULED ORDERS **Item 1 of 1**

Description	Priority	Start Date	Ordered By	Status
COMPLETED BLOOD COUNT WITH DIFFERENTIAL	Routine	12/14 14:00	AARON HARVEY C	12/13 Complete
CBC (BLOOD COUNT)-stat	STAT	12/14 17:58	AARON HARVEY C	12/14 Verified
ELECTROLYTES	Routine	12/14 17:58	AARON HARVEY C	12/14 Verified
COMPLETE BLOOD COUNT WITH DIFFERENTIAL	Routine	12/14 22:00	AARON HARVEY C	12/13 Verified
COMPLETE BLOOD COUNT WITH DIFFERENTIAL	Routine	12/15 6:00	AARON HARVEY C	12/13 On Hold

F1: Help ESC: Leave F11: History F7: MainMenu F8:AddOrder

C

FIGURE 2.8 *Continued*

output will be a weighted combination of those attributes which, when present, signal or identify patients likely to survive at least 72 hours. The constituent elements of the net (attributes with high weights) tell us which measures are significant in assessing the patients. Moreover the set of significant measures might be helpful to identify those with decreased likelihood of survival so that more intensive efforts might be applied, if possible.

A second application could be the selection of all patients who are admitted for a specific treatment (e.g., total hip replacement) and are discharged significantly earlier than average. These patients also are "roses," and the elements of care (medications given, frequency of ambulation, etc.) are all the attributes of interest. The network's identification of the most critical components that characterize early discharge become the elements of consideration for a critical pathway.

Hurdles to Overcome

The confirmation of the existence of a pattern (a positive signal) depends on the net's complex weighted aggregation of an array of attributes deemed important from among all the presenting data. Even though the neural network may signal when a pattern is being observed, however, there may not be any way to explain exactly which attributes of the data pattern the signal depends on. This failure to explain itself, which is due to the convoluted interconnectiveness of the final net, can be a major drawback in certain settings.

The successful application of neural network methodologies in this specific setting also calls for the ability to vary the attributes of concern. In other words, one may need to review a whole family of neural networks to determine which is superior in the selection of a set of critical attributes that can characterize the pattern under consideration.

To address these two hurdles—attribute ambiguity and the need to vary attributes—it is possible to use even newer advances from the areas of data mining and genetic algorithms to overcome the limitations of identifying the pertinent attributes that comprise a pattern.

Data Mining and Genetic Algorithms

Both data mining techniques and genetic algorithms can address some of the kinds of problems tackled by neural networks, but the former have the added advantage of providing their responses in explainable terms (Riolo, 1991; Bonelli & Parodi, 1991). Like neural networks, these new techniques take a table of data indicating a variety of attributes, such as actions taken during a patient's stay, in combination with outcome criteria (which may be viewed as defining a "rose"). For example, one can select all the drugs given to myocardial infarction patients during their stay in concert with outcomes such as length of stay and cost of care. If all patients with significantly low lengths of stay are the "roses" of interest, both these methods review the attributes shared by all patients to see whether the low-stay patients have characteristics in common. If buried within the data is the information that the low-stay patients were precisely the ones who took both anticoagulants and aspirin, the data mining and genetic algorithm methods will find and display this pattern (contributing to a clinical pathway definition). It is not necessary for every patient who stayed a reduced time to have undergone the regimen of anticoagulants and aspirin, since the methods are somewhat forgiving. The methods will find such patterns and represent them in clinically meaningful terms.

Data mining techniques can be more inclusive in searching the data for patterns, but one pays for this virtue by much longer search and analysis times when the methods are run on a computer. Genetic algorithms approach the search process with a series of guesses about a useful mix of attributes and vary (or "mutate") the selection of attributes under consideration to find a pattern in the data (Goldberg, 1989). This sampling approach (an analog to the genetic mutation process in the Darwinian sense) in certain circumstances permits a quick response, although it is possible that a pattern will be missed or that the patterns found will not be inclusive.

Both approaches are usually given selection criteria that define a "successful" record (e.g., "this record is an example of a 'rose' because the length of stay of the patient was below the average"). Both yield rules in meaningful terms that define patterns that arise within the desired outcomes cases. At times, the advantage of genetic algorithms is speed; although potentially slower, data mining has the advantage of possibly greater completeness in pattern definition.

Advanced Methodologies in PACE

The seventh-generation PACE product achieves significant new results by making possible the application of the newest methodologies of genetic algorithms to the vast clinical repository. Through the application of those methods, the PACE system can ascertain whether there is a pattern of care that represents a superior pattern with regard to such patient outcome measures as length of stay and fewest significant variances. The data can also be normalized to take into account the age of the patient and other mitigating factors (e.g., associated diagnoses such as diabetes, initial acuity of the patient, etc.). Thus the pattern recognition capacity can aid in finding the elements of care for defining clinical care pathways, based on the actual experience and history of care provided at a particular site. The method is neutral to any political or philosophical perspectives.

Concomitantly one could also identify other classes of patterns of care that lead to such outcomes as extended length of stay and the maintenance of very high acuity. With the possible advantage of speed, which the genetic algorithm approach may offer, the evaluation module supports real-time investigation and analysis. This approach puts an effective tool into the hands of hospital care evaluators to assess the possibly valuable, but hidden, data patterns contained in the clinical repository.

Accomplishments

With the culmination of this seventh generation of the PACE system, several very broad accomplishments are in hand. The evolution of the focus of this system again is the entire health care team. The information that will be collected will be completely consistent throughout the entire hospital system, be it order entry, standing orders, special procedures, or other categories. The advice and support in turn range over all areas, permitting the use of the product to examine drug interactions, potential complications, and other system interfaces in a unified and consistent fashion.

The PACE system now addresses the role of supporting and documenting the patient's entire medical record. This is a goal that has been envisioned from the earliest days of medical informatics (Weed, 1969; Blumberg, 1958; Powell & Wolf, 1981). Major efforts from the early 1960s over the past 30 years have worked toward this end result. PACE has demonstrated the natural evolution from a very focused arena of the provision of nursing patient care information to an expansion to the overall interdisciplinary needs of health care professionals in their many varied care settings.

As a consequence of this evolutionary approach, PACE represents a successful strategic solution to a very complex and difficult challenge that has confronted similar medical informatics efforts. In the past, medical record development often was initiated by undertaking the entire problem in a singular and unified approach. On the one hand, this strategy is conceptually pleasing. On the other hand, such an approach can be overwhelming, tackling as it does so many disparate issues at once. The PACE project's evolutionary strategy, moving from a core central nursing component to the larger whole, has allowed for the successful development of a holistic system that has proven useful and viable in today's health care settings.

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CHAPTER 3

Initial Knowledge Base Development

Acquisition of Information

In this chapter we identify and explore issues that must be addressed in the initial stages of developing a knowledge base. It might appear to the naive developer that the acquisition of knowledge is primarily an issue of access to experts. Actually, the availability of experts is the easiest component in the entire picture. The real issue is to ascertain what it is that one wishes to acquire from each expert. The information desired must be described so that there is compatibility between elements acquired from one expert in one area and another expert in some other area, as well as from future experts who supply information in the same domain in later years (Giuse et al., 1993; Giuse et al., 1993; Giuse et al., 1989; Suwa et al., 1982).

One cannot suppose that the experts providing the knowledge acquired will possess expertise outside their content-oriented domains. It is not a viable, strategic design to suppose that content experts have any knowledge about computer science or even a concern about the computer science knowledge base issues that underlie the content knowledge they bring to bear. They generally see themselves as content experts. Thus practical acquisition must reflect an awareness that the information will be supplied by content experts who are without awareness of the data structure issues that underlie acquisition. Typically, the experience of knowledge engineers has been to assume the role of midwife, accommodating the responses of the content experts to knowledge base demands.

Taxonomy for Knowledge Collection

The issue of knowledge acquisition must take into account a fundamental requirement of compatibility across the entire knowledge base. To achieve compatibility, there must be a devised taxonomy that orchestrates the nature of the elements that will comprise the desired information and the manner of clustering or "chunking" the components. This "chunking" of information, as psychologists call it, is a most critical issue. The organization of information as presented to the expert must be natural to the content expert's domain. If one organizes information inconsistently with the users' expectations of how information is to be collected, there will be a conflict between the manner in which information is provided and the manner by which the information can be accepted by the system. Hence, a global taxonomy, an organizational schema, is crucial in the acquisition of information.

As noted, this taxonomy must be innately compatible with the structure of the knowledge model of experts *within* each domain. However, if the system is to function over multidisciplinary domains, the structure of the knowledge models of each expert cannot conflict with the taxonomy *among* various sections. Not only must the taxonomy appear natural and intuitive in each section, but also it must remain globally compatible across sections. The challenge of developing an appropriate taxonomy to organize knowledge is not to be minimized. Without such a framework, it is impossible to achieve an underlying organization for the representation of knowledge that will be useful to support health sciences education or patient care.

Health Sciences Taxonomy

The consistency of the underlying requirements for addressing patient care permits a global taxonomy to arise, while remaining intuitively applicable in each individual domain, as specific Sections are encoded. Such a consistent taxonomy was devised and presented to all the health sciences schools for evaluation (Evans, 1977). The full listing of the top-level taxonomy used is provided in the Appendix. After a review by faculty of all the schools, a final version was accepted by all the health sciences for the development of the knowledge bases. Hence, this taxonomy had extremely wide applicability beyond the specific domain of nursing.

The actual taxonomy, which recapitulates the fundamental areas that are known in patient care in a very common, traditional manner, expresses a multiplicity of dimensions. There is an organizational schema that divides knowledge into traditional components such as problems in cardiovasculars, respiratory, and neurological areas, and the digestive system. At the same time there are also patient care issues such as the etiology of disease, its diagnosis, differential diagnosis, patient care, complications, treatments, and discharge teaching.

In the particular domain of nursing, one can expand subsections of the taxonomy with crucial subclassifications, such as nursing diagnoses categories. These categories organize parts of patient care in terms of a specific set of relevant clinical issues consistent with the role of nursing care. For example, in the treatment of the patient with myocardial infarction, nursing diagnoses that may apply involve issues related to impaired breathing patterns, activity intolerance, impaired gas exchange, and inadequate cardiac output. These various taxonomies and taxonomies within taxonomies become very crucial in the acquisition and organization of information in an orchestrated fashion.

In conjunction with acquisition of content, there is the issue of maintaining continuity and incremental growth in the acquisition of knowledge over time. One professional may in fact use the same set of taxonomies but redefine the information in a fundamentally different way. Unfortunately this recapitulation of information, which provides an opportunity for creativity and innovation on the part of the contributor, provides a headache and a challenge to the knowledge base manager. Thus, there must be very organized and well-defined rules by which contributors update and extend prior information. As we shall discuss in Chapter 4, these rules and developments are very important to ensure the efficiency and effectiveness of the acquisition process.

Knowledge Redesign

Changing Knowledge Organization

One can expect and even be certain that over time knowledge will be fundamentally reorganized in ways completely different from prior approaches. This shift is a natural function of the development of health care as we develop a better understanding of research and practice (Grobe, 1990). A radical shift in the organization of information, however, challenges the design of the knowledge base acquisition, since this reorganization must be implemented and orchestrated in an effective fashion within the knowledge base. Thus the basic design of the PACE system needed to permit the expected radical shifts in organization and to accommodate these shifts in some facile fashion. It is very important to recognize therefore that fixed approaches, which might be effective over the short term, would ultimately produce very rigid and expensive strategies.

Nursing Diagnoses Taxonomy

Of particular note in terms of nursing knowledge reorganization has been the introduction and wide use of nursing diagnoses for patient care (Campbell, 1978; Carpenito, 1983; Gordon, 1982; Jenny, 1989; North American Nursing Diagnosis Association, 1994). Within this context, there remain disputes among schools of thought on precisely how nursing diagnoses should be applied (Chang et al., 1988; Flaskerud & Halloran, 1980). Some purists might organize nursing care along nursing diagnoses without regard to the underlying medical diagnoses (i.e., disease state labels such as pneumonia or breast cancer) assigned by physicians to patients. In this case, nursing diagnoses would be identified and resolved without regard to the specific medically defined problem.

The preceding approach is in conflict with other schools of thought, which introduce nursing diagnoses within the context of specific medical diagnoses. For example, this perspective would assign to every primary type of medical diagnosis (e.g., myocardial infarction) a set of possibly appropriate nursing care issues as they are contextually addressed within that medically defined problem.

Finally, in some nursing circles, nursing diagnoses remain a foreign body, unaccepted by the medical and nursing professions alike. Although this last possibility may be disputed by some academic nursing educators, it is a fact. There are innumerable hospitals throughout the United States that have not employed nursing diagnoses for the actual nursing care. Thus, the issues that confront the choice of taxonomies include not only the knowledge base structures themselves but also the relationship of these taxonomies to user acceptance. Without user acceptance, the system will not be properly developed or used.

As a result, the organization of the knowledge must be flexible enough to accommodate different taxonomies (e.g., medical and/or nursing diagnoses). This flexibility becomes a challenge to any designer. The need to accommodate a variety of strategies may not be evident in a single hospital, but success in this area is essential for the wide dissemination of a knowledge-based system. Hence, if one wishes to achieve a wide customer base for any particular product, one must obtain and maintain knowledge in a fashion that permits various representations. Ultimately this approach involves techniques to store, organize, and represent knowledge in multiple formats. Techniques to address this problem are addressed in later chapters.

Changing Terminology

A final issue in the reorganization of knowledge arises when the terminology becomes confounded with other descriptors that were used in the past in one way and are now used in a different context (Iowa Intervention Project, 1992; Lang & Marek, 1990; McCloskey et al., 1990; McCormick, 1988). Naturally, computer-based systems have a more difficult time determining what was truly intended, since there may be no context to which the computer has access. The reorganization of knowledge represents an ongoing problem that usually increases in complexity over time. One should not underestimate the challenge for appropriate changes in the taxonomy as information and terminology are shifted.

Reorganizations in Health Care Delivery

In addition to changes in the taxonomies of information as medical sciences advance and information is reclassified, there are changes in how information is used when the process of health care delivery is changed (Lang &

Marek, 1990). When managed care, and in particular clinical pathways, became widely used, for example, the information that is aggregated includes not only the care issues but also the timing of the delivery of care, and the contingency of one care activity on another. As a result, the ability to represent these time dependencies of the presentation of care must be considered, along with the determination of conditions under which one step may follow the other, to comprise yet new design challenges that should be anticipated at the very onset. Again these issues necessitate a very flexible design.

Scaling Up the Knowledge Base

The expectation that the amount of information collected will grow exponentially fundamentally alters the kinds of issues one must address. It is similar to the conversion of a laboratory process to a commercial chemical engineering scale in an industrial setting. Scaling up of a knowledge base presents its own unique challenges to any effort.

Managing the Flow

In the case of clinical care knowledge acquisition, the amount of information that accrues over the entire domain, ranging from digestive to respiratory, to cardiovascular, obstetrics, preventive care, and so on, is enormous. Within each area, there is a vast array of information about disease states, syndromes, and other matters that need to be considered.

As that information is collected and as differentiation increases, simply the size and scope of the material grows quite quickly exponentially. To manage the size and scope of the information, schemes must be in place that help organize the contributions of expert knowledge. Processes must be in place that organize information as it comes in, manage and maintain the flow of information, and subsequently identify what additional information is needed, what is missing, and so on. Procedures are needed to simply coordinate the activities of a battery of experts who address the areas being defined. Thus, scaling up demands its own set of processes for the management of a huge number of details as well as linkages.

Rising Complexity

At first, it may seem that simply scaling up the organization in terms of its components (number of people working with the knowledge base, number of data entry staff, number of experts, etc.), can be accomplished by making increases corresponding to the growth in the size of the knowledge base areas. A brute-force increase is in fact precisely the problem, because it is not the case that all aspects can be increased without detriment to the efficiency of the entire knowledge acquisition process.

Many components of the expert knowledge interrelate with other components. One component may cross-reference another, creating special linkages; but these links must then be maintained. This is inevitably expensive in time and resources, since a change in one link requires keeping track of any requirements for a change in the other area the link cross-references. In addition, each consulting expert may have special needs, requiring individual attention and assistance. The larger the PACE knowledge base maintenance organization grew, the more intracommunication was required, significantly inhibiting productivity. As a result, a much smaller organizational team is far more effective to properly handle such problems.

Management Team Size

Unfortunately, using a small team to address all relationships among experts and information brings two difficulties to bear. First, the team needs a much more efficient, highly electronic approach to handling the flow of information, the explosion of lists, the changing expert personnel, the tracking of what has been added, what is to be reviewed or reconsidered, and so on. A small team is vulnerable to the very dangerous prospect of some disaster (transfer, departure, or death) eliminating its capability of maintaining the knowledge base. There is a delicate balance to be struck: the team that develops and manages the knowledge base must be small, but not so small a team that the loss of a member cripples the entire effort as a result of insufficient redundancy. Organizational size remains an ongoing balancing act for any organization involved in this kind of knowledge collection. Obviously, automating the knowledge acquisition process is essential for long-term success.

If we look at analogs to other domains that have developed large complex knowledge bases, we find that small teams comprising a handful of highly organized and efficient individuals are able to handle large-scale enterprises. In a similar vein, software development projects that have involved commercial products for PCs, for example, have also used small and highly talented teams that are able to develop the project with the kind of intensity that must be brought to bear on challenges of this magnitude. Organizations that have undertaken massive approaches with complex armies of individuals have sometimes found that the bureaucratic enterprise overwhelms the capacity to achieve the goals at hand.

The counterpoint to highly efficient, smaller units is the need for even greater communication among these efficient and independent elements so that continuity is maintained. In our case, continuity was required between the software developers, who needed to extend the capacity of the software to handle the increased size and scope of the project, and the knowledge base managers, who were collecting the information that had to be compatible with the software developments that were unfolding. The challenge of communication and coordination between these two quite disparate groups should never be underestimated.

Knowledge Base Contributors

Changing Content Experts

It is important to recognize that the contributors to the knowledge base are content expert clinicians without formal systems training. Certainly this has been the case from the early days of the PACE project throughout the length of the entire knowledge base expansion. The implications of this limitation are quite pronounced. Since the clinicians have content knowledge but no particular computer knowledge, they are able to provide their information strictly within the context of clinical expertise. As a result, a system had to be devised that would permit the clinicians to provide their input in a manner they found comfortable that still would be compatible with the computer-based needs of the system. A most central issue in knowledge base acquisition remains the collection of information from experts in a manner permiting the content experts to be just that—content experts—without requiring additional expertise, be it knowledge of an artificial intelligence language such as LISP, or knowledge of computer base system, data structures, or other informatics arcana.

To accomplish this design goal, as noted earlier, a primary strategic approach was to define clinical taxonomies that collected information from clinicians in a completely natural manner. An important design issue in any information collection system is the need to anticipate the overwhelming likelihood that the contributors will be outsiders (to the project team) who will have a limited tolerance for any kind of syntactical rules that might be imposed on how they can convey the content they are supposed to provide. They are interested in their content but are usually willing to provide it (even under contract) only in a manner that is consistent with their view or model of the particular content area. System design should accommodate this kind of clinical expectation. Not only will the roster of contributing clinicians change, but also their approach to certain areas will obviously evolve as expertise in that area itself evolves. Thus one must not only anticipate encoding by clinical content experts performing strictly as clinicians per se, but also the replacement among clinicians over time as new individuals add to the work of others.

From Expert to Expert

An implication of this expected shift is that the contributions of each clinician must be presented in a fashion intelligible to new clinicians so that necessary modifications become apparent and can be easily provided (Giuse, 1993). This means that the information must be cogent in the world the clinician works in. If information is presented in a strange database fashion, using peculiar computer science data structures to organize it (or another "foreign schema"), the clinicians will find the task far too difficult. If one must continually train clinicians to master some "new language" to make a contribution, the amount of time and energy needed will expand exponentially with the size of the knowledge base. Such an approach will likely be quite ineffective or inefficient in the overall design. Thus, it is important that the design accept the clinicians on their own grounds, which entails the anticipation of information updates strictly in terms of typical clinical content. This also means that all external knowledge base contributions needed will be defined in a clinically intuitive fashion so that any clinician can respond accordingly.

Continuity and Discontinuity

Knowledge Base Managers

A final set of planning and development issues we shall discuss in knowledge base acquisition and related software development involves the expectation of discontinuity in three key areas. The first area of discontinuity concerns knowledge base managers of the support organization. Since these personnel will need to be replaced, the whole management process must be easily conveyed to the next set of knowledge base managers to ensure uninterrupted continuity. To keep the process moving smoothly, without a break, the complexity and demands of the position must be such that the managers' job is transferable when the time and requirements necessitate.

Hardware

A second area at risk from a lack of continuity involves computers themselves and the inevitable hardware changes. At the onset in 1971, as the conceptual basis for the PACE project unfolded, the only operative high-level language effectively available was FORTRAN, an early engineering-oriented language. In addition, an entire mainframe was utilized simply to respond to a single inquiry. A single response on a very large IBM 360 machine took approximately 6 hours of processing time. By the time implementation was achieved and dissemination accomplished, fast personal computers (PCs) were available, and the speed was orders of magnitude greater; the storage capacity, also, was many times larger.

We defer discussion of the third area of discontinuity until page 71, turning in the next two sections to additional computer related issues.

Languages and Open Architecture

PACE's underlying operating systems have been transformed and changed, and the applicable languages have evolved. In addition, the interest in open architecture demanded systems compatible with a vast array of computer equipment, languages, and operating systems. As a result, it was necessary to maintain continuity across all these differences. Such challenges are likely to continue, even though manufacturers and developers who recognize the need for mutual compatibility have declared open architecture positions.

As computer languages of the fourth and higher generations are selected and used to implement systems, incompatibilities will continue to arise, and it will be necessary to alter the underlying hardware used to run these different advanced packages. As a result, there will remain the expectation of fundamentally deep and different changes in the nature of the hardware, the operating systems, and the associated languages and software used on both. The fundamental design and implementation of every system must have the capacity to transcend these particular changes.

It would be a mistake to assume that the need just expressed is simply a statement about the nature of computer science and its implementation as a whole, with no apparent relation to knowledge base acquisition. The process of knowledge base acquisition can grow extraordinarily complex. The history of this project shows a substantial increase in the interrelationships and complexity of the knowledge base. As a result, the knowledge base depends heavily on the continued advancement of increasingly fast machinery and greater storage capabilities to permit the applications to run efficiently, even if all else remains constant. Moreover, we have found that over time, the original expectations of the health care team and the implications of the interconnectiveness among health professionals will demand ever more complex associations between knowledge bases that affect physicians, nurses, and other health care providers. Not only will this system necessarily interact with more complex information and other associated taxonomies, but there will have to be "translators" between one taxonomy and another to permit the interaction among the systems, not only at a computer base level, but also at an information level.

The issues in open architecture and interoperability identified above are growing far more vast and complex. As managed care unfolds throughout the United States, the need to articulate one component of the care picture with another to ensure their interaction becomes even more pronounced. A prime requisite is compatibility among systems that may have been designed and developed in isolation. For example, interaction may be required between an order entry system and the nursing system as well as other aspects of the clinical record (which may include the pharmacy system, record keeping, and so on). Thus, the demands of compatibility increase along software, hardware, and taxonomic and knowledge base organization lines.

Informational Dependencies

Over the past several years, there has been a much greater recognition of the informational dependencies among health care professionals as patient care activities impinge on each other. This interrelationship has always been acknowledged from a care point of view as the health care team has interacted on a day-to-day basis. As our knowledge base developments began, the artificial isolation of individual knowledge base constructions had meant that each knowledge base was characterized only by that discipline's descriptions. As the demands of care come to require closer information interactions, however, knowledge base developments must follow suit. Thus, the ever-increasing interactions among health care providers have increased the need for knowledge base compatibility. Currently continuity is lacking between previously developed financial systems, order entry systems, and admissions/discharge transfer programs, and so on. The need for continuity will transcend prior disparate developments and will ultimately affect the entire information enterprise.

We have seen in recent years a radical move away from stand-alone systems, which characterized our initial efforts and were consistent with the hospital community at that time. The current long-term trend is for integrated, health care–wide systems and compatibility. Hospital-wide systems that had become compartmentalized are now slowly coming together as a consequence of the move toward an electronic medical record. Certainly, efforts at an integrated medical record have been ongoing for far more than a quarter-century and will be pursued in the foreseeable future. The size and scope of this problem continues to be underestimated by all participants except those who actually have tried to accomplish this very difficult task. Nonetheless, strong forces are visible from many quarters to electronically capture and integrate the entire spectrum of patient care information among all health professionals.

Managing Staff Discontinuity

A final issue in terms of continuity and discontinuity in knowledge base acquisition is the issue of personnel involvement. Personnel continuity in knowledge base acquisition helps maintain a common and unified philosophy and intent regarding which knowledge areas are to be included and even how content is to be acquired (e.g., appendicitis from the internist's or surgeon's point of view). Personnel continuity also helps maintain knowledge base continuity and uniformity across development time. This point may seem obvious, but in practice, the challenge becomes quite formidable.

For example, among our knowledge base managers and systems programmers, turnover and change occurred several times. Yet documentation regarding philosophy and conceptual approach among such managers is understandably slim. Thus, the need to maintain conceptual continuity through changes in managerial shifts becomes important; there must be continuity during changes of project leadership in each of these areas (the knowledge base acquisition area and the software area that handles the knowledge) so that common goals and approaches remain consistent. It is a challenge to provide this type of documentation to ensure continuity.

Ultimately, the challenge can be seen as one involving both formal documentation combined with personnel management that enables fundamentally different staff constituencies (the software developers versus the knowledge base managers) to have the dialogue needed to achieve the necessary knowledge base development continuity. As the knowledge base increases in size and the software developers and knowledge base management groups also increase in size, the challenge is increased. Thus these personnel issues assume paramount importance in the effort to accomplish the defined goals.

Issues for the Future

Finally, we take note of several key issues as they can be envisioned over the horizon. Even at this juncture, it is apparent that the segregation of health care information into domains associated with each health care profession (e.g., nursing systems, physician-based systems) is giving way to an integrated health care team prospective. The pendulum has begun to move strongly in this direction, and as pendulums will, it is picking up speed. This means that knowledge base acquisition and concomitant software will begin to be fused into complexes that must correlate all health care issues, including drug interactions and drug monitoring, order entry with Kardex requirements, and nursing diagnoses with associated complications. There is the need to maintain continuity of care among patients who shift from outpatient settings to inpatient settings and vice versa. This integration requires more complex approaches, especially as the demands for interactive care increase.

It is clearly the case that complexity and interconnectedness are conditions that will continue to increase rapidly. Systems will be required to address complexity issues and must be prepared to interact with each other even in the face of design incompatibilities (based on software, hardware, language or systems choices, etc.). In later chapters we shall specifically discuss how the PACE system has been able to address some of these issues, in part by extending its methodology into newer and more complex domains, building on its semantic network as well as other project principles.

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CHAPTER 4

Acquiring, Maintaining, and Managing a Knowledge Base

Acquiring a Knowledge Base

Selecting Content Experts

Selecting experts is much like selecting a "significant other"—an extremely subtle and idiosyncratic process. Which individuals will prove to be useful contributors is hard to predict simply by their clinical credentials and performance alone. The personality of the experts becomes a significant factor. It is important that they be willing to follow the established rules by which information is collected. The taxonomy for all specific entries that must be honored has been discussed. There are, in addition, individual aspects of each taxonomic entry that require information from the expert, as well as careful review of what the expert has actually provided.

Some individuals are willing to organize their clinical expertise and information in the context of the taxonomic categories presented, recognizing that this is necessary to achieve the goal at hand. Other experts simply do not have the patience or tolerance to accept this kind of restriction. They have their own drummer; they have a message to convey; and they will provide that information although at times it may be tangentially correlated to whatever categories, questions, or requirements are presented. Obviously the latter are less efficient partners in the process of knowledge information acquisition than those who are more structured.

In addition, we have recognized that some excellent clinicians, who are so recognized, cannot articulate or verbally explicate precisely what it is that they know. Actually identifying the components of one's knowledge even within the clinical context of the area in which one works is a very subtle task. Clearly the need for a knowledge base manager is established in all circumstances, and the need for a knowledge engineer arose a number of crucial times. Fortunately, the author's experience at Carnegie-Mellon University (1967–1974) focusing on artificial intelligence techniques, particularly knowledge engineering, provided the requisite training ground.

In the analogous experience of collecting physician-based knowledge in the early years of the project, various very successful and intelligent medical residents were asked to provide contributions to the knowledge base. The residents were startled by their inability to explicitly articulate the information they actually held in order to codify it for the project. A modest longitudinal study was done in which several outstanding residents were tracked over a number of years. As their residency was completed along with several years of practice, they demonstrated the capability to articulate requested expertise, in sharp contrast to their prior capabilities as residents.

Experienced Contributors

Maturation along with clinical experience was invaluable in coding knowledge. Among experienced clinicians, certain individuals are able to identify their clinical insights while other simply lack a degree of innate capacity to do so. Although training could help aid the latter category to be significant contributors, usually it is not feasible to invest the necessary time and resources. As a result, individual experts and their respective personalities must be evaluated, and those who have at least a natural bent and capability are best pursued.

One of the major issues confronting knowledge acquisition is the need for *basic* information that is extremely crucial and germane. There is a tendency to dismiss the obvious principles or perhaps not even recognize them as part of the basic knowledge and understanding that an expert brings to bear. Not every situation is complex and subtle; at times a clear and grounded understanding is the most appropriate knowledge base from which good patient care arises. As a result, this basic knowledge not only must be at the expert's fingertips, but also must be clearly articulated. In addition, lacking clinical problems and patient presentations, the expert must still be able to identify the kinds of information that should be presented to inclusively cover an area or problem domain. Thus, another important attribute for a good content expert is the capacity to invoke the key principles and identify them without benefit of immediate patient care guiding the explanation.

Knowledge Specificity

One of the most difficult and challenging issues that continues to confront knowledge acquisition is the question of the degree of specificity the knowledge base must provide to be an appropriate presentation of clinical insights (Abraham & Fitzpatrick, 1987; Benner, 1983; Benner 1984; Brennan & McHugh, 1987; Carper, 1978). This issue of the degree of detail has created an enormous amount of contentiousness and conflict, extending from the beginning of the project to this very day. It is not an issue that can be resolved, because philosophically it stems from different points of view regarding the basic practice of nursing care and the degree of basic understanding that any nurse brings to bear (Ozbolt, 1986).

On the one hand, there have been those who criticized the knowledge base as sometimes insulting to nurses by its presentation of particularly trivial aspects of care. Such benchmarks of what were trivial components at times were considered by other practicing nurses to be useful and appropriate reminders. These critics remained convinced that basic information was superfluous other than to those nurses who have been isolated in remote settings for innumerable years. On the other hand, there have been those in nursing leadership, in hospitals as well as in academia, who have presented the opposite position that the knowledge base should have a cookbook presentation of every activity the nurse could be expected to bring to bear to achieve patient care. These nursing leaders have provided the perspective that the system should be utterly definitive in its presentation. Such individuals have from time to time also articulated the position that such computer-based systems could significantly reduce or eliminate the professional nurse and thus provide economies to financially strapped hospitals. The project at its heart has always rejected the particular philosophical notion that nursing can be reduced to a time-and-motion study, such that all care can be completed mechanized.

In an effort to reconcile philosophical differences, a question typically arises as to whether the system could be tailored to an individual's preference, permitting different levels of response at the user's discretion. Although at first blush this degree of flexibility may seem attractive, several difficulties arise as the strategy is pursued. How does the user indicate his or her level of competency about a particular patient care domain? If we lack critical knowledge and yet do not know of such deficiencies, can we assess ourselves properly? Moreover, since there is no lingua franca that communicates or reflects such competency levels, we shall have ambiguity as to whether the system omitted some trivial feature that, for a particular user, was actually necessary. Typically our understanding of even a focused area ranges from great depth to superficiality, especially in this day of ever-increasing knowledge differentiation. Would the user constantly be asked to provide a measure of understanding or competency for every inquiry? Could the system managers ever feel confident they could omit important (although basic) information in the system's recommendations, just in case this simple point might then be omitted in subsequent care, to the dire detriment of some patient? Last but not least, the segregation of information presentation (e.g., this amount for advanced, this much more for intermediate) adds continual decision making to knowledge collection, knowledge updates, and new area development. This discussion indicates how seemingly simple and convenient design recommendations reverberate across knowledge base management in far more complex ways than one might at first perceive.

PACE Level of Knowledge Detail

The PACE system, although it approaches very great detail, nonetheless supposes that an intelligent person is evaluating the recommendations and using professional nursing judgment in its application. The issue of the degree of detail remains challenging (Probst & Rush, 1991; Probst & Rush, 1990). When various recommendations for diet, for example, are presented, one questions the extent to which concrete and detailed examples should be available. If certain recommendations for nursing interventions have been made, it must be decided when definitive details should be made available if the nurse requests them, and to what extent.

The approach to the level of detail and the degree of specification of the knowledge in the knowledge base has remained one of trial and error throughout the entire development of the project over the last twenty years of knowledge base development. The extent of knowledge base specificity cannot be resolved, since it stems from fundamentally different perspectives among various evaluators about the identity of the actual user. Thus, from a practical point of view, what has happened in the PACE project has been a pragmatic evaluation based on a very wide sample of user communities to ascertain the level of detail that appears to be most appropriate and effective, without overwhelming the nurse with a counterproductive amount of detail. This pragmatism has driven a reasonable natural balance, which has produced the results available today.

Increasing Detail

A great deal of extremely basic detail has been desired by nurses, some of whom feel very comfortable eliminating the portions they no longer wish to address, but nonetheless prefer to be in information deletion mode rather than addition mode. Conceptually it is much easier to quickly eliminate things that are superfluous than to generate omissions that were deemed basic but nonetheless may fall through the cracks in any particular setting. The system in its current release also is able to draw on and create detailed work lists and to form specific detailed implementation plans, tying them into Kardex activities, which the nurse historically has also implemented, so that the program's pragmatism is apparent. This balance, as it shifts in today's patient care world, continues to move toward the detailed and specific levels.

In part, this shift arises because of the knowledge explosion and the requirements and demands of nursing care. Formerly optional actions are now mandated activities (with associated documentation requirements) and are part of the responsibility of the competent professional nurse. Thus although they are aware of the requirements and can create such lists, nurses prefer to use their evaluation and assessment skills to prune lists rather than to take the time to make extensive specific additions. The system certainly accommodates and welcomes any additions and permits the nurse to insert them. As the time pressures increase on nursing and the amount of time allocated per unit of patient care decreases, however, the nurse finds the deletion strategy the only viable one most of the time. Thus, knowledge base experts are continually pushed to identify very specific detail, formatting measurable patient care outcomes, and using operational specificity in their provision of nursing knowledge.

Knowledge Base Depth

The question of depth also arises. How much of the range of variations should be addressed, even though some instances may be extremely obscure and remote? This question particularly comes into play when nursing diagnoses are recommended for a given medical diagnosis. In a single setting, two or three nursing diagnoses may accommodate and account for most of the phenomena nearly all the time. However, it is certainly the case and easily recognized that certain extreme situations could invoke a much wider range of appropriate and necessary nursing diagnoses. As a result, the recommended list could run from three of the primary diagnoses most often encountered, which can account for most of the phenomena, to ten or twelve, to account for the bizarre, the esoteric, and the extreme. Therefore, the experts contributing to the knowledge base are now asked to prioritize information such as pertinent nursing diagnoses just so that users gain the added benefit of this differentiation. Not only is it appropriate to ask whether all the basic information has been provided, but also it is crucial to determine the depth of the information or the degree of complexity provided, as well as the extent of prioritization. Hence, the need to balance breadth and depth is never to be underestimated. It presents an evolving challenge, and the pragmatism of the knowledge base becomes its own self-fulfilling answer.

Clinical Feedback Loop

As various clinical sites utilize the knowledge base and bring to bear commentary and requests that are factored back to the experts, the resulting feedback cycle permits the knowledge base to respond specifically to the user community. This feedback loop, which originally had been designed to provide feedback to academia, now yields feedback into the knowledge base development of the commercial product itself. It is an extremely fortuitous feedback loop because it obviously serves the customers who are the users of the product. As the user community expands, the feedback loop continues to expand. The pragmatic tuning of needs to requirements is achieved, and the knowledge base becomes more compatible with these mandates.

The results of feedback have led to much greater basic information detail, with much more effort to avoid providing unnecessary complexity of care.

Since complex patient care (relative to the area under consideration) arises more infrequently by definition, these additions are desired far less often on the part of busy nurses and are invoked by them only in more extreme cases. Thus the pressure of time in the working scenario in nearly all hospitals requires a richness in the basics and a greater degree of breadth. Concomitantly there is greater caution in terms of depth and complexity provided, allowing this information to be invoked only when the nurse feels that this additional commentary is needed or is appropriate. This balance continues to represent the needs in the nursing population across the country as a whole.

Accommodating Style Changes in Knowledge Base Updates

In the acquisition of knowledge, another important issue arises in terms of whether an expert is providing an update that represents a deep and philosophical change or just a stylistic variation representing that individual's approach to the very same material. Stylistic changes that present no new information are themselves obviously expensive. Thus it is important in the acquisition of knowledge that the expert content contributor distinguish between stylistic variation and fundamental information update. This is a difficult distinction for some experts to make. An expert who feels that his or her style represents in fact an improvement will present us with a change that this individual would rank as mandated. However, based on an independent assessment, one can ascertain that the same information has simply been rearticulated in another fashion. It is important to provide guidelines and rules that will enable experts to determine when they have made a style change (and thus should tend to suppress it), and when they in fact are providing an effective update.

This dichotomy emphasizes the role of guidelines and how well they are followed, although guidelines alone cannot do the whole job. Certain experts are willing to offer content changes without attempting to impose changes in style, while others find this impossible. At the onset of the development of PACE, some nurses who were asked to provide input to the system, and to alter their style to fit both the taxonomy and the explicit need to minimize change, preferred to terminate their relationship with the School of Nursing than to consider such an option. Hence, this requirement to accommodate knowledge collection rules can be a very contentious matter, and it becomes an important issue as a qualifier to identify suitable experts.

Multidisciplinary Knowledge Base Management

From the description above, it becomes apparent why high-level professional management of the acquisition of information is so important. We found it was crucial to use outstanding nursing personnel in a managerial mode to negotiate and interact with similar professionals. Their involvement was needed to help guide and instruct expert nurses in the development of expert information or in the advancement of previously developed knowledge base expertise. Without such management, it is probably unlikely that a knowledge base can be acquired and maintained.

The belief that experts simply could collect and provide information, which could be directly incorporated, is a belief that has been in the common lore as a reasonable hypothesis. It is advanced only by those who have never undertaken the effort. Other projects that had content experts who also were totally expert in the project's knowledge advancement were able to "demonstrate" that the experts (viewed as individuals "at random") could in fact contribute. These experts were not "random" at all, but highly skillful members of the projects. The *real* use of nonproject experts represents a challenge that requires management of these outside individuals (Giuse et al., 1993; Giuse et al., 1993; Giuse et al., 1989; Giuse et al., 1988; Giuse et al., 1990; Lassez, 1989; Mars & Miller, 1986). One PACE manager fortunately can orchestrate many dozens of experts as long as each expert's training is well grounded in (and responsive to) the needs of the project. Thus to ensure the success of the effort, the knowledge base management team must draw on knowledge engineering expertise, knowledge base management capabilities, and the contributions of content professionals themselves (as managers) (Musen, 1989; Miller et al., 1986; Politakis, 1982; Suwa et al., 1982; Widmer & Nagele, 1993).

Knowledge Validation

A major issue confronting the acquisition of information was the question of how one knows that the information one has collected is in fact very good information (Mars & Miller, 1986; Politakis, 1982). This point essentially raises the question of validation and proof of the accuracy of the information. Carried to the extreme, however, this validation mandate can be a completely self-defeating inquiry. The confirmation that a recommendation, or any specific nursing action, is without question a well-advised recommendation is proof that cannot be obtained. It is a requirement that probably will never be achieved, practically speaking, in the extreme detail of the knowledge base. Rather, we used a far more subjective assessment. That assessment was the determination of whether other experts found the recommendations to be appropriate, useful, and valuable. One good validation of the information in the knowledge base has been the willingness of hospitals to renew their license to use it. Utilization of the system helps demonstrate its efficacy.

There remains however the intellectual question about the veracity of the information. There are those who suggest that large-scale validation studies determining all appropriate nursing diagnoses, and requiring validation of all recommendations, would be a minimum prerequisite for the dissemination of any information. Such suggestions represent, in the view of this author, the extreme position that all nursing care should be proven before any nursing care is provided. By this reasoning, perhaps all schools of nursing would have to close tomorrow, since faculty are educating nurses and at the same time do not have absolute validation and verification of all the information they provide.

The enterprise to validate all nursing information in a clinical setting represents a goal that may well not be achieved in the foreseeable future. Given the size, the scope, and the cost of undertaking such an effort, as attractive and desirable as it may be, it is not likely to be quickly funded in the context of the tight demands on research dollars that all researchers and research institutions face.

One of the major difficulties that would confound such a validation/verification effort may be summarized as follows: given any specific methodology for the testing that would be necessary, innumerable nursing professionals would not concur with the verification which ensued. Not only would validation confront a variety of different models of care, be it Roy's approach or Rogers's or others, but the population to which such patient care was ascribed as well as the geographic area of the patient care would impinge on the selection and choices involved. Hence, such a requirement for verification may not be forthcoming in any reasonable length of time. We shall see the rise of excellent systems, but their practical value will be confirmed by their use and in their support of patient care, rather than in a completely scientific verification of all the information.

Nursing Care Validation

Yet another issue in the verification of knowledge bases often arises. There is the desire that all information supplied be supported by a scientific argument tracing the recommendation for a specific patient care intervention back to an etiologic or assessment mandate from which the recommendation stems. As a result of this perspective, it is sometimes stated that nursing systems with knowledge bases should be able to provide a logical pathway that shows the assessment or etiologic basis for the recommendation. From a practical point of view, this requirement has not yet come forward from any hospital-based nursing center in which the system has been placed. Nurses utilizing the system do not have the time to invoke the etiologic and assessment pathways for the innumerable basic and advanced recommendations the system would make for any particular patient care problem presented. Clinical nursing in care settings has continued to insist on quick, telegraphic, appropriate recommendations that can be easily utilized. The appropriateness of the recommendations is ascertained on the basis of the nurses' assessments.

It is certainly the case that in an academic setting students would benefit from the intellectual connection that tied etiologic and assessment considerations to subsequent care activity. This would be very helpful, and in fact, would be a very useful teaching device. From a clinical implementation point of view, however, in terms of a practical system in the care setting, such logical pathways have not been a mandate from clinical care settings.

Moreover, the capacity to develop an etiologic and or assessment connection between every recommendation and its origins would in fact entail an exponential explosion of managerial requirements of the knowledge acquisition process. As a consequence, the complexity of the system would escalate, as would the size and scope of the knowledge that would be part of every delivered system. In turn, the demands on the computer support as well as the software would escalate exponentially in the context of such a requirement. Practical considerations, as mundane as they may sound, become extremely crucial in achieving a viable acquisition of knowledge that is germane to clinical practice as it unfolds throughout the country for the foreseeable future.

Bibliographic Resources

Associated with this application has been a somewhat similar development that was not anticipated as the project first unfolded. At the onset, bibliographic citations were provided to support virtually every aspect of care that was recommended. As a consequence, the ability to cite a specific modern and up-to-date nursing bibliographic resource to support the care recommendation was printed out as a regular part of every recommendation. This vast bibliographic support process was repeatedly suppressed by practical nursing care providers, since information overload accrued. It was not that the nurses minded or that they did not desire the bibliographic information; they appreciated it as a resource. Nonetheless they felt it was best considered to be a background truth that they did not really need in a clinical setting. As a consequence, the validation of recommendations by citation resource became an optional system report, although still strongly pursued and maintained in the knowledge base acquisition process.

Experts are still required to provide documented bibliographic citations for each recommendation. One citation may cover several recommended constituent parts; up-to-date and germane citations may be provided that cover several steps. These data are kept as part of the background knowledge information that is available to the system. The material is visually suppressed and serves only as a background resource for the system, since it has not been evoked in any practical clinical setting to date. In contrast, in an academic setting, bibliographic information is obviously an element of great interest. However the usefulness of the PACE system in an academic setting has not proven to be a main application domain. An original goal of the project was to develop a practical tool that would have impact on patient care in the clinical community at large. The instructional process within academia, a special case, remains an application area that is secondary to the primary one of affecting patient care. The present purpose of bibliographic documentation primarily is to assure the knowledge base manager that the experts are drawing on the most up-to-date information.

Maintaining and Extending a Knowledge Base

The initial acquisition of a knowledge base may seem to be very similar to maintaining and extending a knowledge base. This is to some degree true. However the maintenance of the knowledge base as well as its extension introduces several additional important mandates that must be addressed.

Economic Issues

The questions of economies and cost arise immediately. Simply maintaining the knowledge base requires continuous management, and this requires a continuous infusion of human resources. Maintenance is significantly affected by system utilization, which in turn generates income. The altruistic maintenance of the knowledge base without a financial feedback loop guarantees that at some point interest in maintaining such a vast enterprise will subside; any maintenance organization will grow weary, and ultimately the knowledge base will likely be abandoned. This may sound like a simple point, but the implications are quite pronounced. The maintenance of a vast and ever-growing knowledge base, along with the hiring and instructing of experts, requires an ever-growing investment of time and resources that mandates some sort of *financial return* if the effort is to remain viable.

Commercial Support

In the most typical of cases, the knowledge base will have to have some commercial application and prospect of dissemination, to ensure the establishment of a successful economic feedback loop. By implication, then, the usefulness and applicability of the knowledge base must be consistent with some user community needs. It is also implied that there is some sort of distribution that is efficient and effective and will permit those who wish to utilize the knowledge base to do so.

The dissemination of a knowledge base as a commercial enterprise implies efforts such as marketing, sales support, and customer service and support. This calls for a reasonably large enterprise, assuming that the knowledge base itself is reasonably vast. In addition, if the expertise associated with the knowledge base is to remain at a high level, it involves the ongoing supply of revenue to ensure that this kind of quality is maintained. Without these assurances, the use of the knowledge base will decline, and thus revenue will decline. Hence a cycle is established in which added quality is required to promote use, which results in economic feedback. The maintenance of a knowledge base immediately implies a significant and active user community and a (likely commercial) distribution enterprise.

Role of the User (Clinical) Community

On the one hand, it may be said that the custodian of the knowledge base is the academic research community. On the other hand, since the user community is essential to the maintenance of the knowledge base, as the user community evolves and changes, the knowledge base itself must be kept consistent with its expected needs. Thus, maintaining the knowledge base in effect also entails changing the knowledge base in response to the practicing clinical community. Maintaining the knowledge base requires that major intellectual trends be addressed and accommodated. Indeed, the significant introduction at a national level of nursing diagnoses under the North American Nursing Diagnoses Association (NANDA) umbrella has required the incorporation of this model of nursing care in the knowledge base organization. Hence, the academic research community, important as it is in the maintenance of the knowledge base, helps shape the knowledge base over time. Concomitantly the user clinical community changes in response to global conceptual changes in health care trends. The newer trend toward the utilization of critical pathways and managed care in terms of managing resources in patient care also affects the way the knowledge base must be organized. Thus, maintenance requires continual responses to needs collected from both communities in the utilization of the knowledge base itself.

Pilot Versus Commercial Projects

Another issue in the maintenance of the knowledge base involves the personnel at the "pilot level" compared to a "commercial product" level. There are many approaches and strategies that will work at the pilot level when those who are maintaining the knowledge base are in fact the project developers. In other projects reported in the medical informatics domain, the original researchers are the knowledge base maintainers. These people bring to bear vast and subtle expertise and information in their efforts to maintain the initial pilot project effort. When the pilot project is scaled up to commercial levels, however, it is possible that project developers as basic researchers will not continue as knowledge base managers. As a consequence, the commercial product must entail management approaches that do not assume the kind of expertise and understanding typical of an original project developer. Thus as the project is substantially scaled up in size and scope, to maintain an ever-increasing knowledge base, the processes that are defined will come more and more to depend on *process* and *system*, rather than being dependent on a specific *person*. Often it is not apparent until scaling up is undertaken what subtlety of design has been incorporated by a project leader in knowledge base maintenance. Then the recognition that the knowledge base manager must be fluent in LISP, PROLOG, and C++, for example, stands out as an unfortunate discovery.

Maintaining Interest

Another interesting human dimension is introduced in the maintenance of a large knowledge base. On the one hand, the creation of such a knowledge base would be of great interest to practitioners in the field and indeed represents a genuine contribution to the field itself. On the other hand, the *maintenance* of the knowledge base may not appeal to such project developers, who may be informatics *researchers*, interested in other issues.

Indeed, the slowly diffused and diminished interest on the part of an original project director in the continual maintenance of a knowledge base can lead to the demise of the system. This may seem like a mishap that is not endemic to such systems. However, the roots of such loss of interest may be deep and subtle. As noted before, it is necessary for a dynamic team to be able to address the complexity that is required to accomplish the project. As a consequence, the core team may be, and usually is, rather small. With such a small team, disinterest on the part of just one or two key participants can prove fatal to subsequent commercialization and implementation of the project and product. It could be disastrous if the failure of certain key individuals to remain viably interested were misinterpreted as a sign that the effort was not viable. An extraordinary effort is needed to keep up an active interest in a project that could well extend 5, 10, 20, or more years before its implementation is complete. To get the project to a level of viability necessary for ultimate success, a handoff to a commercial (or analogous) organization becomes mandatory. Other handoffs, such as to governmental agencies or to professional organizations, may well be possible. However the effective requirement is the same: as interest diminishes among some of the originators or initial supporters, the initial development team must be expanded to include individuals governed by the goal to drive the project forward.

Extending the Knowledge Base

Defining a Valid Extension

Extending the knowledge base may seem like a straightforward enterprise. Pragmatic implementation, however, introduces another set of issues. One issue that arises is the question of what constitutes a valid extension of the knowledge base. Information that is still research based or experimental may or may not be an appropriate addition. These choices must themselves be governed by a series of rules as well as procedures by which experts can somewhat easily or at least effectively ascertain whether an addition should be made.

Certain difficulties arise that transcend the easier professional choices. For example, it was recognized many years ago that nursing diagnoses would represent a major wave, more than just a passing fancy. The incorporation of nursing diagnoses throughout the entire knowledge base for every single solitary problem, issue, or condition addressed by the knowledge base represented certainly a nontrivial extension. It was estimated that the knowledge base addresses over 2,000 different diagnoses, each of which involves on average about 10 problems or conditions, yielding 20,000 elements at issue. Even this number may substantially underrepresent the matter. As a result, the decision to extend and incorporate nursing diagnoses throughout all this information would have to be made with great care, since the effort would take quite a period of time and could represent an erroneous pathway that turned out to be inappropriate upon completion of the entire enterprise. Thus, a sense of the likely primary paths of intellectual progress is needed to ensure the planning and the lead time necessary to incorporate a transformation desired by the user community as a whole.

In addition, care strategies themselves have both long-term trends as well as short-term fads. A long-term transformation involves the issues of managed care as well as the substantial move of some tertiary care traditionally provided in the hospital to outpatient care in a variety of outpatient settings. As a result, all these transformations have an impact on the strategic planning for properly extending the knowledge base into likely domains. Since any transformation must be accomplished across the entire range of issues the knowledge base addresses, the price of transformations increases over time in at least a linear fashion. Hence the successful commercialization and customer use of the product require an intuitive sense of the direction and the evolution of the field. An accurate sense becomes even more crucial if the product is to be actively usable as the field recognizes new trends as they unfold.

Implications of Knowledge Base Growth

When the knowledge base is extended, several changes may affect every domain, and at the same time, the number of total domains continues to rise. The net effect is an exponential increase in the size and scope of the knowledge base as an extension is elected for a particular area. For example, if all complications as well as discharge planning and discharge teaching are to be incorporated for every single issue area, this addition represents a multiplicity of additions for each and every element in the entire knowledge base. Each addition must itself be cross-linked, and each easily raises other needs. Systems that were designed to handle the size and scope of the knowledge base at one level of size and scale therefore may be inappropriate as the size and scale of the system increases exponentially.

Hardware and Software Bottlenecks

This specific problem was most pronounced as the knowledge base grew exponentially, outstripping the capacity of the delivered hardware to provide an adequate response time. What was a very quick and responsive system at one level with one version became woefully inadequate as the knowledge base with its desired extensions was provided to the user community. Most in the user community, constrained by limited and fixed budgets, had not planned for expenses accompanying an increase in computer power but had still desired a more extensive knowledge base with which to work. As a result, the computer hardware a given institution had financially locked itself into often was incompatible with the information system it desired the computer hardware to deliver. Such incongruities can be devastating as the knowledge base is extended.

Not only can the hardware be overextended, but the software that must support it may similarly be extended beyond its capacities. In certain areas in our experience, when the detail had increased to levels desired by the nursing community, linked lists (which had what appeared to be enormous latitude in their capacity to handle links of certain strings of information) no longer could contain the delivered results. Hence, product extension becomes an intractable part of a complex design that involves the software, the knowledge base, the user community, and the management of all these components in a viable fashion. Scaling up in terms of size and scope can produce unanticipated conflicts that may not be easily resolvable by the prior customers or the project managers.

Maintaining User Options

Following the strategies used by other software vendors, the PACE system achieved a balance between knowledge extension and system constriction at local sites. When the system provided a series of optional versions and updates, customers who were locked into hardware and/or software originally purchased could remain at lower level versions. An incompatibility remained, however, because although the users were at a lower version, they were then also at a knowledge base level lower than professional nursing staff desired. Unlike an older word processor that does not offer features available on the most recent release but lets you at least write your letters, professional care may *require* the expansion of the knowledge base, even if the platform on which it resides cannot or will not be expanded. Thus to avoid putting professional users in an untenable dilemma, one must anticipate the growth inherent in the product and clearly apprise the users at the onset about future requirements. The inability to extrapolate appropriately will cause the users to underestimate the demands they will confront in the future.

In PACE, pilot projects and role-model customers sometimes had to cancel their contracts when the hospitals found that budgets were cut, eliminating expected hardware expansions for nursing, with the result that performance requirements the customers had instigated themselves could no longer be obtained. This unfortunate scenario is sometimes avoidable, but as clearly described above, it may not always be preventable.

Finally certain changes, such as those affecting the health care system as a whole, may require complex changes never anticipated. As a direct analog to the scenario just described, requirements by accrediting organizations or mandates of health care trends may eliminate the possibility of system usage by a site, even with the best intentions.

Managing a Knowledge Base in a Commercial Setting

Different Perspectives

A large number of conflicts arose as a consequence of different philosophical perspectives. Sometimes, for example, the knowledge base was managed first in an academic setting and later in a commercial environment. Within the academic enterprise, control (over knowledge base contributors, knowledge areas to address, and knowledge base development priorities) became a very significant and difficult issue. Because of the institutional concern to have an academic flavor and an academic label tied to the product, the incorporation of outside experts from other sites was clearly not as attractive as it would be under a commercial perspective, which could advertise a wider basis for the support of the product. Areas of great (or little) academic interest were not always representative of clinical users' short-term interests. Thus the issue of control of such decision making presented a source of deep conflict.

In addition, decision-making control within academia necessitated reaching an accord *within* academia, and the rate of decision making in that context is notoriously slow in comparison to some commercial settings. As faculty and administration worked to reach accord, this process could extend over many semesters and possibly not even converge at all as opinions continued to be aired, evaluated, and reviewed. Thus the commercial need to reach closure one way or the other within a product setting was at times in contrast to an academic perspective.

Different Cultures

A sense of timing and the urgency to address user needs produced markedly different responses within the cultures of academia and the commercial setting. In a commercial setting, rapid responsiveness to the user was viewed as extremely desirable for the sake of maintaining strong and positive favorable attitudes. Within the academic setting, the metric used for rate of change often involved the concept of a semester. For a user, this metric represented a length of time far longer than was comfortable for many.

Different Rate of Response

The ability to respond dynamically to customer needs required a great deal of flexibility in order to be responsive to specific customer requests. In the academic decision-making process, evaluation entailed the kind of scientific evaluation and analysis appropriate for research settings but inappropriate for the needs of a commercial enterprise. In clinical care settings, certain reasonable but admittedly ad hoc decisions had to be promptly made. As a result, the discrepancy between the academic and commercial culture regarding the need for responsiveness produced a continual conflict that could not be bridged as the project unfolded. Ultimately it became necessary for economic survival to move toward a very high level of flexibility and responsiveness, which thus led to the move away from the academic setting and toward a commercial spin-off.

In many academic settings, such a separation is considered to be a reasonable and natural evolution, while in others, it may be a more difficult divorce. A well-defined project should anticipate the spin-off and even accelerate it as part of the initial planning, rather than await the inevitable cultural conflicts. Even now, when various academic consultations are obtained on the part of the commercial distribution of PACE, the time metric of semesters is evoked on the academic side, however much it runs counter to the rate of development desired in a commercial setting.

International Differences

In addition to the cultural problems associated with managing an academic versus a commercial product, other cultural discrepancies became apparent. The first arose in the context of the international distribution of the product, as cultural protectionism became more visible. In certain international settings, negative responses increased because the knowledge base development had not been done in the non-U.S. institutions, much as the not-invented-here syndrome appears in the commercial world (Evans, 1985). This not-invented-here barrier created innumerable difficulties, some of which were never surmounted.

In countries where informatics is in high gear, there is the belief that a system similar to PACE could be developed domestically, and thus the local health care professionals will not be as likely to perceive any need for the kind of help that could be forthcoming from an outside, different area. Where vast informatics enterprises are quite rare, however, we found countries far more likely to be receptive to the product (Evans, 1985). Interestingly, linguistic problems arose in areas that were closest to U.S. models. For example, the nursing linguistic differences found in two largely

English-speaking countries—Great Britain and Canada—represented problems that were perceived to be of enormous importance and constituted barriers that made the product nearly untenable. In contrast, in India and other developing nations, differences in language and even in models of care represented a far less troubling difficulty. These countries demonstrated much greater flexibility in using *any* kind of helpful system. Of far more concern than culture differences in developing countries were the bureaucratic hurdles that seemed at times impossible to surmount simply to get a product shipped from here to there.

Differences in Knowledge Updates

In the commercial setting, very rapid updates and very strong customer support were viewed as extremely advantageous. On the other hand, because the academic metric of semesters (two or three each year) was the core measure of time to be used, the concept of rate of updates differed significantly. Ultimately in the commercial setting, quarterly updates became the target. In the academic setting, an update either once a semester, or more ideally, once each academic year, became the default choice. Customer responsiveness mandated that the commercial perspective hold, since the academic perspective is germane in its own setting but appears less relevant in the practical clinical world.

Customer Input

In the commercial culture, customer input and recommendations were viewed as very positive, giving a feedback loop from the user community to the knowledge base maintenance and extension managers. The academic culture accepted such input with a far more jaundiced perspective and preferred to ascribe its own priority schema to the update sequence than the one commercial settings preferred. In the commercial setting, the needs of the customer were viewed as extremely instrumental in identifying the priority sequence for update elements. Academia recognized certain customer needs but perceived the institution's own internal evaluation schema as the preferred approach to determine what would constitute the sequence of updates.

Other Academic Cycles

Certain academic cycles also affected updates. In the commercial setting, the availability of the knowledge base experts was not of concern to the customer base; the driving issue was whether information about certain problems was immediately needed. From an academic viewpoint, the proper response was to wait for the faculty whose area of responsibility was at issue. If a key faculty member were on sabbatical leave, one should await his or her return. Thus this difference represented a further conflict that ultimately was resolved in favor of the commercial perspective. Subsequent analysis suggests that the commercial perspective règarding customer responsiveness probably will come to prevail as the standard for satisfying the clinical customer base that ultimately produces the revenue that enables the product to thrive.

Customer Responsiveness

The expectation of customers in the context of other software systems grows even more demanding, and thus the commercial context of high customer responsiveness remains the benchmark that must be addressed. Of course it would be erroneous to suggest that all customer-oriented perspectives and desires are well posed or even thoughtfully considered. A number of the expectations advanced in nursing practice have stemmed from a poor recognition of the applications involved. Fortunately as nursing medical informatics expertise has increased among high-level nursing leadership in the care community, there have been very minimal demands for extraneous bells and whistles that appear to have only residual benefits to the profession or patient care outcomes.

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CHAPTER 5

System Implementation

Installing a System in a Clinical Setting

Pilot Project Limitations

Installing a system in a clinical setting presents a wide variety of issues. One may at first believe that prior pilot projects will adequately reflect the installation as a whole. It might seem that the evaluation from the limited experience could be extrapolated to the full clinical use of the system. We have consistently found this belief to be completely incorrect. The controlled environment in which a pilot project is initiated inevitably is highly skewed to the particularity of that specific setting.

Special Characteristics

At times, for pilot projects a part of a hospital environment is picked in which the nursing staff is extremely versatile and familiar with a variety of computer systems. Such nurses bring a degree of sophistication that will be quite lacking in the rest of the hospital. Hence their requests for added subtlety and information will constitute overload information and will stand in sharp contrast to what the rest of the hospital desires, once the pilot project is expanded. At other times, an area in the hospital is picked as a pilot because certain political reasons allow that area to have a system piloted. These political characteristics may have a great bearing on the outcome of the application.

Local Disputes

In one particular PACE setting, the political choice for a pilot revolved around an unrelated workplace grievance: various nursing leaders in a particular area had been denied resources they had requested. The PACE system was implemented as a substitute for what the leaders had desired. This decision produced extreme animosity, since the nursing section viewed the system as an example of the inability of the hospital to provide what they really wished (Kjerulff et al., 1981). Hence PACE flew in the face of the original requirements announced by this floor, and the pilot was doomed from the start.

The Overqualified Area

The implementation process is an extremely subtle process that calls for a change in behavior on the part of the users, as well as a change in attitude, a reevaluation, and a new comfort level. In many settings prospective users will lack familiarity with computer systems, and with knowledge-based expert systems in particular. This fact must be accommodated. The individuals who may be utilizing the new system often differ radically in the systems knowledge they bring to bear in their evaluation. Sometimes a hospital will pick an extremely sophisticated user group precisely because its members will be highly oriented toward the product and project. Unfortunately they represent the most uncharacteristic group for the constituency that will be using the product as a whole, and the subsequent user population will not soon match it in comfort level or in perceived needs. Thus incongruities of evaluation arise that are not easily resolved.

The Challenge of Change

In terms of implementation, a product that requires a change in behavior requires more time and effort at the outset to accomplish a task already being performed with the old system (Barry & Gibbons, 1990; Sorrentino, 1991). Whatever the old system's faults and however cumbersome and clumsy it might have been, it nonetheless is comfortable and workable in the current domain. It is usually clear that nursing care is able to continue with the old system and approach in some fashion. As a result, the implementing project leaders find that a new system that inevitably requires change has an enormous challenge in competing with a working system that is in place. If the new system is not mandatory but rather is to be assessed and evaluated, the prior system, if it is available as a stopgap or fallback system, may be often preferred. It becomes very difficult to drop the old system, and it is frequently attractive compared to the new, different, and imposing system.

The pressures at the local hospital level and the demands on the level of nursing care in the face of extremely high acuities and low nursing staff levels all can have a very negative bearing on the perceived outcome of a new system. Thus any implementation needs an environment having sufficient positive forces to create strong expectations of a favorable evaluation. Such advantages still do not ensure success, however, for the system may not be appropriate to the needs of the user community. Nonetheless one will find oneself inevitably coming from behind if pitfalls of this nature are not anticipated at the very onset.

Need for a Champion

As in any change activity, a champion is almost always needed. The perspective and relationship of the champion to the operating environment are equally important. Without someone who represents an ongoing resource support to the change that is unfolding as well as an attractive and highly welcomed change agent, the individuals facing change do not receive the kind of support that is required in a work environment to enable the change to succeed. Thus the site not only must allocate the necessary time and support but also must pick someone who can be a champion, a true believer, with a well-earned reputation in the context of the changing environment. Such a person or persons will greatly assist the system in eliciting a positive response from the user community. Champions must have the respect of the user community to fulfill the role of change agent.

Installing the System in the User Community

Perceptions About the Administration

The initial test setting as discussed above is a very important issue. Once the system has been installed, another range of issues come into play. Now the emphasis is on the hospital and its overall relationship to nursing (Wegner & Hayashida, 1990). The degree to which there is a perceived supportive administration is the degree to which nursing may well be responsive to a recommendation that comes from administration. If the installation's historical context is one in which administration is perceived to pursue only strategies that reduce or eliminate nursing personnel, for example, then to that degree this product will be perceived as merely another means of eliminating nursing roles.

Compatibility with Prior Expectations

Given the introduction of a tool within the context of a very complex environment, it is important to ascertain the degree to which this tool may be incompatible with or significantly different from the other tools that are operating in that environment. For example, if the nursing staff is used to obtaining just straightforward patient care task lists, and such lists are provided immediately at the push of a computer key, the user community will have the perception that all information required is available when a button is pushed. Generally speaking, prior expectations cloud and confound any installation and can mark a system as unable to match already well-defined expectations.

The customer's prior hardware and system experience significantly affects the installation if it has been one of trials by fire. Such negative experiences are instantly brought forward as expectation. As a result, all difficulties may be blown out of proportion, or in any case, expanded beyond any reasonable neutral assessment. To gauge how a new system will be implemented, therefore, it is important to ascertain the prior experiences in the distribution of systems in a user community. The greater the past degree of difficulty, the more important it is to have champions and continuous support systems to ensure the hoped-for effective and smooth transition.

Hidden Conceptual Challenges

One should never underestimate the deep behavioral and conceptual changes that must take place when a complex decision-making system is introduced (Allen, 1991). Even if success expectations are high because of, for example, an order entry system that was easily installed some time earlier, or expectations are extremely positive given previous experience with acuity or other administrative applications, nonetheless the clinical support systems themselves represent a different conceptual challenge. These applications address the selection and implementation of patient care. This area often has not been supported, or even touched, in a systems context. Thus the effective use of such systems calls for totally different behavioral changes. The assessment for proper patient care can create and generate hidden anxieties; the demand for choice and selection may create the need for deeper knowledge than may have been applied. Thus the system may tend to accentuate the perception of the staff's knowledge deficiencies which had been glossed over in the provision of patient care.

The use of nursing diagnoses is an obvious example of a hidden conceptual challenge. Although members of the nursing staff are often aware (at least to a certain degree) of nursing diagnoses, any lack of in-depth knowledge can be certainly accentuated when a system is driven by this taxonomic organization. Even in settings in which a nursing diagnosis approach has been implemented with the full support of nursing administration, this valuable support does not change overall the cognitive basis of the nursing staff. As a result, deep behavioral mistrust can arise as nurses apply a system with which they have a low comfort level. Without a prior in-depth continuing education program and support of nursing diagnoses and its related *philosophy* and approach, staff may not be comfortable enough with the system to use it. What can follow is the misplacement of the anxiety regarding system content onto system performance. The system never meets expectations. There would be no possible way for it to be useful enough to overcome the barriers of anxiety and mistrust.

The Clinical Setting: Validation Testing and Feedback

Getting Good Feedback

One might think that feedback would be straightforward in successful implementations, and that such information could be easily incorporated into the advancement and extension of the system. Unfortunately, this is not the case. The complex task of getting appropriate and useful information continues to be very difficult.

Evaluator Roles Versus Systems Goals

Part of the problem arises because those who have a complaint or difficulty may well represent an extremely small minority of the nursing population. The system users and highly facile informatics-oriented individuals may bring expectations to the designers that few, if any, of their colleagues will ever entertain. The decision of what constitutes pertinent and useful information can be a matter of philosophy. Those who wish complete textbook or cookbook information may conflict with those who are alienated by the amount of detail provided. As a result, one must get wider assessments if useful information is to be gleaned (Zeilstroff, 1978).

Certain conflicts can arise between the roles of highly placed individuals in the clinical setting versus the *goals* of the system itself. An example is sometimes found in the system's evaluation by specialty nurse–clinicians as contrasted with the evaluation by rank-and-file nurses. The specialty nurse–clinician is the expert in some area and has cutting-edge knowledge for that particular domain. Such individuals may well be irreplaceable, representing the ultimate performance the system can only hope to achieve. It would seem reasonable to use these individuals to assess the system. However, specialist nurse–clinicians naturally use as the benchmark for any viable system the criteria of their own high levels of performance. These are the very experts being hired by the knowledge base managers for construction of the knowledge base, and the system itself does not go beyond the level of expertise of the contributors. Hence solicitation of nurse–clinician assessments automatically ensures a neutral or challenged evaluation. The regular role of these nurses conflicts with the system's goal for the clinical setting, which is to simulate nursing expertise when such "live" human expertise is not available or affordable. Clearly, therefore, validation testing and feedback can become extremely difficult in a practical clinical setting.

Antisystem Attitudes

Additional experience has found that those who may be innately antagonistic to the perceived dehumanizing use of a computer-based system tend to take the smallest discrepancies as insurmountable barriers to their use of the system. In one hospital, for example, the knowledge base suggestion of a length of time that *might* be needed for resolution of a certain patient complication made use of the system untenable in the entire hospital. This one suggestion of a range of time, derived from a suggestion in the knowledge base, was sufficient reason for one key evaluator to deem all the system's recommendations as suspect. That the time range in question was labeled an estimate by the knowledge base was not pertinent to the individual's assessment. This reaction suggested to outside evaluators that the dissatisfied user was working from an agenda not apparent within the specific assessment issues articulated.

Overall, the clinical setting brings enormous complexity and difficulties in getting useful information and appropriate evaluation for the commercial sector. Any nursing evaluation team in support of the user community should attempt to obtain a very wide range of input, neutral assessment, and even confidential collection of information, to circumvent difficulties of the kind just described, which have continued to arise throughout the evaluation spectrum.

Understanding the System's Purpose

Various sites have used a consensus approach as a part of the typical nursing evaluation schema. This certainly has proved to be very useful in many assessment activities. However, consensus in the context of the use of the system has brought other difficulties. Those who have felt that the information was deficient have strongly articulated their perception of deficiencies. Further investigation invariably revealed that some particular point an individual nurse thought was a mandate represented only a *possible* suggestion on the part of the system. Many viewed the system's suggestions as requirements and personally rejected it in the context of some particular patient. The failure to see the system as a consultant and advisor, not as an omniscient guide, created significant discrepancies in evaluations which were not easily resolved.

Good assessment is best achieved under a careful, meticulous mode that isolates and identifies precisely the degree to which there are problems, the level at which these problems present themselves, and even the perspective on the part of site evaluators who may feel that a one-time difficulty represents a fatal flaw. Helping the evaluators to assess the criteria for success ahead of time can thus be an invaluable approach to eliciting useful evaluations of the system, ultimately affecting its further design and extension (Kahl et al., 1991a; Kahl et al., 1991b; Staggers, 1988; Wegener & Hayashida, 1990).

The User Community and Practicality

Pilot Versus Real-Time Projects

One must stay alert to the need for practicality in the full implementation and installation of systems versus pilot projects. Although it may seem apparent that certain aspects and elements cannot be implemented in a commercial setting, often other things that seem reasonably acceptable (or are not really terribly annoying) become utterly untenable in a clinical care environment. Pilot project implementers, who often bring complex, sophisticated skills to the product, may minimize user reactions that characterize certain difficulties as major stumbling blocks: simple matters such as the use of log-on codes, or incongruent and conflicting approaches to accomplish the same task in different parts of the system, produce high anxiety which the practical user may not tolerate. Yet a pilot implementer may find the same attributes reasonable and rational. This discrepancy is far more subtle than it may appear because as professionals in the field, pilot project implementers lose perspective on what constitutes an unintelligible element, an extraordinarily clumsy approach, or an inordinately long wait period.

The System Designer Culture

In addition, screen clutter, complexity, and lack of simplicity confound the naive user, while the learned and sophisticated implementer may fail to perceive these conditions as problems. Numerous conflicts arose between system designers on the PACE development team and evaluators who represented and reflected user interest because the naive user inevitably lacked the sophistication and comfort level that the designers had achieved over a period of time. Such conflicts arise in most software development venues and are more pronounced in the health care field.

The health care setting and the peculiarities of health professionals may be even more markedly different from the system designers' culture than most other application settings. For example, in the business arena, the frequent and typical users' applications of software such as spreadsheets and word processors make the targeted user community more culturally similar to the software developers than is the case in the health care field. In health care, as well, the pressures of time and the demands of patient care create situations that are more tense, more demanding, and more intolerant of difficulties than are found in most other business application domains. As a result, differences between the software development community and the user community may be far greater in the field of health care than they are in other settings. As a consequence, the feedback to systems and software managers by the clinical assessment team may appear to be unwarranted, picky, and irrelevant when viewed from the point of view of the implementers and developers' of the project.

Convincing System's Designers

The PACE project found incongruence in cultures arising year after year. Even the addition of nursing experts, who had expert nursing knowledge and system knowledge, failed to bridge the gap. The resolution of the communication and cultural conflict still required not just the articulation of the problem but also the concurrence on the part of the PACE software managers that such customer needs were germane and warranted their attention. Sometimes it required conveying the users' distraught input to the software designers one-on-one, to successfully communicate the users' difficulties or their perceptions of clumsiness of the system demonstrated to them. When the ego and the personal involvement of designers are added to the equation, the prospects for effective feedback can diminish. For such feedback to have credibility in the eyes of the system designers, so that an appreciation of user needs can be obtained, it is crucial that it be documented and possibly even provided by the originators of the complaints.

The Actual Clinical Environment

Testing in the actual clinical setting also can bring forth a different set of requirements that do not arise outside the clinical settings. For example, nursing professionals may test the system, but if they are not engaged in actual patient care with its accompanying pressures, one may not be able to learn how certain system attributes will perform in the actual context in which the system must be used. Thus testing outside the clinical environment is less pertinent in health care settings than it is in certain other settings and applications one might experience. As a result, testing and feedback become again more difficult and more challenging in the health care field as a whole and in nursing systems in particular.

Moreover it is also extremely important to test and evaluate the use of care plan decision support in a setting that integrates the development of such plans with a full spectrum of interfaces to the rest of the hospital information systems. The value of such care plan support can be appreciated simply for its own sake (Brennan et al., 1983; Cengiz et al., 1983; Crosley et al., 1985). However it is PACE's support of both the breadth and depth of interaction with the rest of health care information flow that makes the difference between an auxiliary aid and full integrated decision support.

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Chapter 6

Issues in Semantic Network Development and Utilization

The origins of the semantic network methodology for PACE arose from the author's doctoral studies on the development of Semantic Operators Producing Heuristically Interesting Sentential Types (SOPHIST) system (Evans, 1969). This 1969 development was in turn based on prior research in related studies begun in 1967 (Evans, 1967). Such studies were forerunners of what were later described as semantic trees by Quillian (Quillian, 1966). Since both Evans and Quillian were later in the same doctoral program at the same university, it is not surprising that the conceptual environment should foster commonality in this research area.

A Net Example

One goal of the early research efforts just mentioned was to expand the description of knowledge through formal, yet more expressive and flexible, coding strategies (Shapiro, 1971; Winston, 1977; Minsky, 1968). Figure 6.1 illustrates a semantic approach (part of a semantic network) for the description of part of the ideas related to "animals." Various objects are listed in capital letters, described by attributes (lowercase letters), with links (verb phrases underlined, along the connecting lines or "pointers") that explain how attributes relate to an object.

We see that a bat is a mammal and can fly, and mammals are animals, so logically we may be permitted to deduce that a bat is an animal that flies, and some animals fly. A blackbird is a bird (which can fly), and a bird is an animal, so a blackbird is an animal that flies, too. However this net "knows" (i.e., has coded) the information that a bat has fur, but a blackbird does not, so a logical distinction can be drawn between a bat and a blackbird. The former is a furry, flying animal, and the latter is not. Note that a blackbird is black and so is coal. If the verb "is" is taken too strongly, the logic of the network might be allowed to conjecture that a blackbird is coal. Thus care must be taken to define the permissible logic for links (verbs) that tie objects (such as bats and coal) and attributes (such as black).

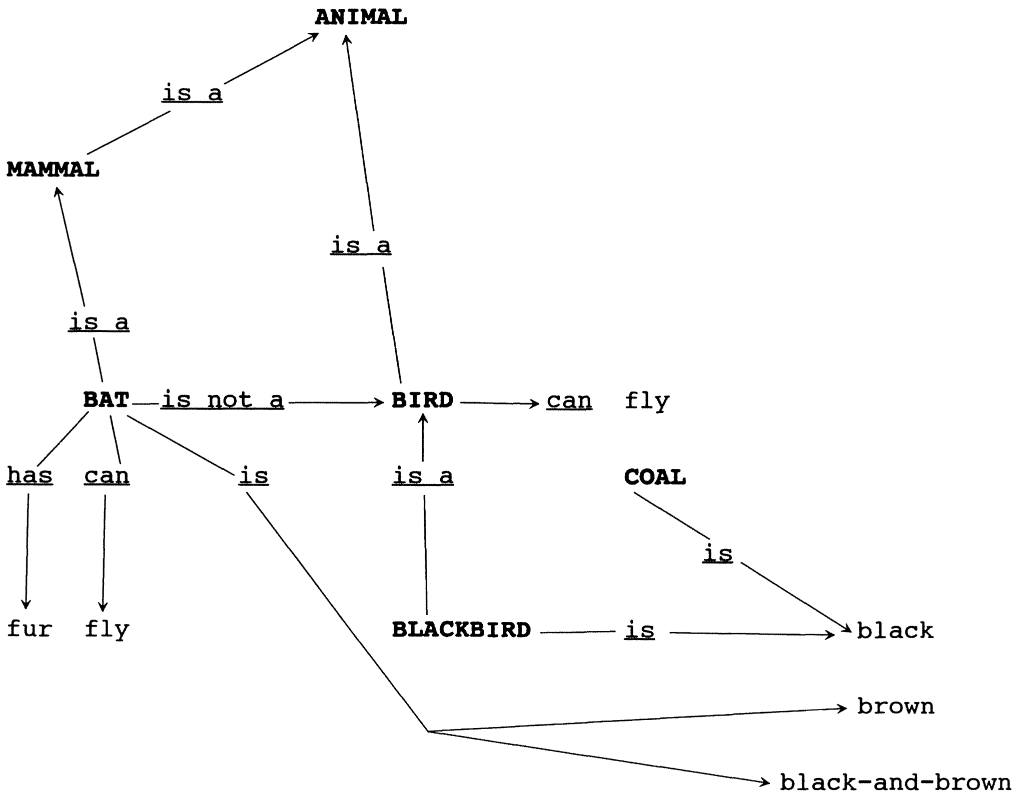


FIGURE 6.1. A semantic approach for the description of part of the ideas related to "animals."

Implicit Rules in the Net

A second thing to note is that a semantic network can contain implicitly a set of rules. For example, we could derive the following set of rules from the net shown in Figure 6.1 by focusing on the verb "is":

If ANIMAL, then (BIRD or MAMMAL).
If MAMMAL, then BAT.
If COAL, then black.

In addition, if we create the convention that any attribute might imply the object, we could add

If black, then consider (COAL or BLACKBIRD or BAT).

If we allow additional conventions of logical extensions, we might obtain the logical sequence:

If black, then (COAL or BLACKBIRD or BAT).
If BLACKBIRD, then BIRD.
If BIRD, then ANIMAL.

The possibilities above demonstrate that a semantic network, in combination with a set of conventions concerning how we may logically interpret the links between attributes and objects, encodes a system of rules that describe additional information (conclusions and inferences) based on the structure of the knowledge coded in the semantic net. The terminology in the net, combined with conventions regarding how movement in the net (logical inferences) is defined along the links in the net, constitutes an embedded system of logic in the net—an "inference engine." If the logic and conclusions correspond to what some experts might have stated, the rules constitute an expert system of knowledge, identical to the collected rules of logic that might have been obtained by studying experts and codifying their observations (Harmon & King, 1985; Buchanan & Shortliffe, 1984; Liebowitz, 1988). However, if we just specify the conventions of deduction, the rules are not explicit but rather are implicit; thus this approach embeds potentially tens of thousands of rules without any explicit effort (although the trade-off is that the net and its complex relationships must be maintained). It had been estimated that the PACE system in its fourth generation, with tens of thousands of nodes and numerous conventions, would represent the equivalent of over 3 million rules if each were made explicit.

Systematized Terminology

The conventions on the selection of terms (objects) we might consider for inclusion in the network may be very usefully guided by a taxonomy, combining and relating the vocabulary of the network. Using a taxonomy, the development of a knowledge domain can proceed in a very organized way, yielding a formal, very systematic definition and description of a knowledge domain.

Pre-PACE Developments

Early developments and applications of the semantic structuring of knowledge were undertaken by the author at Carnegie-Mellon University in the domain of management science. Over a four-year period, a complete knowledge domain and semantic network were structured, along with a set of conventions or rules defining permissible movements in the nets. At the end of 1974, the author concluded in a Ford Foundation grant report that one of the most productive areas that could utilize this semantic approach was the health care field (Evans, 1974a). It was argued that the utilization of up-to-date information in health care would likely produce some of the most significant and worthwhile payoffs.

Beginning in 1975, the PACE initiative was undertaken by the author in concert with Dr. Robert P. Heaney, then the vice president for the

Creighton University Health Science Center, to apply these methods specifically to the health care domain (Evans, 1975). Not only was the overall PACE conceptualized, but also more specifically, it was proposed that semantic networks could effectively accomplish the task of intelligently organizing all the health care information in the Creighton Health Sciences Center. With some dedicated effort, this vision was successfully communicated to the W.K. Kellogg Foundation of Battle Creek, Michigan, which responded with a massive funding initiative. The ensuing effort covered all health sciences schools at the university.

In addition to the collection of knowledge, as we shall describe, many other aspects of the process to structure knowledge were systematically and uniformly initiated. The sections that follow describe the methodology, the structuring, and the paradigm in which this process unfolded.

Taxonomy for the Health Sciences

A thorough taxonomic organization guides a uniform approach to the coding of an entire field of knowledge. To accomplish uniformity in coding terminology, the author developed a multidimensional taxonomy that encompassed not only the individual health sciences knowledge domains but also the process of health care (Evans, 1977).

We shall summarize each of the dimensions of this taxonomy, which was crucial to the achievement of an organizational schema that successfully classified all the phenomena, allowing their integration and coding. The overall schema is summarized in Figure 6.2.

Taken as a whole, the taxonomy organized the entire domain of health care and the health care process. Without such an all-encompassing view, it would not be easily possible to organize the information and systematize the semantic coding processes. Such a unifying taxonomy for each domain, whether it be health sciences or the area of business or any other, is extremely valuable. It is the underpinning for the systematic process of collection, organization, and codification.

The First Dimension

The first dimension focused on the health provider, a category comprising three fundamentally different subdimensions. These three domains emphasized the clinical problem-solving process (as used by health care professionals), the professional's use of products, and the health care provider as a professional, with a set of professional responsibilities.

The *CLINICAL PROBLEM-SOLVING PROCESS* was divided into data gathering, assessment, conclusion drawing (or diagnosis), selecting and planning treatment, and implementation of treatment. Implementation of a treatment had several subcategories (technical procedures, medicinal

A: PERSON HEALTH NEEDS
1. Preventive care and health maintenance
2. Psycho-behavioral
3. Social-economic-cultural
4. Environmental support
5. Spiritual support

B: PRODUCTS

C: PROFESSIONAL RESPONSIBILITIES
1. Historical role of health professional
2. Cultural aspects of health professional
3. Legal issues
4. Ethical principles of health professional
5. Research principles
6. Intrinsic education
7. Professional interdependencies
8. Health care systems
9. Management
10. General skills and attitudes

D: DYSFUNCTIONS & CONDITIONS
1. Infectious diseases
2. Neoplasms
3. Musculoskeletal diseases
4. Digestive system diseases
5. Oral diseases
6. Respiratory tract diseases
7. Otorhinolaryngologic diseases
8. Nervous system diseases
9. Eye diseases
10. Urologic diseases
11. Gynecological & obstetrical diseases & conditions
12. Cardiovascular diseases
13. Hemic and lymphatic diseases
14. Neonatal diseases and abnormalities
15. Skin diseases
16. Endocrine and metabolic diseases
17. Nutritional diseases
18. Immunologic diseases
19. Injury, occupational diseases, poisoning
20. Animal diseases
21. Signs, symptoms, syndromes, and situations
22. Behavioral and mental disorders

E: PUBLIC HEALTH
1. Defined responsibilities
2. Social responsibilities

F: CLINICAL PROBLEM-SOLVING
1. Data gathering
2. Assessment
3. Conclusion-drawing (diagnosis)
4. Selecting and planning treatment
5. Implementing treatment
6. Evaluating treatment

FIGURE 6.2. Overview of the taxonomy for the health sciences.

therapy, health education and counseling, etc.). A final stage of clinical problem solving included evaluation of the treatment.

The second subdimension, *PRODUCTS*, included issues such as food, drugs, cosmetics, and devices when treated as health care products rather than as part of a treatment regimen. The third and final subdimension, incorporating *PROFESSIONAL RESPONSIBILITIES*, captured aspects of the professional when viewed as a health care provider irrespective of the content that was available or the intellectual processes the professional might use. Thus included were such categories as historical issues, legal issues affecting the profession, ethical issues, and research issues and principles.

Second Dimension

The second major dimension we formulated addressed the specific areas of health care knowledge that would be required. This dimension also had three constituent parts. The first part defined the healthy person and that *person's health needs*. A second segment viewed the person as a patient, hence considered *dysfunctional problems or conditions* the person or patient may exhibit. The third subdomain focused on *public health*: issues involving the aggregation of individual persons and patients seen as a collective whole. In turn, every individual category was broken into subcategories.

Third Dimension

The third major dimension included *intellectual, attitudinal, and psychomotor processes* that could be exhibited. This dimension reflected the recognition that as a health professional undertakes to solve clinical problems in a particular area, the processing of information and the problem-solving behavior might include cognitive, psycho-motor, and affective capacities that are invoked in dealing with the other two dimensions.

Subtaxonomy Divisions

In addition to the global taxonomy that covered the overall organization of the total domain of knowledge, a second subschema was needed for each element in each of the components of this three-part organization. Perhaps the most significant subschema was the organization of the various areas of dysfunction. Within each disease domain (e.g., cardiovascular diseases), a broad organizational taxonomy was employed to orchestrate all the knowledge that would be covered in this area. This broad organization encompassed five components. The first of the five major subschemes covered issues of general assessment, etiology, prevention, and overall detection. Each of these areas was divided into very detailed subcomponents. The first subschema as a whole addressed broad-level health care issues in cardiology.

The second major subschema within each disease domain covered general dysfunctional problems and considerations for that specific area. This was an important division because it aggregated broad areas of abnormalities and abnormal conditions of disease states. This section defined the main problem areas in the aggregate but did not yet define specific disease disorders.

The third broad subschema was the category of therapies, which represented the aggregation of understanding about therapies. In cardiovascular disease, for example, we must consider the pharmacology surrounding diuretics or cardiotonics. It was important to capture very broad areas of knowledge, which the professional held, above and beyond specific applications in particular disease domains. Other such similar matters included general issues of diet and rehabilitation.

The fourth broad subschema consisted of all the specific dysfunctions within each area. Within this subschema, a systematic division of the area was achieved, to permit the definition of a conceptually organized and coherent approach. For example, within cardiovascular dysfunctions, the divisions included primary heart disruptions, blood vessel disruptions, and cardiovascular surgery. Each of these areas was divided into subsubschemas appropriate to that area.

Finally, the fifth general subschema within each dysfunction was that of the "integration of knowledge and skills," viewed as a separate conceptual enterprise, above and beyond the specific articulation of each distinct entry. The concept and process of clinically formulating plans of care or actually doing an effective history and assessment were viewed as integrated collections of knowledge, psycho-motor, and affective skills that went beyond the individual elements addressing any specific dysfunction or area of concern.

Thus, with a systemized taxonomic division of all the processes surrounding health care and health sciences together with an individual taxonomy that orchestrated the domains of knowledge within each subschema, an overall schema was developed for the systematic and uniform guidance of the knowledge acquisition process.

In each health science area (e.g., nursing), this overall taxonomy was applied to the respective knowledge domain. For all intents and purposes, this general taxonomic approach worked very well for all health professions. This common application of the taxonomy facilitated the subsequent codification of knowledge within each subschema.

Content Information

It is also valuable to recognize that as the subschema organized an area into constituent elements (e.g., "the disease of emphysema," "rehabilitation for emphysema"), the actual content information for each concept was then defined in an elaborate and detailed fashion as a "module of educational information." For example, a deep level of the schema might itemize progressive occlusions, partial and/or temporary occlusions, and complete occlusions. Myocardial infarctions would be included under "complete occlusions." The expert would describe the knowledge a nurse needs concerning myocardial infarction. The information would be further organized as a content expert deemed most appropriate. In the initial program definition for nursing, this content for myocardial infarction (MI) was described with a goal/subgoal format as follows:

COMPLICATIONS WITH AN MI: recognize the life-threatening complications of a myocardial infarction

Cardiac Arrest: describe the signs and symptoms of a cardiopulmonary arrest and the required treatment.

Assessment: identify signs of cardiac arrest & list steps of "Code Procedure" for most institutions.

Cardiopulmonary Resuscitation: demonstrate the proper technique for cardiopulmonary resuscitation.

Cardiogenic Shock: describe the pathophysiology and methods of circulatory assistance in cardiogenic shock including the intra-aortic balloon pump and the external circulatory assist device.

At the actual content level, the detailed subgoals (and even sub-subgoals if desired) provided the final organization of the knowledge of the content expert. Hence, by the encompassing nature of the taxonomy, ultimately all content was organized and categorized by the taxonomy, with the bottom level defined by the actual content known to the expert. Then, when the overall organizational taxonomy was employed, and a series of subschemas for each was achieved, including the detailed final level articulation of the content information held by experts, a further semantic net codification development was undertaken for each content unit or *module of information.*

The semantic coding process focusing on each conceptual unit of information was undertaken to specify in telegraphic fashion all the intellectual elements for that conceptual entity. For example, in the specific area of thrombophlebitis, the content knowledge included the goal of "formulating a plan of care with supporting rationale for a patient with thrombophlebitis." Two specific subgoals were defined to achieve that goal. The first involved prevention and detection, which included identifying the patient at risk, and the second involved predicting signs of a pulmonary embolism as well as identifying suitable interventions to prevent this complication. Other specific goals would be enumerated, all leading to the codification of the intellectual basis by which care for the patient with thrombophlebitis could be planned.

Given that every content statement was very specifically articulated, key terms and phrases for each statement were selected and semantic net information systematically itemized. For example, the "signs of pulmonary embolism" would be selected, and the actual signs enumerated and entered as semantic terms under the phrase. "Specific inventions" would be selected, and possible individual interventions would be itemized and entered into the net under the phrase. In this manner, all the conceptual elements comprising a final, lowest level statement of intellectual activity or health care action were specified. This detailed specification yielded a series of individual words or phrases or terms, which would then be linked appropriately into the semantic network.

Structure of the Semantic Net

Linkage of Concepts and Content Within the Semantic Net

The linkage process for every term or word in the semantic net begins by applying a three-part distinction or division to every single conceptual element. In our example in Figure 6.1, we described a "blackbird" as "is" a bird and "can fly." In PACE, the allowable verbs in the semantic net are (a) "is a part of," (b) "is the same as," and (c) "has particular attributes such as." These three components were called, respectively, the general areas, the synonyms, and the subareas (Evans, 1974b; Evans, 1977b).

The first of the three-part divisions identified general areas in which the term might be expected to arise, given the specific context for the module of information in which the term was used. General, broader level terminology was listed to provide the context for that word as the first set of descriptors to be supplied. The second set of semantic descriptors comprised any synonyms viewed as equivalencies for that term. The third set of semantic descriptors identified detailed attributes, subareas, or individual instances, and/or any other particulars that were appropriate for that concept within the associated context.

For example, if the individual term were "bacterial pneumonia," then the "general areas" list might include "pneumonia" and "respiratory disease." The synonym list might include "bacterial pneumonitis." If therapy for bacterial pneumonia was discussed in the specific module of (content) information, one subarea might be a variety of specific therapeutics (e.g., penicillins). The overall principle was to link to every single concept the semantic context of that term, with three sets of descriptors of the context: general areas or broad frameworks in which that word or concept arose; synonyms or equivalencies; and attributes, particulars, or subareas or details that were appropriate for that word in the context of the module of information in which the term arose.

This fundamental conceptualization of a broad three-part level of semantic descriptors for any term in the context of each module of information in which the term arises is at the heart of semantic network utilized by PACE. It is important to recognize that the total PACE semantic net contained a pointer to the module of information that used a given term; the module of information contained the local semantic net for each term occurring in the module, with the result that PACE had an "understanding" of a term within the module where the local semantic definition was created. Hence PACE could "understand" each module through its own use of terms; in the total net, which was the aggregation of all terms, PACE "understood" a term in the integrated context of the many ways that term had been considered by all experts.

What this methodology accomplishes is a representation of the relationships among all concepts, with all links integrated into a single unified network. The resulting net's organization and structure define the meaningfulness of each idea in a total context. Moreover, the semantic net not only represents the integration of all the concepts, but also cross-links each concrete concept to its content. As noted, since in each content module of information each concept has its own local semantic network, the context of each concept or area is preserved at the content level.

For example, one area, such as "abortion," that has the context of a "procedure" in one module of information thus has a series of specific general, synonym, and subareas terms that discuss that procedure. When the term "abortion" arises in the field of ethical dilemmas, however, it has an entirely different family of associated terms, which define and are associated with that word in an ethics-related module of information. For a specific search for content on "abortion" as an ethical issue, pointers in the total semantic net permit the network to locate both modules that deal with abortion; an inspection of the semantic net tied to each module then enables the system to determine which module addresses the issue from the ethical perspective. Specifically, PACE selects modules on "abortion" that have the correct (i.e., ethical) semantic context in the general areas for the term. Because the entire net is available to the system, PACE could also identify the multiple contexts in which a concept occurs. Thus the system also has the power to transcend the limitations imposed by any one encoder of information, since the system is able to aggregate the different contexts via the integrated semantic tree (yet still preserve the local semantics for each module, as each expert contributed to one intellectual domain).

Changing Semantics

Within the nursing area, a series of evolving subtaxonomies arose over the history of the project. Unlike the domain of the world of medicine, whose paradigm remained reasonably stable over the past decade, the nursing model of organizing knowledge has had a number of significant shifts in relatively recent years. Perhaps the most significant has been the introduction of nursing diagnoses to organize the nursing patient care response. (Campbell, 1978; Carpenito, 1983; Gordon, 1982; Jenny, 1989; North American Nursing Diagnosis Association, 1994). For example, the area of emphysema no longer was associated with a linear list of care activities. Nursing now might organize its response in terms of a series of nursing diagnoses of patient problems which are appropriate for that patient. Given a medical diagnosis of emphysema, nurses might identify an impaired breathing pattern as the issue they would address, and they would have a series of goals or expected outcomes to achieve, and a series of interventions to bring about each. In addition, they might identify the problem of impaired gas exchange, for which there would be yet another set of expected outcomes, and, as a consequence, a set of interventions that could be undertaken to achieve those outcomes. In general, a particular patient might require a number of nursing diagnoses for any specific medical diagnosis.

One might view each nursing diagnosis as a patient-centered diagnosis which the nurse addresses. Thus the semantic organization of the content (as well as the content itself) for nursing care evolved over time. In the semantic net, these new nursing diagnosis subareas were included along with further subdelineations. Content for each potential patient problem was then linked, with semantic terms tied to each new module of information. If maintaining a dual model for nursing care (one with, and one without, nursing diagnoses) had been desired, the old and the new linkages could all remain in the net. If the old model of expression were to be discarded, selected links in the net could be "cut" or removed, to cause "forgetting" in the net. (Since the system would be unable to infer the concepts that had been removed, and also could not access associated modules of information, the associated content in the modules of information would be "forgotten.")

Expanding Nursing Diagnoses in the Net

The incorporation of nursing diagnoses changed the organizational schema throughout the entire nursing semantic net. For every nursing issue, there were nursing diagnoses for each concept, goals for every nursing diagnosis, expected outcomes, associated interventions, as well as broader categories (discharge teaching, discharge planning, etc.) for the overall problem or issue under consideration. Not only could medical diagnoses such as emphysema be treated in this fashion, but nursing diagnoses could be similarly approached as well.

Each nursing diagnosis was encoded as an entity, described with semantics for every specific attribute and aspect of that nursing diagnosis. This coding included goals associated with the nursing diagnosis, interventions, and any detailed information that could be provided. On the one hand, in this "pure" context, "impaired breathing pattern" could be addressed irrespective of whether it arose as a result of emphysema or myocardial infarction. On the other hand, a nursing diagnosis in the abstract could not provide the specificity of the context that could be extracted from the nursing diagnosis related to emphysema, for example. Hence the semantic network representing emphysema included entries for nursing diagnoses, goals, interventions, and so on that were far more specific and precise than the network entries representing nursing diagnosis concepts without the additional medical diagnostic context.

Academic nursing theorists speculated that in certain select situations at least some nurse–clinicians might prefer to apply nursing diagnosis without the context of a so-called medical diagnosis. The system certainly accommodated this possibility by incorporating complete encoding for every nursing diagnosis in a general manner. So far, however, there has not been an instance of a clinical setting applying nursing diagnoses without a medical context. This result is understandable, given the recognition that patients inevitably come with a medical diagnosis that greatly affects the context in which they need care and in which they are immersed. It becomes extremely difficult to eliminate this context when approaching the care of the individual patient.

With the prior context of a medical diagnosis, there is the ability to be very concrete and pragmatic in terms of the specifics of care. For example, a specific intellectual division within emphysema might be "discharge teaching for the patient with emphysema." The subareas in the semantic net corresponding to this concept underneath the concept of "discharge teaching for the patient with emphysema" would be all the actual elements of discharge teaching that one might consider. The semantic detail would be a series of phrases such as "avoid activity causing dyspnea," "rest before and after activity," "importance of progressive activity," "need for adequate rest," and "use of home oxygen."

Rules Within the Net

An often misunderstood aspect of the PACE semantic net was the use of the implicit structure of the net to hold the rules of deduction, which in other systems are separated from the net of relationships. In PACE, when a specific inquiry was made, a search of the net corresponded to rules implicit in the structure of the net itself. To give a concrete example of this process, if one specified a search term of "emphysema," the search system would go to the node of emphysema, where it would invoke two processes. The first would be to resolve the context of emphysema, as intended by the inquirer. Connected to the node of "emphysema" were the "clinical care goals" and perhaps other contexts in which the term was addressed in the knowledge base. The contexts would be displayed as a series of statements explaining each context. The inquirer would pick the one intended. For example, one context might be, "nursing patient care for the person with emphysema." Once a context had been selected, the system would go to a conceptual domain defining the "clinical problem-solving process" in the semantic net. This organization would guide the choices under emphysema to be pursued (i.e., the aggregates of nursing care activity that defined the appropriate care). This care definition might include concepts that identified the need for assessment, the suitable application of nursing diagnosis to differentiate and address this problem, the appropriate implementation of discharge teaching, and so on. Thus all the constituent concepts pertinent for nursing care would be retrieved, and concomitantly, the content modules of information for each concept would be retrieved, along with the local semantics for each such module.

As each clinical module of information was collected, the modules in turn might be linked to a series of submodules that explicated every clinical care step even further (Evans, 1974b; Evans, 1977). The semantic net content linked to each module of information gave the detailed activities that would be appropriate if the nurse were to fully accomplish that clinical content module of care. The order of the deepest level modules of information and the associated detailed content of the semantic net associated with every module guided PACE's final output in terms of the clinical activities recommended. The moves in the semantic network along with a structured retrieval and presentation of the content of the links in a certain fixed order constituted a complex series of rules on the knowledge base, whose final result was guided by the content of the semantic network as well as the semantics tied to the content modules.

Thus the system and its moves between its modules of information and the content in its associated semantic net implicitly defined a set of search rules defined by the linked lists, the ordering of the links, and the concepts to which the links pointed. If the initial concept the system user selected was itself a complex combination of ideas (e.g., "diabetes and pregnancy"), PACE's response to a combination of terms guided its move through the network according to another set of rules of interpretation. All together, the semantic net, the content modules, and the defined movements and retrieval in the net represented the response of the system. In this way, the rules (or inference engine) were implicitly buried in the content of the net, the way the net was searched, and the way the various cross-links were activated between each module of knowledge and its semantics within the system.

Other Links in the Net

Other collections of data were also interlinked with nodes in the semantic net. For example, associated with each module of knowledge in each domain was a set of bibliographic references that provided documented support for the intellectual detail given in the linked semantic net tied to that module. Thus for every individual module of information, one could link to the bibliographical data file that substantiated the content in the module of information. As a second example of links in the net, given a specific concept within the semantic net, one could link to all the broader conceptual domains that employed the specific concept. Important capabilities arose from this search capacity.

As one considered some concept—for example, "discharge teaching for emphysema"—one could link "up" to the complete clinical definition of care for the person with emphysema. One then would discover that related issues, such as "prevention" and "rehabilitation," were also appropriate. By electing the option to link to associated nodes and viewing the semantic net, one would be guided to other associated ideas one had not necessarily initiated at the onset. In a similar way, since the semantic context of every concept was linked to every node, one could ask about any particular related subdomain, whereupon the system, using its semantic network, could link to the knowledge content of this node and retrieve proper information.

The system could also move several steps "up" the semantic network and recognize that "emphysema" itself was but one of several chronic obstructive pulmonary diseases. This was just one context in which emphysema was coded. Once the context of chronic obstructive pulmonary disease (COPD) had been selected, one could view that node and see that general treatment and therapies for COPD were specific subareas of that node. If therapy had been of particular interest for emphysema, the system could be directed to go down that semantic link, retrieve the corresponding knowledge and detail tied to it, and return that information for the user as part of a more expansive response than the user may have in fact initiated.

Put another way, the system could both generalize from a given idea by several movements "up" the net, and extend the idea by lateral movements through linked synonyms. Then through a downward movement from the broad areas or synonyms in the net, the system could retrieve specific details. Then content information of which the inquirer or system user was initially unaware, at least in relation to the original inquiry term, could be retrieved. As a consequence, the system could give a more expansive response to inquiries than merely a fixed rote search technique would have permitted.

Measurement with the Net

The semantic net also imposed useful "metrics" that could be applied to resolve ambiguity regarding the inquiry intended by a system user. For example, given a particular search term, the system could move "up" the semantic net to a "higher" context. From there, it could review the range of terms in this second context. In turn, it could review the general areas or context of *those* terms. Thus a feature of the system was the ability to calculate the degree of specificity of the original term in relation to the terminology in the total taxonomy. That is, the system automatically counted the number of upward steps, or cycles, that could be completed before it hit a ceiling (i.e., no new higher terms accrued).

For example, a particular treatment for a specific cardiovascular disease might be 'treatments for myocardial infarction." That disease might be indexed under the "care of a patient with myocardial infarction," which in turn is one of a family of such diseases (coronary artery occlusion), which is underneath "pulmonary heart disruptions," which is underneath "cardiovascular disease." In following this progression upward, one could traverse a countable number of upward movements or node steps before the overall area of "cardiovascular disease" as a final category was met. On the other hand, the broad term "general therapies for cardiovascular disease" is one of the subcategories immediately under "cardiovascular disease." Thus the first category of "treatments for myocardial infarction" is calculated as far more specific or "nitty-gritty" than "general therapies."

The use of this step-in-the-net metric for "degree of specificity" was one of the parameters in evaluating the nature of a system user's inquiry and the system's best set of responses. This calculation of the generality of a term (or its specificity) was also a feature the system used to differentiate among otherwise similar system inquiries involving several combined search terms.

The net also defined levels of content similarity. If synonyms of a searched term in the semantic net yielded subarea concepts that were not included in the subareas of the term itself, these subareas of synonyms were evaluated to be "intellectually very close" and thus correlated to useful content information to possibly provide to the user. Thus the system calculated a series of levels of "association" or "closeness" of information for any given inquiry. In the broadest sense, this metric of association or closeness provided a way for the system to decide how useful a related module of information might be, given a specific inquiry presented by the user.

Frames of Usable Information

Also incorporated into the delivery system were overall frames or models of patterns of expected usable information. These patterns were stored for each class of problem or medical diagnosis in the semantic network. The system used these patterns as guides for the retrieval of information about the problem or disease. Thus frames of information constituted another series of implicit rules stored in the net to guide the system's progress in a clinical setting. For example, if a patient has the medical diagnosis of emphysema, then for clinical care purposes, the nurse would want to address care issues such as the organization of the nursing diagnoses for emphysema, the expected outcomes for each, and the associated interventions, as well as discharge teaching, and so on.

It is the foregoing model of information flow, stored in the semantic net as the clinical care guide, that directed the construction of the clinical care plan from among all the content entries available. Thus the clinical setting in a hospital introduced an additional set of implicit rules that guided the default retrieval of information.

Open-Ended Searches

In contrast, purely open-ended PACE searches are possible in which the knowledge base is searched with no preconceived clinical focus defined at the onset. This search approach (called "Browse") allows the system to provide a far more open-ended response and to display the results of a search for information in a way that allows users to select the context(s) in which they are interested. Thus the full range of exploration of the available information and search capabilities inherent in the system via the semantic net is available in the system without preconceived frame restrictions. Typically, however, this option is not utilized in busy clinical care settings.

Content in the Semantic Network

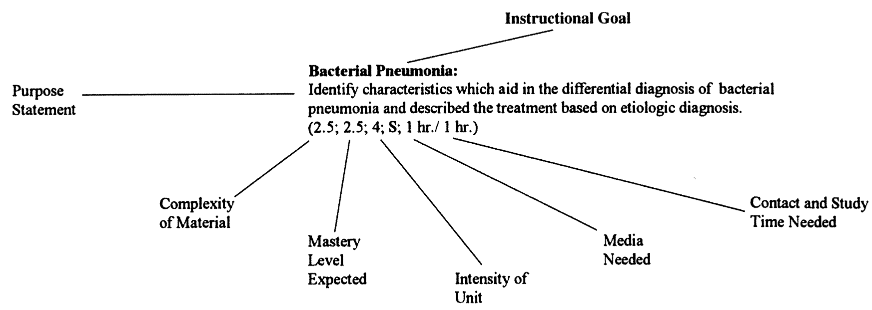
Knowledge Structuring

It will be instructive to elaborate further the process by which clinical content knowledge is structured. An area is organized conceptually by beginning with the overall global goal to be addressed (e.g., "provide nursing clinical patient care for a particular problem or condition"). Once this has been established, it is necessary to describe the subgoals that will ensure the achievement of the overall goal. The global intellectual organization arising from the unifying Taxonomy of the Health Sciences (provided in the Appendix) guides the development of the individual areas of the global goals. Semantics for the net can be defined after a complete intellectual definition has been provided.

At the outset of the PACE process, every behavioral goal in the entire curriculum for each health profession was defined with its constituent subgoals. Every subgoal was further divided into sub-subgoals; the process ended when no further conceptual division was possible. Then for each and every single deepest level subgoal, an additional "vector of instructional information" was specified. This vector clarified precisely the degree to which that information would be intellectually approached, as well as the nature of the approach. To make this clear, it is first necessary to identify the elements that constituted the vector of instructional information.

Vectors of Instructional Information

A vector of instructional information comprises a series of numbers or letters that quantify or specify selected attributes about some content module of instruction. The first number in the vector identifies the degree of complexity or depth of presentation that would be undertaken for the particular concept or area. The second number indicates the expected (i.e., appropriate and proper) mastery or level of performance. The third number supplies an indication of how demanding it would be for the usual student to achieve such mastery, given the complexity identified. The fourth element identifies any type of learning media that would be mandated to achieve mastery, given the complexity defined. The final element is the amount of structured learning time as well as subsequent self-study time that would be needed to accomplish the specific goal. Thus every module of information carried with it at least five descriptors indicating the degree of complexity, mastery, demand, media, and time required. A typical goal with its modifiers (and the interpretation of the associated numeric scales) is shown in Figure 6.3.



LEVEL OF COMPLEXITY ____

Cognitive Domain	or	Psycho-motor Domain
overview: highlights and perspectives	-1-	simple motor skills: easy repetitive movements needed
	-2-	
introduction: perspectives & some essential principles	*	applied motor skill: care and dexterity required
	-3-	

MASTERY ____

Cognitive Domain	or	Psycho-motor Domain
recognition: can recognize information/retrieval	-1-	lowest competency: slow and awkward
	-2-	
recall: can recall information/ formation/material	*	moderate competency: not as slow with moderate precision and accuracy
	-3-	

INSTRUCTIONAL DEMAND ____

-1-	lowest demand: the instruction demands little initiative
-2-	
*	moderate demand: the instruction demands moderate initiative and concentration
-3-	

A

FIGURE 6.3. A typical goal with its modifiers.

<u>intermediate:</u> virtually all essential principles plus a few topics in depth	-4-	<u>involved motor skill:</u> coordinated and involved, multiple manipulations necessary	<u>application:</u> can adapt learning for application to unfamiliar situations	-4-	<u>intermediate competency:</u> methodical and meeting all minimum standards of precision and accuracy	-4-	<u>intermediate demand:</u> an average level of initiative and concentration
	-5-			-5-		-5-	
<u>advanced:</u> all principles plus the majority of topics in depth	*	<u>complex motor skill:</u> requires choice of methods or alternate manipulations, added dexterity	<u>synthesis:</u> can derive new knowledge or arrive at new solutions	*	<u>advanced competency:</u> good speed, with precision, accuracy, and finesse	*	<u>high demand:</u> substantial initiative, concentration, and independent learning required
	-6-			-6-		-6-	
<u>most advanced:</u> great depth in virtually all topics	-7-	<u>most complex skill:</u> strength, endurance, and/or extreme dexterity needed	<u>research:</u> can extend frontiers of knowledge or invent new approaches	-7-	<u>highest competency:</u> maximum speed, precision, and accuracy with elegance	-7-	<u>strongest demand:</u> intense initiative and concentration required

TIME

contact time:	study/practice time:	totals:

MEDIA

Enter media code letter or name of other media forms:

S =	C =	A =	R =	L =	T =	P =	A/V =	O =
Specified later	Clinical practicum	Applied laboratory	Reading	Lecture	Tutorial	Learning package	Audio-visual	Optional

FIGURE 6.3. *Continued*

B

More broadly, a *complete* goal definition has the following components: a statement of the purpose of the goal, a list of prerequisites to achieve before undertaking the goal, a list of subgoals (the accomplishment of which ensures that the goal will be achieved), indexing terms used in the statement of the goal (to be discussed), and a description of any testing needed to determine that the goal has been achieved. Ten elements constituted the total definition provided for each goal (and each subgoal of every goal) defining a knowledge area. These elements are summarized in Figure 6.4.

In the definition of an entire field such as the care of the patient by a nurse or a physician, the vector of information helped clarify at the onset the specific instructional expectations involved. Although these 10-part vector descriptions were meticulously added for every goal and subgoal to the deepest level of definition (up to 17 levels deep for some program definitions) for every health professions program, over time the vector descriptions were ignored. One of the primary reasons for the failure to

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(1) Purpose Statement—states the educational purpose with respect to the subject matter, attitude, or psycho-motor skill about which this goal is concerned.
(2) Complexity Level—is an estimate of the degree of superficiality or depth to which the goal's subject-matter or skills are treated.
(3) Mastery Level—is an estimate of the degree of comprehension or competence a student is expected to obtain, given the complexity level and purpose described.
(4) Level of Instructional Intensity—is an estimate of the (instructional) demand for initiative and concentration required of the student to achieve the stated mastery and complexity.
(5) Media—describes any communication modes required (or employed) to deliver the instruction to the student.
(6) Time—is an estimate of the contract and study time required to complete the goal, given the complexity, mastery, and intensity.
(7) Prerequisites—specify the knowledge, attitudes, and/or skills, (written as goal statements) required of students before they can begin pursuit of this specific educational goal.
(8) Subgoal List—is a list of goal statements which specify what must be accomplished in order to fulfill the goal in question; it is the list of constituent tasks which comprise the educational goal.
(9) Semantic Summary—is composed of a group of keywords selected from the purpose statement indicating the essential content of the statement together with sets of indexing terms which clarify the context of each of the keywords identified.
(10) Testing—provides a summary of any evaluation approach used to determine the student's readiness for the goal as well as post-tests which confirm accomplishment of the educational goal (at the complexity level indicated, mastery level specified, etc.).

FIGURE 6.4. The components of a goal statement.

maintain these descriptions was that within the clinical setting, which constituted the principal application in later years, it was assumed that professional clinical care would mandate *whatever* complexity, mastery, media or mode, or time was needed to achieve a given goal. In other words, the vector values defaulted to the implicit expectations of the health professionals who provided that particular area of care. Nonetheless, the design of the system permitted the user to select or restrict any or all of these specific vector attributes in combination with an area context for a single inquiry the user might wish to give the system (Evans, 1982). Using these choices, the system could properly retrieve a response that was appropriate for the inquirer.

It was also possible to specify the type of health professional who was making the inquiry (e.g., a nurse, physician, etc.). Even though the semantic net originally stored all the health professionals' knowledge aggregated in total, it could differentiate the interest of the "nurse and emphysema" from the interest of a "physician and emphysema" by coded vector assignments, which at first were given so that the system could later correctly retrieve information as desired. Initially it was not expected that the user would specify this differentiation, and an inquirer would get the aggregate of responses of all health care professionals for the problem identified.

In applications of PACE as a product, however, it was rarely of interest for one health professional to look at other health professionals' responses for a problem area. At the onset of the beta site testing of PACE in the early years, the only interest in multiarea health profession searches was displayed by nurses who first looked at organized nursing knowledge for a particular problem, and then approximately 50% of the time reiterated the search, initiating the physician "code" for information retrieval. The nurses always printed out the nursing information; they nearly always just reviewed the physician information on the screen. In later years, this capacity to differentiate information was dropped from the delivery system because of lack of use.

One might speculate what the impact would be if patients were allowed access to the system—a prospect consistent with recent trends in empowering the client or patient. When the idea arose in the early days of the system's implementation, however, high anxiety among health profession project advisors greatly dampened interest, and no further efforts were made along those lines. In very recent times, a number of software products have become available to the public, including drug information packages and health information packages that certainly would have been comparable to the system's early output (I Didn't know I Could Do That On Compuserve, 1994). This present availability reflects in part advances in technology (e.g., CD-ROMs); but equally, it reflects a shift in attitudes to more consumer participation in personal health care than was the case in the early PACE years.

The Audiovisual Consultant

Not only could clinical care information for patients be defined with the strategy that was taken, but also any class of structured knowledge could be so defined. As a variation on the clinical care theme, our initial efforts included hiring a wide variety of health professionals who were directed to review audiovisual materials addressing health care. Their task was to divide a videotape into the intellectual elements the video addressed. The encoder might indicate, for example, that the first three minutes provided a description of the epidemiology of a particular disease. They might then indicate that the next five minutes addressed the differential diagnosis of that problem. The third five-minute component might summarize suitable therapies, and so on. Then, having provided an intellectual division of the information, the encoders identified the rest of the vector of information to describe each goal achieved by the video (in addition to the required semantic net entries). As a result, videos were incorporated as elements into the knowledge database of PACE at the onset. When a user searched the database, and the A/V(medium) was specified, this restriction was applied to the system's search, and only audiovisuals addressing that problem would be retrieved. Upon retrieval, the conceptual elements of the video (e.g., epidemiology, diagnosis, and treatment) would be displayed.

If the user wished, the system could then retrieve detailed annotated content by linking to the semantic network encoded for the video. As noted earlier, all citation references in the net were cross-linked to every intellectual module. Thus the user could also get the details of the library's code numbers for the video that provided the information. A feature of the original system was an automatic ordering form printed at the terminal whereby the A/V could be borrowed from the Creighton University library, assuming certain other criteria were met. The current PACE product, however, includes none of these features.

Other Applications of the Net

Academic Management Information System

Originally the intellectual definition of the entire domain of knowledge was undertaken not by clinicians as is done now, but by faculty for each of Creighton's health sciences programs. The faculty defined the recommended material in the context of all that was provided in the educational programs at the Creighton Health Sciences Center. The modules of information corresponded to elements in some faculty member's lecture or presentation, somewhere in the entire health sciences educational program at the university. Moreover the details of the vector elements of complexity, mastery and so on corresponded to the expectations of the faculty member providing the content. With its search capability, the system automatically yielded an academic management information system (Evans, 1984c). One could identify a particular conceptual area to see how it was addressed throughout the entire educational program. One could look at the levels of complexity and intensity for any intellectual area that was provided in one or many programs. One could search the audiovisual library for resources to support any kind of intellectual component offered by any program. This could all be done with no additional faculty labor whatsoever.

In one particular accreditation review for the nursing program in the School of Nursing in Creighton University, all the educational goals and subgoals (the behavioral objectives for every lecture for the entire program) were easily provided by simply doing a program "dump" of the conceptual contents of the PACE system (restricted to nursing). What was extraordinary was the organization revealed: the definition of all the information was conceptually arranged, not just by lecture or even by course, but as an integrated conceptual whole, governed by the taxonomy that structured the entire framework of knowledge. A subsequent request simply by "media," which specified each course number (and even included the class and the lecture in which that intellectual unit resided), yielded a printout that was structured by traditional curricula organization. Thus the accrediting agency could see where all information was presented for every course, what parts of the world of information it presented, and how all the information was structured and leveled (utilizing the vector of complexity for its appropriate purpose).

Curriculum Analysis

The process of defining the original, desired domain of knowledge on the part of the faculty itself was an extremely valuable undertaking. There were some faculty who were not always described as cheerful when they addressed this part of the project, but nonetheless it produced an extremely valuable result. The health profession domains were defined and organized, and the specific areas into which every conceptual component was placed were identified. The first definition was based on, and created, as the faculty's ideal program irrespective of the current one, any budget limitations, or other restrictions. As a separate request from project administrators, faculty were asked to provide their behavioral objectives across all courses (for their respective programs as they currently provided such instruction). These objectives were carefully compared to the faculty members, systematic exposition of their desired, ideal, and organized program covering clinical care information.

As a result of this process, there was a master document produced that showed whether each defined, desired intellectual objective had a "home" in the currently offered program, whether there were concept "orphans" that needed to be addressed somewhere in the curriculum, whether certain activities were being undertaken that appeared to have no correlation to the definition the participants themselves had created, or whether some intellectual elements were addressed in redundant ways. Redundant material typically occurred as identical topics presented without increased complexity or mastery levels (substantiating the case for duplication).

Hence this process created an organized, institutional way to evaluate curricula and orchestrate and systematize change. It was estimated by one former dean who helped orchestrate the process that approximately 20% of the school's curriculum was revamped as a result. This curriculum analysis is another application of the methodology as it is realized in an academic setting.

Test-Writer Application

As the semantic network and associated modules of information expanded, more complicated search routines were built that made use of PACE's implicit rule strategy. One such application, called TEST-WRITER, demonstrated how the implicit search in the net would in effect correlate to numerous rules that would have had to be written in the traditional rules-based approach (Evans, 1984a; Evans, 1984b).

The TEST-WRITER system module had as its goal to write test questions for any specific problem domain a user might identify. If the user identified, the area of "pneumonia," the system would search in the semantic network and see that "pneumonia" is listed as a disease. With the concept "disease," the system would search the network for the node of "disease" and discover that diseases have a defined pattern, a variety of subarea components, which define the idea of disease. One component is "cause of disease," a second is "diagnosis," a third is "therapies." Selecting these subareas, one by one, the system might, for example, take "therapies." PACE would return to the original semantic node of "pneumonia" and determine whether there were "therapies" underneath this node in the net. It would find the subcategory under "pneumonia" called "pneumonia therapies." Returning again to the general frame of "diseases" and the subarea frame "therapies," and beneath that, "specific drug therapies," the system would find in its net that there are sometimes "complications" listed under "specific drug therapies." Returning to "pneumonia therapies," it would search for a semantic node under "pneumonia therapies," indexed as a therapy. Upon finding several, it would select one of the therapies (e.g., "penicillin"), find it indexed under "specific drug therapies," and look for "complications" for that therapy, (i.e., "complications with penicillin" indexed under "complications").

This semantic node in turn had specified subareas identified as specific complications that might arise from the use of penicillin in pneumonia. All this information was then aggregated to a test question constructor. In summary, the system now "knew" that it had an entity "pneumonia," which was defined to be a disease, that diseases have "therapies," and that this particular disease appeared to have a therapy category. It had within the category a specific therapy (viz, penicillin), which it recognized to be one (of several) "specific drug therapies." It found that "specific drug therapies" could have complications, and this one was coded with some. These complications were retrieved. Next the question-frame constructor created the question:

Given the *disease* of *pneumonia*, and certain *therapies* that might be provided such as *the drug penicillin*, identify some of the *complications* you might expect in the provision of *penicillin* for *pneumonia*.

Your answer should include the following *complications*: (the list of complications followed as stored in the semantic net).

The underlined terms above were derived from the directed net search and module of information retrieved and plugged into one of many frames for question construction.

In its alpha testing, the system was so successful that physicians, hired to write questions for board certification tests in certain areas of medicine, utilized the system at Creighton for its test generation capacity. After using TEST-WRITER to generate comprehensive questions sets, these physicians then pruned and submitted them to the board as their own contribution for their designated areas. This particular application area was never successfully made into a commercial product, although there was great interest among selected academics. The experience demonstrated, however, how searches in the net in combination with other information stored in the net formed the ability to derive and refine the retrieval of information in a heuristic fashion that could be very advantageous.

To emphasize this point in our discussion of TEST-WRITER, we point out that with one more move to a higher level in the semantic net, the system would also generalize a problem such as "pneumonia" to the broader level in which it is set. It would then look at the network for specific associated ideas tied to pulmonary disorders (e.g., COPD), and in turn generate questions about these other related issues (e.g., "rehabilitation for the patient with COPD"). It did the same task when open-ended search questions were posed about an area. Thus the degree and subtlety of search based on guided movements in the semantic net constituted classes of rules applied dynamically by the content of the semantic net to retrieve as well as evaluate information contained within net.

Semantic Net Searches for Diagnosis and Assessment

A yet more subtle variation of the foregoing use of the net was accomplished at the very end of the third generation of the PACE system. Rather than specific nodes of information or packets of details provided at a specific semantic node, programming code to be executed was stored at some nodes. Upon selecting these nodes, PACE found a packet of code to be executed. It then interrupted its current processing, executed that code, and returned to the node for further processing. The code might send the system into the net to collect and compare data from nodes defined by the subareas of a particular node, which in turn might have led to a node that itself contained more code to be executed, rather than information, per se.

This design is not greatly different from a much earlier concept in which a semantic net contained "demons" (Hofstadter, 1979). Each demon could execute a series of subprograms (on a database), possibly involving itself as a subdemon (Sussman, 1975). PACE at the very onset (1971–1974), was executed in LISP, which permits a recursive approach that greatly facilitated this type of strategy (Winston, 1977). After 1974, no recursive languages were used, but by experience, we knew that the level of recursion never exceeded known, specifiable levels of depth of recursive routine calls. Thus, although the system was ported from LISP and never subsequently performed in truly recursive mode, it still performed appropriately with this application through simulated approaches to true recursion.

A particularly interesting application of embedding executable code in the semantic net was achieved in a conversion of PACE into a limited medical diagnostic system (Evans, 1985; Evans et al., 1995). As a user searched on a particular set of patient assessments or complaints (e.g., edema and fever), each characteristic or complaint directed the system, via code embedded in the net for these diagnostic symptoms, to a series of different subsearches. The subsearches collected information from the patient's assessment list, or the system queried the patient to ascertain whether he or she exhibited those characteristics. When the composite patient record indicated the presence of those characteristics, additional subsearches were directed based on the aggregate information. The components of certain characteristics and attributes would enable the search process to find modules described by that set of conditions. The coding of these modules would direct the search further, either gathering more assessment information or eliciting more from the patient (e.g., lab tests, additional questions to answer, etc.).

The evolving patient status might produce yet other inquiries, which then led to further packets of information retrieved, or other submodules activated (which might be requests for further tests to be performed). This particular diagnostic model replicated many attributes of the traditional diagnostic models that were available at that time, particularly INTERNIST developed at the University of Pittsburgh.

Although far simpler, a strictly net content example can be given to demonstrate this use of the net. Consider a "search list" that is actually an imagined patient's set of complaints and assessments. On the list is lower left quadrant pain and fever. Imagine that these two terms are searched ("lower left quadrant pain" AND "fever"), and PACE finds a module of information called RULE-OUT APPENDICITIS. The associated semantics with this module are "nausea," "high white blood cell count," and "positive x-ray for inflamed appendix." These symptoms are checked against the patient's assessment list. They are not found on the list, and thus are posed as information requests. Suppose further that an x-ray is done, and "positive x-ray for inflamed appendix" is added. A search on this term on the patient's assessment list then finds the module "Diagnosis: Appendicitis." On the other hand, if just nausea is confirmed, along with a high white blood cell count, the search with "Rule-out Appendicitis" AND "nausea" AND "high white blood cell count") will find a module indexed with these terms called PUTATIVE APPENDICITIS. The subareas of this module, "diagnosis—putative appendicitis" and "take x-ray for inflamed appendix," are then added to the patient list. Note that the process requires only the usual search capacity of PACE, the usual capture of the content of the semantic subareas placed on a list, the repetitive search on the current list (combining or "ANDing" the conditions found), and the proper coding of modules and their local semantics.

The mathematically oriented reader will see that PACE operates in this fashion as an automaton, with a current state and a transition to a new state based on input to the automaton for the state it is in. In recursive function theory, one can show that an automaton, even in its simplest form as a Turing machine, can accomplish what can be achieved with any computer programming, albeit not necessarily simply.

A complete model using this semantic net adaption approach was developed for the diagnosis of hereditary cancer (Evans, 1985). What was demonstrated by the diagnostic application using PACE was a clearer example to the informatics community of how the net and the search process *together* in effect are equivalent to a complex set of rules, with the analysis and decision making dependent on the structure and content of the semantic net on which the search is executed.

One very important characteristic of this embedded-rule approach taken by PACE was that since the rules are within the structure and content of the semantic net, they need not be itemized or made explicit and checked except for the part of the net being investigated. Thus the total decision-making capacity of PACE could be correlated to quite literally several millions of rules (in the net's later stages), executed in a contingent fashion on the net's structure, where the directionality and content of the net defined the next logical rule transition at that point. Since the rules were implicitly embedded in the structure of the net, administration and growth of the entire network was very manageable. Maintenance of the decision-making application became a corollary to the maintenance of the net itself, and the linkages contained within it.

This last point is an extremely important accomplishment arising from our departure from a traditional set of *explicit* rules to embrace an *implicit* set of rules embedded within the directionality and structure of the knowledge base and its correlated semantic network. The upgrading of knowledge (and concomitant semantics) automatically upgraded the rules as they were locally applicable to that particular portion of the knowledge being upgraded. Maintenance of the knowledge base was tantamount to maintenance of the rules. In our approach, consistency and compatibility of the rules became an automatic feature as long as the knowledge was systematic and updated.

Forgetting in the Net

The use of patterns defined within the net led to an easy strategy by which "forgetting" could be implemented in the net. If a particular area, such as "therapies for pneumonia" was no longer appropriate, that subarea under pneumonia simply was removed in that specific context. Then as the system searched in that context, it would never find that link to that subarea. Thus it would have "forgotten" or eliminated that particular attribute. Although the knowledge remained in the knowledge base, the net link was cut, and the system would not search for it. If the knowledge were still valid in some other context, those net links would remain, and a search would activate the knowledge correctly.

This point accentuates the ability of the system to keep track of which family of semantics was tied to which specific conceptual domains. The search followed the semantics tied to *each* conceptual context, not any semantics arbitrarily integrated into the total net in general. This is an important distinction because it increased the context of the nature of the retrieval that made the difference between proper performance and potentially irrelevant retrieval.

Tailoring the Net

In later generations of PACE, the ability to differentiate the retrieval of knowledge based on the specific context of the knowledge desired became a very useful addition to the clinical application of the system. In individual hospital settings, there might be a particular approach to pneumonia for the newborn that was special to the neonatal area in that hospital. PACE permitted the definition within the semantic network of a series of linkages that could be tagged by labels special to that particular division the hospital (or the hospital as a whole, however the institution might wish). When the system undertook its searching, it would first check to see whether distinctions were being defined in that area by the hospital. If this were found to be so, the system would search and retrieve just the contextual answers that corresponded to the definition the hospital or subarea within the hospital desired, rather than the general response that PACE might give otherwise. Later the system permitted every computer terminal to be tagged by the area in which it was located. A terminal in the neonatal area would automatically pick "pneumonia for the newborn" as its default response, as defined by *that* hospital, rather than "pneumonia for the newborn" as generally defined by PACE, or "pneumonia in general" without regard to the age of the patient, as might also be available within PACE too. This differentiation obviously was extremely advantageous and appealing to nursing clientele.

New Aggregation of Information

The semantic coding methodology of PACE created a series of families of interesting associations. The first family was the intended intellectual division of the domains of knowledge as defined by our Taxonomy for the Health Sciences, used to organize all information. Correlated to each concept was a series of individual semantic terms (e.g., respiratory disease, obstructive respiratory disease, chronic obstructive pulmonary disease, rehabilitation for COPD, etc.), which categorized that intellectual division. Thus the specific concepts of the taxonomy divided each domain into constituent parts, and naturally led to groupings within the semantic network. Since the net had pointers to the associated content for each concept, the content was similarly divided into common groupings.

Beyond this obvious intellectual division, the net itself acquired families of divisions in addition to the taxonomy divisions. For example, the net could aggregate all information along such divisions as specific patient characteristics (e.g., nausea, pain, dyspnea, etc.) or drug usage (e.g., use of diuretics, anticoagulants, etc.). There could be a search on all aspects of "pain" or "patient depression." Functional clinical problem-solving areas such as "assessment" or "patient teaching" could be used to direct the search for all the content in the knowledge base along these conceptual lines. With its very systematized conventions for coding the semantic context of content, PACE could undertake multiple rearrangements of knowledge, in informative and interesting ways (Evans, 1983).

Prospects for utilizing this semantic network–acquired hybrid reorganization of content knowledge have not been fully evaluated either by PACE or by its many product spin-offs in the years it has been available. The preceding examples of TEST-WRITER and the diagnostic application only indicate some of the applications that are possible from the net's linkages. As one further example, since patient attributes and conditions are included in the system, and the semantic net cross-indexes all such attributes—so that "nausea," for example, is linked to all the problems that can lead to "nausea"—we have an automatic way to assess the patient's problem of "nausea" and can even begin undertaking a diagnostic approach if we compare this characteristic to the defining characteristics of the nursing diagnoses that have been (or could be) assigned for the patient, given his or her medical condition. Thus, in the PACE nursing application, the semantic network lends itself to the capacity to correlate initial nursing assessments with subsequent patient nursing diagnoses and patient care and then link patient progress with ongoing critical assessments.

Methodology for the Codification and Interpretation of Knowledge

Over the years, it has become apparent that the three-part semantic network coding characterization of the "context" or "general area," synonyms or equivalencies, and particulars or subareas represents the very minimum that must be employed in a semantic net to provide the system enough power to achieve the differentiation and search capability required. On the other hand, more than this description does not appear to be needed, since the three categories can be aggregated and used through a search process to produce more complex and higher levels of analysis. Hence a case can be made that these categories are both a necessary and a sufficient division for the intellectual classification of knowledge to permit extremely complex retrievals appropriate for the health care domain. It can be argued that these three categories will adequately define a metathesaurus that would be sufficient to resolve ambiguities and other similar problems as defined in the literature in medical informatics. It will remain for other researchers to apply this methodology to achieve the resolution that will be necessary in evolving systems in the future (Soda, 1995; Tuttle et al., 1992; Michel et al., 1989).

Scaling Up the Semantic Net

A corollary to the semantic network's complexity worthy of note arises from the extent of development of the semantic net itself. It might appear that working with a larger net is simply the linear extension of working with a smaller one. Yet this mundane observation is in fact not true. Much as scaling up of chemical and physical processes often entails circumstances that never arose in the prototype, so is it the case that massive semantic networks and the massive number of linkages involved do not correspond to simply an increased order of magnitude of expectations and difficulties that accrue when small networks are created. Scaling the process up generates a completely new class of problems that are not easily seen when a small network is built.

On the other hand, however, the positive outcome of this scaling-up process is the accrual of a great deal of surprising implicit associative power as semantic information is categorized and expanded within the net. Differentiation and subtlety increase as the network increases, but such differentiation can increase at a level far greater than linearly to the size of the semantic net. We found that extremely complex, extensive nets together with the linkages discussed (i.e., the general areas, synonyms, and subareas for every term) produced far more sophisticated, subtle results, which had not been anticipated at all when small nets were built in limited areas. We can only speculate that just as physical, sensor-based optical recognizers grow inexplicably robust once a certain threshold has been reached, there are some points of critical mass for very large semantic networks at which extremely insightful and surprising connections begin to be made. To our knowledge, PACE continues to maintain, in all of health sciences throughout the known informatics world, one of the largest organized semantic networks that is consistent, coherent, and uniform. This is not merely a *Guinness Book of Records* observation; rather, it represents a set of experiences from which interesting lessons can be learned.

Extremely large semantic nets with implicit rules of search similar to those developed for PACE may reach unanticipated levels of performance, in the analogy of Perceptrons for pattern recognition of many decades ago (Rosenblatt, 1958). Unfortunately it would appear that few project teams have had the interest, inclination, or tenacity to build and maintain the vast semantic net knowledge base and cross-linkages required to characterize an entire domain of knowledge. In this sense, PACE will remain a singular example of such an effort that may be characterized by its uniqueness for quite a period of time.

Semantic Measures of Conceptual Closeness

Although the clinical setting has not utilized the degrees of semantic flexibility (or what we called search "relaxation") that are used by PACE and its search techniques, nonetheless this is an important feature employed by the system to resolve ambiguities in the search process. The resolution of certain ambiguities was approached in terms of the concept of the "closeness" of a retrievable idea compared to the initial idea advanced by the user.

The user might wish to receive certain information about "bacterial pneumonia." In this context, let us suppose, for example, that the system has nothing encoded about bacterial pneumonia. At its highest (most germane) level (level 1), the system would identify nothing at all that it knew about, which could meet this particular need. However let us suppose that bacterial pneumonitis has been described to the system and has been indicated to be a synonym of "bacterial pneumonia." The system at the next level (level 2—a very closely associated level) could provide information about bacterial pneumonitis and thus would apprise the user that the matter can be addressed at level 2.

Now assume that the system recognizes that it has no specific information about bacterial pneumonitis but does have specific information about "diagnosis of bacterial pneumonitis" and its therapies. The net would indicate that certain intellectual subareas of the concept at issue have been addressed by experts, namely, the diagnosis and therapy for bacterial pneumonitis. The coding of the general areas of the semantic network tell the system that these particular subareas are being addressed, although the whole area has not been addressed. If the entire area were addressed, there would have been an intellectual concept used as a key word in some content area. Recognizing that such a concept has not been used as a key word, the system at least knows that there are particulars with which it can deal. Thus it can apprise the user that at the next level (level 3—or a somewhat close intellectual domain) it can deal with this problem; that is, it can discuss and give information about the diagnosis or therapy.

Finally let us suppose that PACE knows nothing at all about any of the concepts just mentioned but recognizes bacterial pneumonia as one of the many pneumonias about which it has general information. This means in effect that the system can generalize or move up the net to a broader area (i.e., pneumonia), and it has information at least about this broader area. Thus, the system with its movement in the net (and its ability to correlate the nodes in the net with the availability of content information at that node level in the net) has a way to understand the degree to which it has specific information or related information in which the user might be interested. Thus, the levels of search that correlate to movements in the net and associated information defined in the net represent a variety of search technique that helps retrieve and resolve ambiguity, given the particular search inquiry of the user.

Added to its definition of single-term searches, PACE permitted the use of AND, OR, and NOT. It also created special new expression connectors such as IN THE CONTEXT OF and RELATED TO. PACE permits a much wider range of search resolution than is actually utilized in the current *clinical* PACE. The range of interaction has been replaced with default, programmed choices, since the application focus has been narrowed to the clinical care patient setting. It is known that such settings have a series of well-defined requirements, which are assumed to be operative for the PACE application. This presumption is similar to frames in TEST-WRITER, in that a single built-in frame or paradigm automatically drives the current clinical care retrieval process.

Originally PACE permitted the user to control the choice of the operating paradigm. For example, the system understood the nursing process, and if the user wished the nursing process to be applied to the area of "pneumonia," the model of nursing process contained in the semantic net would drive its systematic retrieval of information corresponding to the nursing process. If the user identified a physician model, the form of that model (including epidemiology, diagnosis, therapy, etc.) would guide the specific retrieval of information. Other whole intellectual domains such as Orem's nursing model could have been delineated, and the retrieval of information would have been guided accordingly (Orem 1985). What this indicates is that the system has easily the capacity to store a variety of retrieval models as part of its semantic net guidance. When that model is selected interactively with the user's concurrence, it in turn guides the manner by which the links are traversed and the information retrieved. Thus, PACE innately can be far more variable and responsive to the user's interest than the current default mode. On the other hand, the default mode makes the current system far more efficient for the settings that employ it 99% of the time.

Preprocessing Responses

Last, we note an important efficiency achieved by PACE that is indicative of a more general principle applicable in this area. As the system grew exponentially, the response time for searches became unacceptably long. To tackle this problem, we noted that we could identify a vast number of likely search interests on the part of the typical user (e.g., all patient care medical conditions defined under DYSFUNCTIONS AND CONDITIONS in the taxonomy). Once identified, the system could be directed to undertake the appropriate expected retrieval linkages within the PACE semantic net for the problem of interest. For example, if "emphysema" is an expected area of interest, we request PACE to address this problem using the standard approach, and the output is then stored as a prepared response if this search is entered by the user in "real time."

Approximately four times a year, PACE is directed to undertake the search and retrieval of virtually all the possible major areas of interest. Thus "emphysema," "pneumonia," "bronchitis," and literally thousands of problem areas are artificially activated. The system is directed to do complete searches and itemize its entire response. These pathways, searched and completed, are then written, stored, and kept as prelink lists for such times as any of the nodes might be activated. As a result, when the user initiates an inquiry such as "emphysema," rather than completely activating the entire search "live," the system retrieves the already completed search and development of materials in its file, and that complete element is quickly made available to the user.

This is the same strategy the earliest PACE system (employed at Carnegie-Mellon) used to overcome the deficiency of the computing power that was at the level of one ten-thousandth the computing power currently available. Since the complexity of the system has grown 10,000-fold, this strategy for increasing efficiency still must be employed. The preprocessed searches account for at least 90% of all the inquiries.

PACE systems analysts have calculated that the increase of the power of computer central processing units (CPUs) available at this time would finally permit a "live," response-calculating system, without resorting to a preprocessing strategy. At the currently lowest computer power level of implementation of the system, its "live," nonpreprocessing "performance" is estimated at approximately a few seconds wait time to deliver its response. Currently the system with its preprocessing strategy responds just as quickly as the screen can be refreshed, and thus it is still quicker than the three-second response that might arise from real-time calculations.

The next generation of PCs and CPUs could eliminate this draw back, and PACE could operate dynamically and live for any particular search requested. Since the complexity of the system continues to increase, one would guess that this preprocessing strategy may remain viable for the next generation until such time as the rate of CPU power overwhelms the current wait time of a few seconds.

The danger in the preprocessing strategy is that there remains a great temptation to continue to maintain it throughout subsequent generations of the system, thus losing a certain amount of the subtlety of the search capability that is possible if in fact the search is "live." There might be a differential between the system's best response and the default response because the preprocessing does go forward with the "expected" and standard response model, tabulated for every node that is activated in the preprocessing batch mode run. As noted, this standardization is based on a very attractive model, carefully tuned to the expected needs of nursing patient care. Nonetheless, those rare unexpected correlations that are eliminated in the standardization review process are sometimes precisely the interesting results or recommendations that add surprise value to the results from a "live" system. Given the intensity of the role of nursing care in the hospital setting, however, the excitement of surprise does not appear to be an attribute hospitals feel they can afford to implement in their support systems. Thus it is likely that the elimination of such surprise and the increase of standardization will remain the rule as health care in the United States continues to undergo dynamic and significant changes in the next few years.

It has been the intent of this section to give a brush-stroke understanding of the nature of the methodology of PACE and some of its features. This broad understanding may help guide future researchers in the possible selection of this approach in the application of search and retrieval as these tasks arise in different areas within medical informatics.

Working with the vast detail of the semantic network development that is necessary to accomplish a useful product in this field presents a greater challenge than writing code for the search/retrieval process. Indeed it has remained formidably difficult to develop both the vast knowledge base and the crucial correlated semantics necessary to produce commensurate examples of this in any other research setting involved with nursing informatics, so that others may experiment and extend the accomplishments of the PACE development.

To our knowledge no other similar effort either of modest size and scope or of major dimensions has been initiated within nursing informatics. Some knowledge base expert systems with individual rules and some specific content related to those rules have been constructed. The classic rule-based informatics strategy, however, represents a different entity, and its usefulness and viability in nursing remain to be proven. For this reason, PACE may remain for some time the only viable demonstration of the application of large-scale semantic networks. This prospect has been another reason for collecting and summarizing in this volume the lessons learned and the information gained.

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Chapter 7

Synthesis of Principles and Lessons Learned

System Design Principles

Keeping It Simple

Several design principles can now be more easily recognized. The original PACE design had a rich and interactive software system that involved the users extensively to ascertain their needs and fine-tune their specific interests. It is extremely difficult, however, to take full advantage of such a dynamic interactive software "front end," in the present health care environment (Ball & Douglas, 1995). Users today rarely have the time to interact, and they preferred the system to be responsive in terms of a guess at what their needs would be. They preferred that the system produce a highly accurate first guess that was most often correct, requiring them only to fine-tune it to a specific patient's needs (Metzger & Teich, 1995). As a result, the investment in the capacity to explore, tune, and permit the user to reflect on a wide variety of intellectual interests represented an academic orientation that had less applicability in the actual clinical practice setting.

In contrast, what evolved was an extremely practical system that made the appropriate guesses, ascertained the most likely expectations of the user, and responded accordingly on the basis of a model that attempts to mimic human intuition. Such a system was far more appropriate and germane in the clinical setting. In addition, innumerable support systems such as automatic spelling support modules, practical care plan development capabilities, and easy screen fill-in additions became very important features, making the difference between an academic design and a practical design that would work for busy nurses.

The degree of information overload, although somewhat expected at the very onset, still reached levels that had not been anticipated (Evans, 1988). For example, the disinterest in having bibliographic citations appear at all (to support recommendations) was widespread; such intellectual verification components were incongruent with the pressing time demands of the nursing clinical working environment. In addition, all editing and selection features needed to be formatted in a point-and-shoot style, rather than by means of more complex keyboard entry approaches. A click with a stylus pen would be even better. A delete and/or select menu style of information management was crucial to the successful utilization of the system.

Making It Intuitive

The system itself needed to be able to provide menus and choices quickly and efficiently so that the nurse could simply use his or her assessment and intuitive skills to properly select desired responses (Benner & Tanner, 1987). This was preferable to either entering information or extensively interacting to get the right answer for the patient needs at hand. To guess user needs accurately most of the time, the PACE system had to be even more insightful than earlier projections had indicated (Brennan & McHugh, 1988).

Understanding the End Users

A number of features that were added, all of which appeared to be intellectually enticing and interesting, were nonetheless irrelevant under the intense demands of clinical practice. As a result, the project designers recognized that the requirements as perceived by the user community reorganized the priorities of the software capabilities along lines that differed from those contemplated by the analysts who had guided the system development (Evans, 1975, 1986, 1988a, 1988b). Typically in system design work, this pitfall arises when the end user is not part of the initial design consideration. In the development of PACE, however, nurses were involved at every stage.

The difference in perspective arose as a result of the functional role differences between the nurse designers and the end users in the ongoing, challenging clinical environment. Attempts were made to incorporate input from actual care providers, and indeed this was achieved. Care providers assessed and evaluated the system, and this strategy was continuously undertaken. In the face of all these efforts and the wide recognition of this common problem, nonetheless incongruities arose between the nurses "in the trenches," dealing with the intensity of care, and the individuals responsible for assisting with system designs for system development. Thus, inevitably, nursing committees were only partially correct in identifying what the bulk of the nursing practitioners felt was an appropriate usable tool. Similar lines of developments and applications would be expected in other areas related to health care and health care professionals.

System designers should ensure that the true end user has a voice in the ultimate design. It is not always easy to include these individuals in the software design phase. Certainly when the system is distributed, this is accomplished, and hopefully it is not too late to permit the kind of feedback and revamping often needed to obtain an effective and desirable system.

Coding Flexibility

The original use of the semantic network together with further additions and advancements of it proved to be extremely appropriate and wise, given the expectation that the organization, size, scope, and types of knowledge would change radically in the future. Fixed approaches would have constrained the system far too much, and the need to remain flexible and dynamically interactive, in the manner provided by a semantic net, served the design and the system well for most of the history of the original project and the subsequent implementation of the commercial system. Although very recent efforts have significantly diminished the need for responsiveness of the semantic net because of the enormous accuracy and specificity of the knowledge base implementation at this time, the semantic net may prove to still be valuable in the future (Tuttle et al., 1992; Rasmussen & Bassoe, 1993; Prokosch et al., 1995; McCray, 1989; Do Amaral Marcio & Satomura, 1995).

Organizational and informational structures will begin to change and evolve, and the system will need to be more responsive to a multiplicity of different constituents at the very same time (Butler, 1985; Laborde, 1984; Romano, 1990). The semantic net has proven valuable in this context. As it has helped evolve the knowledge base to a state in which the user community is now well served, far less variation is now needed and its use is less obvious. As health care delivery changes, greater flexibility in medical record interpretation may become necessary. Then the semantic net approach can again become appropriately responsive to such needs. The semantic net may well receive another revitalization and renovation so that it can serve future needs.

The PACE development tested the usefulness of the semantic knowledge descriptors used by this system. The approach taken (as elaborated in Chapter 6) appeared to represent the minimal organizational structure necessary to define and provide context for a concept or idea. We expect this minimum differentiation to be the heart of future uses of a thesaurus or metathesaurus, as semantic indexing is used to reconcile ambiguities and permit more significant searches.

Those who develop information pertinent to users' needs must remain alert to user community expectations (Probst & Rush, 1991). This correlation is extremely important if the system is to become an effective tool in the patient care arena. A tool that must be consistently tweaked by the users is a tool that becomes cumbersome as the demands for information grow and available time diminishes.

The continuing glut of information remains a challenge in health care. What is needed is judicious organization and selection, to provide optimal patient care. The utilization of a semantic network to interpret the knowledge base, to provide a minimum of understanding and use, and to guide proper organization and selection will continue to be one approach that can be quite effective in resolving crucial problems in the future. Strategies that combine semantic nets and embedded expert systems to direct the system's analysis will continue to make such relational databases and linked-list systems effective in addressing problems of the kinds system designers will need to solve in the future (Soda, 1995).

Knowledge Base Development Principles

Changing Knowledge

The experience of nursing has been very reflective of other knowledge base developments; hence it is an excellent case example that is applicable to a wide range of other specialized domains. Some of the most significant issues that arose occurred in terms of the radical shift in the organizational structure of information the knowledge base addressed at the onset (Abraham & Fitzpatrick, 1987). It is not unlikely that in many other similar domains, the structure of the knowledge and its organization and the taxonomies employed to organize the information will shift over time (Saba, 1992). Hence, it is imperative that the organizational schema that keeps track of the information remain flexible enough to handle easily and quickly a radical shift in the structure of the information itself.

Not only will the organization of the information change, but its uses will evolve over time, often to utterly different and unanticipated domains (Ford, 1990). To take these alternations into account, therefore, the presentation and organization of the information must also be flexible and varied.

Knowledge Base Growth

One must also expect an exponential increase in the size of the knowledge base, irrespective of the expectations brought to bear when the knowledge base was first defined. Such preparation is necessary partially because the very existence of a knowledge base changes expectations: as a result of its creation, far more extensive expectations are permitted to arise, and an exponential explosion in the size of the knowledge base should be anticipated.

Handing Off Project Development

A very significant management decision in the last few years has been to plan for the prospect that there would be essentially no ongoing continuity of project developers and/or knowledge base managers. Any viable commercial enterprise must be designed so that newly introduced professionals can easily pick up the baton as it is passed, without prior understanding of esoteric knowledge. This independence from specific project developers is imperative for the successful maintenance of a knowledge base. In addition, given the size and scope of the expected knowledge base, one should anticipate that management needs will far exceed the original efforts in the creation and development of such a knowledge base. The regular management of a vast amount of information with multiple participants and a changing environment involving feedback, extension, and updates is a complex task. Clearly an infrastructure is required to support the knowledge base growth, and typically, this support system will exceed the capabilities of the enterprise that created the original knowledge base. Without the resources, the commitment, and the desire to provide this component, one will produce only a pilot project, which must be passed on to other developers in that context.

Different Knowledge Base Perspectives

The knowledge base itself also involves a normative perspective on what constitutes important, prioritized, or useful information. As a result, decisions on what knowledge should be maintained and extended will be contingent on some group's perspective (Benner, 1983; Benner, 1984; Butler, 1985; Carper, 1978). If in fact the user community is to have a role in the definition, the organizational structure should reflect the capacity to respond to such user needs. If the resources and feedback necessary to sustain the knowledge base come from a user community, then that group must have a role in affecting the future of the knowledge base development; otherwise, the system will not be responsive to these users' needs. If the users and the supporters of the knowledge base are ultimately mismatched philosophically, this incongruity will likely result in the demise of the usefulness of the system over the long term.

Dissemination

Application Environments

Principles in system dissemination involve the recognition of the demands of the clinical environment in contrast to any hypothetical pilot project world that cannot incorporate this reality. Dissemination entails both simplicity of the system and an intuitiveness that often transcends the clumsy first effort, which may be appropriate for a pilot project but would be deadly for any effective widespread dissemination outside the limited environment in which the project was created. As the system is disseminated, viable and useful feedback germane to system redefinition is difficult to achieve and must be approached with care, to ensure the realization of useful extensions. As one attempts to expand such systems in the international environment, cultural differences become quite pronounced. If one does not take these into account, it is likely that the system will have little value outside the national setting in which it was created.

Adequate Infrastructure

Dissemination requires a vast effort in marketing, sales support, and product support resources, all of which enable a site to ascertain the usefulness of the tool and its appropriateness. As a consequence, an enormous amount of resources is needed, both to undertake such an effort and to work through the many accompanying steps until success is obtained. One should never underestimate the amount of tenacity and time that will be needed to go through the sales cycle until the tool is recognized and employed in clinical settings.

User Satisfaction

Support of the user community is more and more crucial in the software environments unfolding before all project developers. As a consequence, as the system is disseminated, there must be a concomitant increase in efforts at user support, user satisfaction, and responses to user needs, so that the word-of-mouth support, which is all-important for health care products, will be achieved in each individual setting (Kahl et al., 1991a; Cassassa, 1990; Kahl et al., 1991b; Staggers, 1988).

Performance

Finally, fidelity of system performance is imperative. The intense working environment of health care professionals has unforgiving requirements for high levels of performance and near perfection. The health care field brings extraordinary demands, rivaling virtually any other application because of the high stakes involved. As a result, dissemination mandates a level of performance that may strain the application of a system that would have been acceptable in virtually any other environment. Thus it is critical to recognize the intensity of the environment, to be able to plan an application commensurate with the constraints placed on it.

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Appendix A

Taxonomy for the Health Sciences

Purpose

The Taxonomy for the Health Sciences was developed to provide a structured model of all the essential aspects affecting the educational development of a health professional. This model encompassed three intersecting dimensions. The first dimension focused on health professionals themselves, identifying three fundamental characteristics: the use of a clinical problem-solving process, the focus on a variety of products the professionals managed, and their professional responsibilities (ethical, legal, management, etc.). The second dimension focused on the client or patient, emphasizing individuals' health needs, dysfunctions and related conditions that may be encountered, and public health. The third dimension addressed essentially the learning modalities, including cognitive, psycho-motor, and affective components. The intent was to be able to characterize or position all instruction for any health professional within this three-dimensional framework.

Use

The initial PACE educational development needed a common model because it was intended to define all instruction in all programs in a way that would enable an educator to compare one unit of instruction with another. The taxonomy would help classify things in a uniform way which facilitates comparisons. In addition, when indexing terms were assigned, these categories could help guide the classification schema, much as the employees of the U.S. National Library of Medicine use classification schema to guide the encoding (and thus, the search) of the world's medical literature. The taxonomy was employed by all the health sciences schools virtually without alteration and was found very useful to characterize each program. Thus, it is like the organization of a thesaurus, in this case giving a conceptual frame into which all health sciences concepts and terms (particularly our coding of indexing terms) could be placed.

Taxonomy Components

To understand the taxonomy fully, the categories are provided with their constituent components that define the concept. At the end of the taxonomy is a glossary of key terms. The original framework was devised by the author and circulated among key health professionals from all the health sciences programs to be sure any anticipated instructional component in their respective programs would find a home within the taxonomy. With a number of useful suggestions, the final version of the taxonomy was presented and approved for use by all programs in the project. The final version was revised in 1978 and issued thereafter.

Overview of the Taxonomy for the Health Sciences

A. Person Health Needs
   1. Preventive Care and Health Maintenance
   2. Psycho-behavioral
   3. Social–economic–cultural
   4. Environmental Support
   5. Spiritual Support

B. Products

C. Professional Responsibilities
   1. Historical Role of Health Professional
   2. Cultural Aspects of Health Professional
   3. Legal Issues
   4. Ethical Principles of Health Professional
   5. Research Principles
   6. Intrinsic Education
   7. Professional Interdependencies
   8. Health Care Systems
   9. Management
   10. General Skills and Attitudes

D. Dysfunctions and Conditions
   1. Infectious Diseases
   2. Neoplasms
   3. Musculoskeletal Diseases
   4. Digestive System Diseases
   5. Oral Diseases
   6. Respiratory Tract Diseases
   7. Otorhinolaryngologic Diseases
   8. Nervous System Diseases

9. Eye Diseases
10. Urologic Diseases
11. Gynecological and Obstetrical Diseases and Conditions
12. Cardiovascular Diseases
13. Hemic and Lymphatic Diseases
14. Neonatal Diseases and Abnormalities
15. Skin Diseases
16. Endocrine and Metabolic Diseases
17. Nutritional Diseases
18. Immunologic Diseases
19. Injury, Occupational Diseases, Poisoning
20. Animal Diseases
21. Signs, Symptoms, Syndromes, and Situations
22. Behavioral and Mental Disorders

E. Public Health
   1. Defined Responsibilities
   2. Social Responsibilities

F. Clinical Problem Solving
   1. Data Gathering
   2. Assessment
   3. Conclusion-Drawing (diagnosis)
   4. Selecting and Planning Treatment
   5. Implementing Treatment
   6. Evaluating Treatment

G. Learning Modalities
   1. Cognitive
   2. Psycho-motor
   3. Affective

Taxonomy for the Health Sciences
A. Person Health Needs

1. Preventive Care and Health Maintenance

I. Normal health standards
  A. Identification
  B. Principles of maintaining health
    1. Personal hygiene
    2. Exercise
    3. Nutrition
    4. Accident prevention
    5. Periodic evaluation
    6. Immunization
    7. Mental health
    8. Others
II. Perinatal concerns
  A. Genetic counseling
  B. Maternal health
  C. Others
III. Infancy and school age
  A. Child neglect and abuse
  B. Immunization
  C. Others
IV. Adolescence
  A. Behavior patterns and values
  B. Sex education
  C. Chemical abuse
  D. Others
V. Adulthood
  A. Work adjustment
  B. Marriage counseling
  C. Parenting
  D. Lifestyle
  E. Others
VI. Middle age/Older age
  A. Involutional change adjustments
  B. Senescence
  C. Others

2. Psycho-Behavioral

I. Emotional and intellectual
  A. Emotional
    1. Security
    2. Love and belonging
    3. Self-esteem

- B. Intellectual
  - 1. Communication
  - 2. Understanding
  - 3. Self-actualization
- II. Stages of emotional and development
  - A. Perinatal (prenatal–28 days)
  - B. Infancy (28 days–6 years)
  - C. School age (6 years to 12)
  - D. Adolescence (12 to 18 years)
  - E. Adulthood (18 to 35 years)
  - F. Middle-age (35 to 55 years)
  - G. Older-age (55+)
- III. Interpersonal emotional and intellectual needs
  - E. Community relationships
    - 1. Structure
    - 2. Function
    - 3. Development
  - F. Family structure
    - 1. Structure
    - 2. Function
    - 3. Development
    - 4. Maintenance

3. Social–Economic–Cultural

- I. Socioeconomic
  - A. Incidence of disease
  - B. Attitudes toward health care
  - C. Constraints in obtaining health care
- II. Cultural
  - A. Family
    - 1. Structure
      - (a) Matriarchal
      - (b) Patriarchal
      - (c) Nuclear
    - 2. Function
      - (a) Roles
      - (b) Communications
      - (c) Interactions
    - 3. Development
      - (a) Newly married
      - (b) First child
      - (c) Others
  - B. Reactions to illness
    - 1. Coping behaviors
    - 2. Reactions to distress
    - 3. Reactions to death and dying
    - 4. Others

- C. Health practices and behaviors
  - 1. Self-care practices
    - (a) Nutritional
    - (b) Folkways
    - (c) Others
  - 2. Self-referral practices
    - (a) Care seeking
    - (b) Compliance
    - (c) Others
- D. Racial differences
  - 1. Incidence of disease
  - 2. Physical differences
  - 3. Others

4. Environmental Support

- I. Safety needs
- II. Comfort needs
- III. Transportation needs
  - A. Rescue squads
  - B. Other emergency needs
- IV. Aesthetic needs
- V. Perceptual needs
  - A. Orienting needs
  - B. Stimulation needs
  - C. Needs for rest and quiet
- VI. Special needs due to disability

5. Spiritual Support

- I. Spiritual needs
  - A. General
  - B. Specific
    - 1. Dying
    - 2. Bereavement
- II. Religious concept
  - A. Rites/rituals
    - 1. Christian
    - 2. Jewish
    - 3. Other
  - B. History and philosophy
  - C. Paraspiritual
    - 1. Divine healing
    - 2. Meditation
    - 3. Other

B. Products

1. Foods
2. Drugs
3. Cosmetics
4. Devices

C. Professional Responsibilities

1. Historical Role of Health Professional

I. Current development
II. Future development

2. Cultural Aspects of Health Professional

I. Personal
II. Community
III. Society

3. Legal Issues

I. America's jurisprudence system
  A. Definitions
  B. Regulations vs. statutes
  C. Court system
    1. Legal
      (a) Civil
      (b) Criminal
    2. Equity
  D. Court awards
    1. Civil
    2. Criminal
II. Professional statutes and regulations
  A. Accreditation
  B. Certification
  C. Licensure
  D. Professional practice acts
III. Federal Statutes and Regulations
  A. OSHA
  B. Federal funding
  C. Alcohol laws
  D. Medicare/Medicaid
  E. Controlled Substances Act
  F. Food, Drug, Cosmetics, and Device, Act
  G. Others

- IV. Standards of care
  - A. Intentional injury
    1. Assault
    2. Battery
    3. Mental distress
    4. False imprisonment
    5. Trespass
    6. Wrongful death
    7. Others
  - B. Unintentional injury
    1. Negligence
       - (a) Elements of the tort
       - (b) Defenses to the tort
       - (c) Case interpretation
    2. Unavoidable accidents
    3. Statutory negligence
    4. Strict liability
- V. Commercial/contractual principles
  - A. Contract law
    1. Elements of a contract
    2. Forming a contract
    3. Discharge of a contract
  - B. Vicarious liability
  - C. Uniform commercial code
  - D. Warranties
- VI. Professional conduct
  - A. Patient's Bill of Rights
  - B. Helsinki agreement
  - C. Euthanasia
  - D. Patient records
  - E. Use of paraprofessionals
  - F. Others

4. Ethical Principles of Health Professional

- I. Values
  - A. Judeo/Christian
  - B. Other
- II. Standards

5. Research Principles

- I. Prospective study
- II. Analytical investigation
- III. Data critique

6. Intrinsic Education

7. Professional Interdependencies

I. Knowledge base
   A. Common
   B. Unique
II. Roles and functions
III. Health care team

8. Health Care Systems

I. Current status and problems
   A. Structure
   B. Access to care
      1. Special groups
         (a) Minority
         (b) Poverty
         (c) Aged
         (d) Disabled
         (e) Rural
      2. General population
   C. Costs of care
      1. Average costs
      2. Proposals to contain costs
   D. Determination of health levels
      1. Social optimums
      2. Distribution of illness
   E. Needs and demands
II. Health manpower
   A. Education (M.D., DDS, R.N., R.PH., others)
   B. Supply (M.D., DDS, R.N., R.PH., others)
   C. Patterns of practice (M.D., DDS, R.N., R.PH., other)
III. Health in the health care setting
   A. The hospital
   B. Nursing homes
   C. Office practice
   D. The community
   E. Comprehensive health centers
IV. Financing health care
   A. Private
      1. Types
      2. Issues and problems
   B. Public
      1. Types
      2. Issues and problems
      3. Indigent care
      4. Social care

V. Alternative to existing systems
   A. Issues and problems
   B. Health maintenance organizations (HMOs)
   C. Private
      1. Group
      2. Solo
   D. Public
      1. National health schemes
      2. Other
   E. International schemes
VI. Assessing adequacy
   A. Measuring quality
   B. Peer review
   C. Utilization
   D. Cost/benefit analysis

9. Management

I. Administrative science
   A. Objective setting
   B. Decision making
   C. Management process
      1. Planning
      2. Organizing
      3. Directing
      4. Controlling
   D. Leadership principles
   E. Communicating
   F. Risk in management
      1. Insurance principles
      2. Types
      3. Analysis and evaluation
II. Fiscal resources
   A. Financing a professional practice
      1. Capital requirements
      2. Analysis evaluation
   B. Financial statements
      1. Statement of financial position
      2. Income statements
      3. Accounting principles
      4. Financial analysis
         (a) Liquidity
         (b) Financial position
         (c) Profitability
         (d) Efficiency
      5. Business and taxes
   C. Electronic data processing

- D. Controls
  1. Budget
  2. Nonbudget
- III. Personnel resources
  - A. Human motivation
    1. Behavior models
    2. Applications
  - B. Individual behavior
    1. Perceptions
    2. Attitudes
    3. Defense mechanisms
  - C. Group behavior
    1. Managing groups
    2. Group decisions
  - D. Staffing
    1. Preselection techniques
    2. Recruitment and retention
    3. Orientation and training
    4. Supervision
    5. Compensation
    6. Evaluation
- IV. Physical resources
  - A. Location analysis
  - B. Organizational structure
    1. Business organization
       - (a) Entrepreneur
       - (b) Partnership
       - (c) Corporation
    2. Other organizational structures
  - C. Functional organization
    1. Line
    2. Staff
    3. Function
  - D. Layout and design
    1. Optimal characteristics
    2. Qualitative analysis
    3. Quantitative analysis
  - E. Purchasing
    1. Needs
    2. Sources of supply
    3. Terms of purchase
    4. Handling
    5. Evaluation
    6. Methods
  - F. Inventory control
  - G. Pricing and professional fees
  - H. Patronage and promotion techniques

10. General Skills and Attitudes

I. Professional attitudes or characteristics
  A. Dependability/trustworthiness
  B. Initiative
  C. Industry
  D. Maturity in judgment
  E. Consideration for patient
  F. Consideration for patient's family
  G. Rapport with staff
  H. Performance under pressure
  I. Utilization of full potential
  J. Appearance
  K. Poise
  L. Adaptability
  M. Motivation
  N. Reflects ethical standards
  O. Emotional stability
  P. Willingness to accept criticism
  Q. Self-confidence
  R. Self-assurance
  S. Cognizance of own limitation
  T. Cognizance of need for continuing education
  U. Appreciation of the dignity and worth of mankind
II. Professional technical skills
  A. Aseptic techniques
  B. Monitoring
  C. Manipulation
  D. CPR
  E. Other
III. Professional communication
  A. General communication
    1. Oral
    2. Written
    3. Nonverbal
    4. Large group/small group
  B. Patient/client teaching
    1. Assessment
    2. Learning goals
    3. Teaching methods
    4. Practice
    5. Evaluation
  C. Interprofessional communication

D. Dysfunctions and Conditions

1. Infectious Diseases
2. Neoplasms
3. Musculoskeletal Diseases
4. Digestive System Diseases
5. Oral Diseases
6. Respiratory Tract Diseases
7. Otorhinolaryngologic Diseases
8. Nervous System Diseases
9. Eye Diseases
10. Urologic Diseases
11. Gynecological and Obstetrical Diseases and Conditions
12. Cardiovascular Diseases
13. Hemic and Lymphatic Diseases
14. Neonatal Diseases and Abnormalities
15. Skin Diseases
16. Endocrine and Metabolic Diseases
17. Nutritional Diseases
18. Immunologic Diseases
19. Injury, Occupational Diseases, Poisoning
20. Animal Diseases
21. Signs, Symptoms, Syndromes, and Situations
22. Behavioral and Mental Disorders

E. Public Health

1. Defined Responsibilities

I. Vital statistics
  A. Morbidity/mortality rates
  B. Birth/death
  C. Census/geographic
  D. Licensure/records
II. Environmental survey
  A. Air standards
  B. Portable water service
  C. Dairy standards
  D. Food sanitation
III. Communicable disease control
  A. Epidemiology
    1. Respiratory diseases
      (a) Tuberculosis
      (b) Histoplasmosis
      (c) Diphtheria

- (d) Streptococcal
- (e) Others
2. Venereal disease
3. Enteric disease
   - (a) Biological
   - (b) Chemical
4. Epizootic diseases
   - (a) Reservoir Arbovirus
   - (b) Vector—rabies

B. Health education
1. Food handling
2. Venereal diseases
3. Vector control
4. Others

C. Immunization
1. Endemic oriented
2. Epidemic oriented

IV. Occupational survey

A. Acute situation (hazards)
1. Urban
2. Rural

B. Chronic situations
1. Urban
2. Rural

C. Regulatory development

V. Health maintenance

A. Physical/biological orientation
1. Clinics
2. Programs
3. Projects, research
4. Services

B. Mental orientation
1. Drug abuse
2. Alcoholism

C. Dental orientation
1. Surveys
2. Emergency

2. Social Responsibilities

I. Preventive care

A. Well-baby clinics

B. Maternal/child welfare

C. Dental
1. Oral hygiene
2. Education

3. Diagnosis
D. Screening services
II. Legal interpretations
A. Individuals, organizations
B. Community, state
III. Political process
A. Education
B. Research
C. Statistics
IV. Attitude development
A. Problems
B. Priorities
C. Solutions
D. Ramifications
V. Behavioral monitoring
A. Peer group
B. Geographic
C. Ethnic awareness
VI. Social–cultural–economic monitoring or determination
A. Recognition
B. Education
C. Applied research
VII. Planning, implementing, evaluating
VIII. Health maintenance

F. Clinical Problem Solving

1. Data Gathering
2. Assessment
3. Conclusion Drawing (Diagnosis)
4. Selecting and Planning Treatment
5. Implementing Treatment
   A. Technical procedures
   B. Medicinal therapy
   C. Health education and counseling
6. Evaluating Treatment

G. Learning Modalities

1. Cognitive
2. Psycho-motor
3. Affective

APPENDIX B

Glossary for the Taxonomy for the Health Sciences

A. Person Health Needs

1. Preventive care and health Maintenance — health care enabling a health professional to serve a person's need for continued or enhanced physical well-being.
2. Psycho-behavioral — health care serving individual needs for continued or enhanced psychological balance and behavioral development (e.g., dealing with situations of stress related to health problems, human developmental stages, etc.).
3. Socio-economic-culture — health care dealing with health needs related to a person's background and values that have their basis in a socioeconomic status or cultural heritage (e.g., cultural food patterns, male/female role perceptions, child-rearing practices, etc.).
4. Environmental support — health care fostering physical arrangements that contribute to the ease and comfort of those with special environmental health requirements (e.g., safety needs, perceptual needs, special needs due to disability, etc.).
5. Spiritual — health care supporting a person's health need for a sense of significance, worth, value, and purpose in life.

B. Products

1. Food — all forms of nourishment normally ingested for human growth and development.
2. Drugs — substances intended for use in the diagnosis, cure, alleviation, treatment, or prevention of disease.
3. Cosmetics — substances intended for improving or enhancing the appearance of the skin, hair, and nails.
4. Devices — equipment or mechanisms designed to maintain health or assist the handicapped;

fabricated items that substitute for or assist a part of the body.

C. Professional Issues

1. Historical issues	issues and perspectives involving the evolution of the role of health professionals over time.
2. Cultural issues	issues regarding broad human behavior patterns that impinge on the role of health professionals.
3. Legal issues	professional standards of conduct, legal rights and responsibilities, and related issues and perspectives.
4. Ethical issues	philosophical, bioethical concerns that could confront or confound the health professional.
5. Research principles	the basis, the methodology, and the practice of research as well as the evaluation of research results.
6. Intrinsic education	material learned simply for its own sake, such as aesthetic appreciation for the complexity of man.
7. Professional interdependencies	roles as an effective member of a health care team; knowledge about the roles and problems of various professionals, etc.
8. Health care systems	health care as a total social system (e.g., professional standards review organizations, HMOs, third-party payers, delivery systems, interest groups, practice options, etc.).
9. Management	managerial functions including planning, organizing, directing, controlling, and staffing of the professional's own health care environment or organization.
10. General attitudes/skills	broad general topics influencing professional behavior, such as stages of the grieving process, fear of death, the health professional's mien, coping with personal prejudices, and putting a patient at ease.

D. Dysfunctions and Conditions

1. Dysfunctions and Conditions	a set of health dysfunctions and conditions affecting man (based on a categori-

zation derived from the Index Medicus issued by the National Library of Medicine).

E. Public Health

1. Public Health	health care needs of the community at large, including responsibilities for disease control defined by public officials as well as responsibilities of the health professions to protect and enhance public well-being.

F. Clinical Problem Solving Process

1. Data gathering	the collection of needed information about any condition involving typically either verbal or physical data (e.g., history taking, lab test, screening procedures, etc.).
2. Assessment	the determination of a normal versus abnormal condition based on the data gathered (some determinations include polyphagia, polyuria, polydipsia, acidosis).
3. Conclusion drawing (diagnosis)	the determination of the nature and/or causes of an abnormality, condition, or potential dysfunction (e.g., drug overdose, diabetes mellitus, stress due to familial strain, impacted tooth, etc.).
4. Selecting and planning	the determination of a suitable strategy or regimen and elaboration of a plan to administer it.
5. Implementing treatment	the achievement of the treatment or prevention plan via:
a. Technical procedure	any act, method, or manner of proceeding with some medically oriented course of action.
b. Medicinal therapy	any topical, oral, parenteral, or other medicinal therapeutics.
c. Health education/ counseling	counseling activities to inform, motivate, demonstrate, or assist a person to enhance his or her personal, family, or community well-being.

6. Evaluating treatment	the appraisal of the consequences of treatment or management as a well as reconsideration of other earlier clinical problem-solving steps.

G. Learning Modalities

1. Cognitive	learning modalities involving the ability to recall information, to locate and use appropriate references, and to comprehend the full meaning of information obtained, requisite to the successful performance of health care tasks.
2. Psycho-motor	learning modalities involving the ability to carry out a variety of procedures and technical skills in support of health care tasks.
3. Affective	learning modalities involving the ability to reflect those emotions, attitudes, and states of mind necessary for effective health care.

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