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EXPERT SYSTEMS AND KNOWLEDGE-BASED ENGINEERING (1984-1991): IMPLICATIONS FOR INSTRUCTIONAL SYSTEMS RESEARCH

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Expert system technologies are varieties of artificial intelligence (AI) approaches in which decision-making knowledge is codified and modeled. This design case has the challenging task of characterizing this set of technologies during a particularly important period in its development (1984-1991), with an emphasis on a particular system that was used in food production environments by Campbell Soup. It analyzes the social and research impacts of early, pioneering information elicitation and processing strategies that focused on the distillation of the knowledge or know-how of individuals construed as experts in particular arenas, approaches broadly labeled as "knowledge-based engineering" (KBE). Widely-publicized notions of "thinking machines" and "canned experts" provided motivation for a good deal of early expert systems development (Feigenbaum & McCorduck, 1986), with accusations of "hype" often levied (Blair, 2002). This article historically situates these technological strategies in the period from 1984 though 1991, then links them with current instructional systems approaches that more fully involve collaborative elements as well as contextual perspectives. The motivation for this article is to explore how larger technological and social trends and assumptions can influence particular research efforts, especially in the richly interdisciplinary area of information systems. The article also explores the circumstances and consequences of "failures" of system development, with expert systems providing widely-discussed exemplars (Gill, 1995; Oravec & Plant, 1992). This article is rooted in the assumption that historically-informed perspectives can provide some underpinnings to the building of humane and sustainable research projects, particularly in areas that have human subjects and volatile contexts as essential elements. This article also addresses the continuing legacy of university curricula and business training initiatives that were shaped to accommodate expert system and KBE approaches in past decades. Discourse about human expertise generated by expert system efforts in 1984 through 1991 holds insights for current research and development, as well as signals potential sources of dysfunction of, and opposition to, future instructional system initiatives.

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INTRODUCTION

Consider the following statement from a noted expert systems pioneer:

> *To build expert systems is to attempt to capture rare or important expertise and embody it in computer programs… In one sense building expert systems is a form of intellectual cloning. Expert system builders, the knowledge engineers, find out from experts what they know and how they use their knowledge to solve problems. Once this debriefing is done, the expert system builders incorporate the knowledge and expertise in computer programs, making the knowledge and expertise easily replicated, readily distributed, and essentially immortal.* (Davis, 1984, p. 18)

Declarations such as the one above (with phrases akin to "intellectual cloning") were commonplace in research agendas and grant applications during the period of 1984-1991

(Oravec & Travis, 1992). Social and historical perspectives on expert systems and knowledge-based engineering (KBE) in this period can provide insights for current research and development directions in instructional systems, especially when placed in contrast with contemporary focuses that are collaborative and responsive to context (generally more in keeping with Internet-related affordances). As outlined in the sections to come, problematic perspectives reflected in such phrases as "essentially immortal" expertise (found in the above quotation) may indeed have skewed research directions and otherwise derailed system development projects, whatever technological considerations were involved.

As a part of artificial intelligence (AI), expert system and KBE strategies attracted considerable academic, corporate, and military attention in the 1980s and early 1990s (Oravec & Plant, 1992; Waterman, 1986; Winston & Prendergast, 1984). Some analysts describe the period as having a "bandwagon" or "bubble" quality (Leith, 2010). After analyzing an assortment of definitions, O'Leary construes "expert systems" as having the following characteristics:

- a rule-based approach is used to model decision making knowledge, and that those rules may include some kind of factor, to capture uncertainty
- interacts with a user from whom it gathers environmental assessments, through an interactive consultation (not always present)
- designed to help facilitate solution of a particular task, typically narrow in scope
- generally performs at the level of an informed analyst.
  (O'Leary, 2008, p. 9)

The term "expert system" was reportedly coined for some early system initiatives in 1968 by Edward Feigenbaum of Stanford University (Feigenbaum, 1992), and an assortment of systems were developed in the following decade (Duda & Shortliffe, 1983). Although expert systems and KBE research and development efforts have continued to this day, the 1980s through early 1990s were especially salient in terms of academic and commercial research agenda setting as well as the establishment of funding sources. I was involved with expert system research and artificial intelligence instruction at the University of Wisconsin during this period and was able to witness as well as participate in some of the KBE bandwagon-style phenomena, including international teleconferences and promotional videos (Oravec, 1988). Linkages of more recent knowledge management approaches with the pioneering expert systems and KBE initiatives described in this article are often problematic: some researchers have worked actively to distance themselves from the early "outrageous" claims for the future of expert systems and KBE research (Leith, 2010; Stafford, 2001; Vaux 2001). The assertions that expert systems would soon displace many human experts were certainly off-putting to many computer professionals who were seeking appropriate-technology applications for their systems rather than the production of "black boxes" in which something labeled as "knowledge" would be stored (Perrolle, 1991).

Many of the founding knowledge elicitation strategies focused on the capture of the expertise of individuals. Some of these initiatives were literally labeled "expert in a box" (as described in O'Leary, 2008). In contrast, many of today's knowledge-related and instructional efforts emphasize collaborative knowledge such as that obtained through various networking platforms and social media (including recommendation systems and wikis), made popular with the rise of the Internet. Emphasis on the context of knowledge production has increased in recent years as well (Anderson & Dron, 2010). The more recent focuses on collaboration and context have strong ties to the ubiquitous availability of the Internet as a platform, a presence that was just emerging as a widespread societal force in the 1980s. However, the emotionally-involving discourse in academic and popular culture arenas generated in this seminal era concerning whether expert systems could "think," as well as the prospect of replacing human experts with expert systems, still has implications for instructional system efforts, especially those supported by agencies and corporations with long legacies of expert system and KBE initiatives. For example, Stanford Research Institute (SRI) in Menlo Park, California is still often linked with its pioneering "Prospector" expert system that was designed to assist geologists in mineral exploration (Waterman, 1986).

VISIONS GUIDING EARLY EXPERT SYSTEM DEVELOPMENT

Dreams and visions related to particular technologies can indeed be emboldening; for example, dreams of manned space flight to Mars have stimulated efforts to build rockets and proceed with space-related initiatives (Lambright, 2014). A good amount of early research and development in expert systems technology was explicitly framed with the guiding notion of replacing human experts after their knowledge had been "mined." Consider this ambitious research projection for expert systems research efforts in the 1970s:

> *For an expert system to be truly useful, it should be able to learn what human experts know, so that it can perform as well as they do, understand the points of departure among the views of human experts who disagree, keep its knowledge up to date as human experts do (by reading, asking questions, and learning from experience), and present its reasoning to its human users in much the way that human experts would (justifying, clarifying, explaining and even tutoring).* (Barr and Feigenbaum, 1982, p. 80)

A 1986 cartoon from *Popular Science* provided a sense of how easily and unproblematically human expertise was to be transferred to expert system format via floppy disk (Hawkins, 1986, p. 83)

Early expert systems and KBE efforts had strong parallels with Tayloristic perspectives and the routinization of human expertise (Perrolle, 1991; Stafford, 2001), decreasing reliance on particular humans rather than enhancing individuals' abilities using instructional systems and other intellectual support technologies. Frederick Taylor, a pioneer in industrial engineering and scientific management in the early part of the twentieth century, worked to streamline and commodify human labor in an assortment of workplace settings, especially industrial ones. Leith (2010) describes the linkages of Taylorism to expert systems in economic terms: "The promise being made in the 1980s was that cheap, good quality advice would allow us to discard the need for expensive experts." The contrast with perspectives in later decades on knowledge is dramatic, as evidenced by the definition below in a prominent knowledge-themed text of the late 1990s:

> *Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices, and norms.* (Davenport and Prusak, 1998)

A number of computing efforts in the early 1980s involved the beginning stages of popularly-accessible networking capabilities (Hall, 2009). Many industrialized nations were on the verge of the widespread Internet dissemination of the 1990s, but computer networking was still a factor largely in business and research contexts and not in everyday household and community applications. The considerable influx of expertise and attention provided when Internet capabilities were disseminated across wide spectrums of society served to alter many computing strategies (including knowledge-based ones), supporting the notion of collaborative knowledge generation rather than the mining of specific individuals' expertise.

Expert systems and KBE approaches are strongly linked to artificial intelligence (AI), although they expanded beyond AI to cognitive science, knowledge management, and various other information technology emphases (McCarthy, 2007). International perspectives provide some insight as to why the US and Japan initiated so much expert systems research. Artificial intelligence had a number of research successes from the 1970s and 1980s, but early support came largely in the US and Japan rather than the United Kingdom. The UK's Lighthill Report of 1974 was a devastating attack on artificial intelligence research that directly resulted in the nearly "complete dismantling" of AI research in England (Crevier, 1993). The exaggerated claims made for AI were a part of this backlash in the UK, as well as the competing demands of other areas of computer research. In the early 1980s in the US, AI as a research and development area was just emerging from a period of relative neglect, with fields such as computer networking and database design attracting attention and funding. In efforts to move beyond this stage, commercialization of expert systems and KBE became more of an imperative in order to attract new research talent and funding: "With the expert system boom in full swing, epistemology was brought into public view and was shown to have commercial value" (Stafford, 2001). Hellström and Raman (2001) write in comparable terms of the "commodification" of epistemology through these technologies. Artificial intelligence researchers and professors were searching for ways to make their research more useful in a practical sense, thus attracting industrial and governmental dollars. After the early successes of expert systems, textbooks such as those written by Hayes-Roth, Waterman, and Lenat (1984) and Waterman (1986) made expert system and knowledge-based engineering strategies more accessible to students as well as industry practitioners.

The book *The Fifth Generation: Artificial Intelligence and Japan's Computer Challenge to the World* disseminated KBE approaches and drew in strong corporate support (Feigenbaum & McCorduck, 1984), in part because it asserted that Japan was seeking to be first to explore and exploit expert system technologies for commercial gain. The popularly-distributed paperback *The First Artificial Intelligence Coloring Book* was intended to demonstrate the simplicity of notions behind expert systems (Cohen, Cohen, & Nii, 1983); supposedly, even children could understand basic ideas behind computer-supported knowledge distillation and packaging. As a faculty member in computing and artificial intelligence during this period, I can attest to the intense interest students had in these books and related materials. Students along with many faculty and staff were motivated by discourse that linked philosophical ideas about computers and the human mind with practical applications, with bold rhetoric about the future of artificial intelligence often appreciated as much as subtle nuances. The late ethnographer and computer scientist Diana Forsythe documented some of the animated discourse that emerged in Stanford University and the University of Pittsburgh during this period, particularly concerning the interactions between culture (including user experience) and knowledge (Forsythe, 2001; Oravec, 2004).

Following on the notion of humans being displaced by computers, the label of "engineer" (rather than that of "interviewer" or another soft term) became associated with many expert systems practitioners:

A "knowledge engineer" interviews experts in a certain domain and tries to embody their knowledge in a computer program for carrying out some task. How well this works depends on whether the intellectual mechanisms required for the task are within the present state of AI. When this turned out not to be so, there were many disappointing results. One of the first expert systems was MYCIN in 1974, which diagnosed bacterial infections of the blood and suggested treatments. It did better than medical students or practicing doctors, provided its limitations were observed… Its interactions depended on a single patient being considered. Since the experts consulted by the knowledge engineers knew about patients, doctors, death, recovery, etc., it is clear that the knowledge engineers forced what the experts told them into a predetermined framework… the usefulness of current expert systems depends on their users having common sense. (McCarthy, 2007, para. #5)

In the above selection, McCarthy describes an engineering mindset that potentially excludes some relevant human factors, although many of today's engineers are apparently far more sensitive and responsive to context and user concerns. An assortment of academic programs and courses explicitly labeled as "knowledge engineering" arose in higher education institutions in several Western nations in the 1980s and early 90s (Liebowitz, 1993), such as in the University of Maryland at College Park. A number of the individuals selected by universities and corporations for training in knowledge engineering had backgrounds in the humanities and social sciences, at least temporarily infusing needed ethnographic talent and insight into knowledge-related pursuits (Mykytyn, Mykytyn, & Raja, 1994).

A number of influential books that were highly critical of artificial intelligence levied specific attacks on the claims and projections delivered by many expert systems researchers. Works by these authors "occupied the center stage of a heated debate" among many computer scientists about the nature and limits of AI (Brey, 2001, p. 38). Titles of some of these books reveal their approaches*: Man over Machine: The Power of Human Intuition and Expertise in the Era of the Computer* (Dreyfus & Dreyfus, 1985) and *Computer Power and Human Reason: From Judgment To Calculation* (Weizenbaum, 1976). Winograd and Flores sought to steer artificial intelligence research away from an expert systems and KBE emphasis and toward a more biologically-inspired basis in *Understanding Computers and Cognition: A New Foundation for Design* (1987). The authors of these books all had considerable background in cognitive science and AI, with Joseph Weizenbaum a noted professor of AI at the Massachusetts Institute of Technology (MIT) and Terry Winograd at Stanford; however, they were all inspired to protest what they considered the more outlandish claims of AI and expert systems proponents.

DEVELOPMENT INFRASTRUCTURE OF EXPERT SYSTEMS

The era in which expert systems blossomed was one of great growth for knowledge-related considerations as a whole. Marc Porat's (1976) identification and cataloguing of various knowledge professions (following the work of economist Fritz Machlup) stimulated interest in the "knowledge economy" and awareness of its economic dimensions. Some philosophers added their input as well as economists. Artificial intelligence pioneer John McCarthy's overview of AI research included an adaptation of T. H. Huxley's quotation about the couplings of philosophy and science: "Extinguished philosophies lie about the cradle of every science as the strangled snakes beside that of Hercules" (McCarthy, 2007). Identifying "knowledge" as consisting of sets of rules (however sophisticated the knowledge "engine" that served as a shell) does not in itself constitute a philosophy, although it was apparently significant in energizing a number of artificial intelligence developers.

The programs Dendral and Mycin are generally considered as the first expert systems (Waterman, 1986), although there is some controversy here. Dendral served to automate the decision making procedures of experts in organic chemistry. Its name reportedly stems from the phrase "Dendritic Algorithm." Stanford University provided the environment and support for computer scientists Ed Feigenbaum and Bruce Buchanan, along with subject matter experts Joshua Lederberg and Carl Djerassi, to develop Dendral in the mid-1960s. In the early 1970s, Mycin (another early system) was developed at Stanford as part of the doctoral dissertation of Edward Shortliffe. Expert system projects have indeed retained some popularity as dissertation initiatives in a number of fields, providing a way for dissertators to demonstrate their tenacity and inventiveness within a structured technological framework. Mycin identified bacteria related to severe infections and often recommend specific antibiotics. Many antibiotics have the suffix "mycin" (so the name "Mycin" was deemed appropriate). Stanford was also the scene of a great deal of research on AI, so synergies between and among researchers developed.

The notion of the "knowledge engineer" emerged in the late 1970s, with Stanford University the site of much of this effort. Edward Feigenbaum's Heuristic Programming Project Memo 77-25, entitled "The Art of Artificial Intelligence," states that "the knowledge engineer practices the art of bringing the principles and tools of AI research to bear on difficult applications problems requiring experts" (1977, p. 1). By the mid-1980s, knowledge engineering evolved into a larger initiative, sometimes even given the status of a "profession." Clancey (1987) asserted that "people who are naturally quick learners are attracted to this profession (and there are some dilettantes), the knowledge engineering process is a skill that can be taught." However, librarians provided some early resistance to the notion that knowledge engineers somehow "invented" the basic notions behind knowledge elicitation, arguing that they had been doing the kinds of knowledge elicitation that knowledge engineers were doing for decades if not centuries (Molholt, 1986). With the increasing availability of expert system "shells," knowledge acquisition and processing was declared to be liberated from the domain of professionals and placed in the hands of the people (Feigenbaum & McCorduck, 1984). The shell structure, with its separation of the knowledge base from the inference engine or other processing unit, was a salient aspect of many early expert systems approaches (in contrast to those structures in which knowledge and inference elements would be intertwined). Some of these shells were made available commercially for personal computers (PCs), spurring the development of a number of AI and PC-themed magazines, journals, and related conferences. The "AI Business" began to be lucrative (Winston & Prendergast, 1984), drawing many AI professionals away from academic life and into startup organizations or larger industry settings. In 1985, Allen Newell, a noted AI theorist, labeled expert systems as the "major advance" in artificial intelligence for the past decade:

> *The emergence of expert systems has transformed the enterprise of AI, not only because it has been the main driver of the current wave of commercialization of AI, but because it has set the major scientific problems for AI for the next few years.* (quoted in Bobrow & Hayes, 1985, p. 385)

Examples of discourse on the "hype" and "hubris" associated with expert systems efforts abound. Blair (1985, 2002) discusses the "gold rush" in which expert system developers were engaged. Davenport and Prusak (1998) declare that "The field of knowledge technology has suffered from overly high expectations and excessive levels of hype, particularly with regard to expert systems" (p. 126) and note the "limited success" of these early efforts. The "knowledge engineering bottleneck," the difficulty of codifying knowledge from real-world situations, became a critical factor that derailed a number of real-world expert systems projects. Knowledge acquisition has remained a labor-intensive aspect of expert system development, with some researchers developing specialized systems just for this purpose (Rafea, Hassen, & Hazman, 2003). Demonstration projects and academic theses in which individuals could work non-stop on creating and refining rule bases for their projects may have been temporarily successful in showcasing some of the positive aspects of expert systems (such as the dissertation work of Edward Shortliffe), but projects in which volatile contexts and reluctant experts were involved were far less successful. This unfortunate situation was documented in cases provided in the special issue of the *Journal of Systems and Software* on expert system failures that I co-edited with Robert Plant of the University of Miami (Oravec & Plant, 1992).

REAL WORLD APPLICATIONS OF EXPERT SYSTEMS: CAMPBELL SOUP

In the advent of expert systems and KBE, artificial intelligence research was moved from the laboratory and framed as ready for practical application, such as in the Campbell Soup example described in this section. Duda and Shortliffe declared in *Science* (1983) that "some consultation programs, although limited in versatility, have achieved levels of performance rivaling those of human experts" (p. 261). Duda and Shortliffe followed with the notion that a "collateral benefit of this work is the systematization of previously unformalized knowledge in areas such as medical diagnosis and geology" (p. 261), thus linking expert system initiatives with larger efforts in information organization and retrieval. Buchanan (1986) listed sixty expert system ventures that were currently in service or able to be placed in practical contexts, and declared "the quantity of AI research may decline as a result unless the applied systems are experimented with and analyzed" (p. 32).

One of the early exemplars of a "successful" expert system in practical industry application was developed for the US Campbell Soup Company in 1985 by Dr. Richard Herrod of Texas Instruments (Herrod & Smith, 1986). The Campbell expert system was widely promoted in expert systems books and lectures as a triumph, however limited its application and untimely its retirement. The system was designed to gauge how long to cook its products (Mans, 1995). One of the experts assigned to this effort (Aldo Cimino) was retiring after forty-four years of service, and the system was reportedly designed to replace him rather than make efforts to train skilled human apprentices. Below is a description of this initiative:

> *Campbell's maintenance person, Aldo Cimino, had 44 years of experience on the giant hydrostatic cookers that sterilize soup and other canned products. He knew more than anyone in the company about these complex pieces of equipment and was called in to consult at plants around the world.* (Mans, 1995, p. 16)

Herrod of Texas Instruments (TI) endeavored for more than a year to locate the kind of application that would make a suitable showcase for the TI "Personal Consultant" expert system shell (Herrod & Smith, 1986). As outlined in Bobrow, Mittal, & Stefik (1986),

Choice of problem for expert system treatment was perceived as critical: if the problem relied on too much contextual information, the system would have needed to have so many rules that updating and fine-tuning the system would have been prohibitive. Herod is quoted as stating that "You build an expert system when you have a significant specialized knowledge that exists only in a few people's heads and is acquired through years of experience" (UPI, 1989). The specific rationale for eliciting Aldo Cimino's knowledge through expert system applications rather than training an intern or apprentice is not entirely clear, but reportedly was in keeping with Campbell Soup's overall corporate perspective during this period (Sidorick, 2009). The following account provides a narrative of what transpired in early interactions concerning the system:

> *One day his boss woke up and realized that Aldo was going to retire soon, and then who would answer the tough questions? He called in Dr. Herrod and his group to capture Aldo's expertise. The project took six months and endless man-hours, but resulted in an expert system capable of answering most of the problems as well as Aldo could.* (Mans, 1995, p. 16)

The Campbell Soup design experience underscored some of the affective aspects of expert system development and installation. Aldo Cimino is quoted as stating "At first I thought, 'Oh my God, they're going to get rid of me… But then I realized that I was 64 years old and getting ready to go anyway. They just wanted to save some of what I knew. It felt weird at first, but I got used to it. It's like I left a piece of myself at that plant" (UPI, 1989). Experts who are associated with these systems have reported a sense of personal connection with them, making issues involving their use and ultimate termination more problematic (Feigenbaum & McCorduck, 1986). The Campbell Soup system was originally named "Cooker Advisor," and later "Aldo on a Disk," the word "disk" relating to the large floppy disk upon which the system was stored and with which the system was often portrayed in rhetorical terms. The system eventually was renamed "Simon," in honor of Herbert Simon, 1986 National Medal of Science recipient and also a Nobel Laureate, one of the early pioneers of artificial intelligence (Ambrosio, 1990).

The notion that expert systems provide a kind of "canned knowledge" was in some ways literally true in capturing information about how to cook soup at Campbell Soup Company. Mistakes in the large-scale food preparation arena are costly, wasteful, and potentially dangerous to human health: the Campbell Soup sterilizers involved were seventy-two feet high and heated 68,000 cans of soup to 250 degrees. The system that resulted from the efforts of Herrod and Cimino (along with Texas Instruments' knowledge engineer Michael Smith) took over a year to develop and had approximately 150 rules (Graubard, 1988), many of which had to be rewritten during the productive life of the system. Through using the system, Campbell Soup reportedly saved up to two million dollars a year (Day & Rostosky, 1994). The system was retired in the mid-1990s, in part because experts were still required for difficult cases. As related in an interview with computer scientist Dorothy Leonard, the Campbell Soup system "was very helpful to people, no question; but did it capture all of the expert's knowledge? No way! The deep smarts we're talking about, and the pattern recognition, will not be captured through rule and rule-based logic" (Ubiquity Staff, 2005, para. 51). Subsequent expert system efforts at Campbell Soup were initiated in different areas of food production, but none were put into extensive service, making expert system ventures successful in this organizational context at a demonstration level but not in terms of technological concept proliferation.

Brittleness (inability of the system to adapt to changing conditions and input, thus producing nonsensical results) and "knowledge engineering bottlenecks" (previously discussed) were two of the more popular explanations why early expert system strategies have failed in application (Guerlain *et al*., 1995; O'Leary, 2008). Reluctance of users to invest time and effort to work to overcome these and related technological problems (in part perhaps because of the expert system rhetoric discussed in this article) is also a critical factor (Gill, 1995; Oravec & Plant, 1992). In 1988, I presented and published a paper on how "dependence" on these emerging expert system applications could inhibit the intellectual growth of potential new expertise. The dependence theme was indeed relevant to many kinds of computer technologies, but was not as salient as I projected in regard to expert systems that had barely left the lab (Oravec, 1988). However, attributing the specific reasons for failures or success of any particular system is a complex process requiring detailed analysis, so only the broadest of generalizations can be made along these lines.

As intriguing narratives about expert systems such as Campbell Soup's emerged from the 1980s, Gary Hochron, Director of the Knowledge Engineering Group at AGS Information Services, advised US businesses to "Capture That Information on an Expert System" (1990, p. 11) in the *Journal of Business Strategy*. However, initiatives to use expert systems in everyday business efforts often failed, extending only into the 1990s at Famous Footwear ("Hype is gone," 1995); few other major businesses publicized related projects with substantial lifespans in that period.

EXPERT SYSTEM LINKAGES WITH INSTRUCTIONAL DESIGN

In the 1984-1991 time frame, expert system development in instructional design was not as active as in financial, commercial, and manufacturing arenas. Although Feigenbaum and McCorduck (1984) and other expert system promoters projected that the systems would revolutionize education, there were relatively few tested and implemented projects other than master's degree initiatives and doctoral dissertations. According to Pollock and Grabinger (1991), expert system development was difficult because of the lack of skilled technical talent available to educational institutions at the time. Many talented individuals migrated to business and

Figure 1

Knowledge Base Example

Facts

A book is a medium.
A slide/tape is a medium.
Computer-assisted instruction is a medium.
Video tape is a medium.

Low is a level of learner control.
Moderate is a level of learner control.
High is a level of learner control.

Verbal abstraction is a type of instructional message.
Simulation is a type of instructional message.

Individual is a group size.
Small group is a group size.
Large group is a group size.

Rules

1. If content is primarily verbal abstractions
and high level of learner control is necessary
and group size is small
Then appropriate medium is a book.

2. If a moderate level of learner control is desired
and group size is large
or group size is small
or group size is individual
Then appropriate medium is slide/tape.

3. If a high level of learner control is desired
or a moderate level of user control is desired
and instructional method is simulation
and group size is individual
Then appropriate medium is CAI.

4. If a high degree of learner control is desired
and group size is individual
Then the appropriate medium is CAI.

FIGURE 1. Knowledge base example from Pollack and Grabinger (1991, p. 100). Used with approval from Lawrence Lipsitz.

governmental arenas in which they could achieve higher salaries. Some prototype systems were construed as useful exercises for outlining and clarifying expert knowledge within a certain context, but few fully tested and implemented system efforts materialized. Romiszowski (1991) projected that teacher anxieties about the implementations of expert systems in the classroom, and their possible "role-threatening" positions, could affect their eventual use in educational contexts. However, he countered that "maybe they [teachers] will perceive the potential educational benefits and see themselves in full control as managers of the resources at their disposal" (p. 24).

Another of the problems noted by Pollock and Grabinger was that many of the existing expert system development approaches were rooted in the mining of expertise of a single expert. Expertise from multiple sources is often needed, especially in instructional design arenas and curricular development initiatives: "ideally, the reasoning of several experts should be encoded to give consensus solutions" (Pollock & Grabinger, 1991, p. 104). An assortment of expert system initiatives have intentionally endeavored to integrate the expertise of multiple experts (Abdullah, Kimble, Benest, & Paige, 2006), which provides considerable strategic and technical difficulties for developers. In 1991, Pollack and Grabinger provided the following "knowledge base example" as an exemplar of the kind of activity needed for expert system development, efforts that generally involve some differences in opinion and perspective (Figure 1).

It may be difficult for today's instructional system designers to understand the appeal of the early expert system research agendas, such as those encapsulated in the following statement: "The goal of expert systems is to solve specific problems and present and 'explain' the solution in terms comprehensible to humans" (Madni, 1988, p. 395). Some expert systems developers worked to moderate this overall goal so as to make expert systems approaches more in keeping with larger information systems trends toward context sensitivity and user personalization (Leith, 2010). However, the notion that the energies behind these research undertakings were solely fueled by unappealing motives may miss some of the more altruistic efforts associated with expert systems research. For example, two decades ago, a research report from India described potential uses of expert systems for developing regions of the world in the following terms:

> *To make use of the knowledge and skill of specialists and experts in various fields gained over a long period of time, to have "canned knowledge" or "canned expertise," computer programs called "Expert Systems" have been developed in many fields, particularly for medical diagnosis. These enable persons with much less knowledge and experience than the specialist in a field to operate at a much greater level of efficiency and knowledge as if they are experts.* (Pandalai, 1994, p. 28)

In regions where expertise was not as commonly available, the promise of expert systems to convey needed expertise in a portable form indeed may have provided hope for many in dire circumstances.

Expert system and KBE research agendas have indeed continued to this day (Suhasini, Palanivel & Ramalingam, 2011). These research efforts generated considerable discourse on the nature of expertise as well as on cognitive science itself, which in the 1980s was emerging as a force in computer science (Gardner, 1985). However, in the 1990s research and development emphases shifted away from the expert contexts and toward instructional designs that are more supportive of exploration and problem "finding" as well as the solving of specific, delimited problems. Expert systems are still being developed for specialized purposes in a number of instructional arenas. An example here is Engin *et al.*'s (2014) rule-based expert system designed to support students in making some decisions concerning university course selection. However, most of these recent systems are designed to work along with professionals (such as academic advisors) and not directly and entirely replace human expertise.

CONCLUSIONS AND REFLECTIONS

The period in which expert systems and KBE approaches emerged as a considerable influence in information technology (from the 1980s to the early 1990s) provides insight as to the power of assumptions and perspectives to shape how research is conducted. This era was followed by an assortment of efforts to moderate and fine-tune the initial goals of KBE as to make it more suitable for instructional technology systems and other application areas. Economic and social aspects of knowledge technologies are critical to consider along with philosophical perspectives (Bolisani, 2008; Kling, 1991; Oravec, 1996). Through the many failures of expert systems and KBE research to fulfill practical application objectives, knowledge management proponents acquired more adequate (and possibly less arrogant) ways of framing their activities (Oravec & Travis, 1992). Early strategies were often linked to the basic model of the "mining" of the know-how of experts and the creation of rule bases for subsequent processing in expert system shells. The notion of the refinement of knowledge "nuggets" has been a legacy of some early expert system and KBE efforts (Geisler, 2006). Expert systems and KBE also inspired a great deal of investigation into the question of what constitutes human expertise (Perrolle, 1991), although some of this early research aimed to simplify and distill know-how rather than understand the nature of expertise. Many of the early initiatives were ultimately deemed as failures and no longer utilized. However, as outlined by Howard (2011), the analyses of such failures may serve important roles for individuals "who share common dilemmas, constraints, goals or contexts" (p. 50).

The "thinking machine" notion served to energize a good deal of early expert systems and KBE research (O'Leary, 2008). However, the fear that automated systems would soon displace or undervalue computer programmers (Kraft, 1977), librarians (Molholt, 1986), lawyers (Leith, 2010), and other knowledge professionals was indeed a force in constraining and delimiting the applications of expert systems rather than expanding their domains. Reluctance to work with knowledge engineers or otherwise contribute to expert system projects may have halted some otherwise interesting efforts, giving KBE technologies less potential than anticipated (as described in Subramanian, Yaverbaum, & Brandt, 1997). Today's learner-centered approaches and social media advances have injected more collaborative dimensions to knowledge elicitation efforts as well as expanded the role of context, although the idea of mining individual expertise has still persisted in a number of formulations to this day (as in the logistics and supply chain management expert system efforts of Gunasekaran and Ngai, 2014).

Donald Norman's notion of "disruptive technologies" in *The Invisible Computer* (1999) has some applicability to expert systems and KBE efforts. Norman construes disruptive technologies as those that have the ability to change everyday life as well as the course of their respective industries; he also describes the initial, strong resistance to many of these technologies. In effect, expert systems and KBE efforts have often extended beyond Norman's disruptive levels to be "disconcerting" technologies. They were often directly linked in theme and approach to the displacement of human professionals and potentially even the undermining of the value of human intelligence, both salient topics that involve economic concerns about the unemployment (or underemployment) of a number of highly skilled and well-educated individuals. Expert system failures sent a powerful message to knowledge and information researchers about the importance of intense and continuing human involvement in system design and implementation (Oravec & Travis, 1992).

Artificial intelligence research has indeed had some remarkable successes: for example, chess-playing computers can defeat grand masters, as predicted by a number of AI pioneers. The success of computers in chess has apparently not stopped chess players from enjoying their activities and benefiting from them (Miller, 1992). Many individuals also enjoy acquiring and using information even though computer systems can also do so (albeit in distinctly different modes). Today, collaborative initiatives are often given more emphasis in knowledge-related research; however, in future decades, more individual-centered approaches (such as those found in early expert system development) may well emerge in some "retro" form in an assortment of applications. Analysis of the historical and technological trends that made expert systems research less of a success than predicted (such as the outlandish claims of many of its researchers, the systems' tendencies towards brittleness, as well as the knowledge engineering bottleneck) can be of help in assisting today's instructional designers in sidestepping comparable obstacles.

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