Mastering Engineering Concepts by Building an Expert System

A. M. Starfield, K. L. Butala, M. M. England *and* K. A. Smith,
Department of Civil and Mineral Engineering, University of Minnesota

Knowledge-based consultant systems, or expert systems, are structured representations of data, experience, inferences and rules that are implicit in the human expert. Expert systems draw conclusions from a store of task-specific knowledge principally through logical or plausible inference, not by calculation. (A good overview[1] and more detail about expert systems[2] can be found elsewhere.) Expert systems are finding applications in many areas, from medical diagnosis to mineral prospecting. Most of these systems are large, involving many man-years of effort in their construction.

A new approach arose from the senior author's conviction that very small expert systems have an important role to play in engineering: small systems on microcomputers should be capable of providing a more intelligent alternative to much of the qualitative information ("how to do it," "what technique to choose," design heuristics and procedures) currently to be found, often with difficulty, in engineering handbooks. It was with this in mind that he introduced a few lectures on expert systems into a senior mining engineering course. To illustrate how an expert system can be constructed, he gave the students an assignment in which they had to choose a suitable topic and then develop a small expert system related to that topic. The assignment had an unexpected side-effect: the students found it a novel and effective way of acquiring a thorough understanding of the topic they selected.

The process of constructing the data base for a small expert system seems a particularly effective technique for gaining expertise, and we can recommend its deliberate use as a tool for teaching certain classes of engineering concepts.

After introducing expert systems as they might conveniently be introduced into an undergraduate engineering class, we offer an example of a small student-constructed system to illustrate what students can achieve in this kind of assignment, as well as the sort of engineering concepts that lend themselves to this pedagogical approach. The article ends with comments from both faculty and students.

Expert Systems

The objective of an expert system is to help the user choose among a limited set of options, actions, conclusions or decisions, within a specific context, on the basis of information that is likely to be qualitative rather than quantitative. A system to guide an inexperienced student on how to plan his evening could serve as an illustration. We begin by specifying his options. These might be:

1) Review lecture notes
2) Work on assignments
3) Prepare for a test
4) Relax.

The complete list of options or decisions defines the scope of the expert system. Once these have been chosen, the next step is to compile a list of questions to elicit information needed to choose the appropriate action or decision. Associated with each question is a list of possible answers. For example:

Question 1. *Are you very tired?*
Answers: (a) *yes* (b) *no.*
Question 2: *When is your next test?*
Answers: (a) *tomorrow* (b) *this week* (c) *next week* (d) *in the indefinite future.*

The final step is to build a set of rules linking the questions and their answers to the list of options or decisions. Additional examples and other ways of building expert systems have been described.[3] These rules are constructed in what is called an *if-then* format. For example:

Rule 1.

If you are very tired
and you do not have a test tomorrow
and no assignment is due tomorrow
Then relax.

More formally, Rule 1 can be written:

If Question 1 answer (a)
and not Question 2 answer (a)
and not Question. . . .
Then Decision 4.

> "The assignment was perceived as being work-related, as providing a form of ersatz hands-on experience and as a way of putting textbook knowledge into practice."

Each rule will end on either a decision from the original list of options or on an intermediate conclusion which, in turn, will appear in the "if" section of another rule. A complete example is given on page 106.

The set of decisions, questions and answers and rules constitutes the expert system. A general computer routine can be written that will accept the decisions, questions, answers and rules of a specific expert system as a form of data and then operate. First, the routine will ask the user to select a likely decision. Next, the routine will search for a rule that ends on that particular decision, i.e., one containing that decision in the "then" portion of the rule. Next, the routine will ask the user the questions (one at a time) in the "if" portion of that rule. If the user's answers all satisfy the rule, the routine will end by confirming the decision. If an answer does not satisfy the rule, the routine will drop that rule but remember the answers to the questions already asked. It will then search for another rule that ends on the decision selected by the user. If all such rules are exhausted, the routine will conclude that the decision is invalid.

This process is known as a backward procedure. More sophisticated programs will persevere until they validate one of the decisions, irrespective of the decision actually selected by the user. They will also respond to the question "Why?" in a way that explains to the user the logic behind their choice of a particular question or decision.

Programs that will handle small expert systems can easily be implemented on microcomputers. While it would be advantageous for students to have access to such a program, it is not absolutely necessary for them to automate the expert systems they have built. The essential tasks they must perform are those of listing the decisions, collecting a suitable set of questions and answers, and constructing a set of rules. The subject and scope of the system must be defined by the instructor in such a way that by collecting the relevant data and constructing the rules, the students will become familiar with and understand the chosen subject. We have found that a system of not more than 15 rules forces students to concentrate on an assignment's essential features. An example of an expert system on rock-blasting produced by students is given on page 106.

Comments and Conclusions

Students were unusually enthusiastic about building their own expert systems, perhaps largely because they felt they were doing something worthwhile. The assignment was variously perceived as being work-related, as providing a form of ersatz hands-on experience and as a bridging exercise which took textbook knowledge and put it into practice. They enjoyed the synthesis—the process of tying it all together—and were strongly motivated to read, search, argue and consult faculty. (The students who constructed the example on blasting estimated that they gleaned about 60 percent of their material from textbooks, 15 percent from company literature, and 25 percent from questioning faculty experts.) Students felt they were coping with a task that was neither easy nor straightforward but was "real" engineering; they felt productive. One student put it this way:

An Expert System Built by Students

Smooth blasting and presplitting are alternative rock blasting techniques for producing a fairly smooth and controlled rock surface at the boundary of an excavation. Depending on the size and location of the excavation and on rock properties, either smooth blasting or presplitting will be the preferable technique, while in some cases neither will be applicable. It requires experience and a thorough grasp of blasting practice to choose the appropriate technique. The following expert system was designed by two seniors to help mining engineers make this choice.

Choosing a Rock-Blasting Technique for Mining Engineers

In addressing the alternative rock blasting techniques, **these are the possible decisions:**

1. Presplitting is feasible and recommended.
2. Presplitting is feasible but not recommended.
3. Smooth blasting is recommended.
4. Conventional blasting is recommended.
5. Presplitting is feasible but some experimentation is necessary to obtain appropriate design parameters.

The following is the list of questions:

Q1. *Is it critical to have a smooth rock surface and/or maintain the integrity of the boundary rock?*
1) Yes 2) No

Q2. *Where is the blast?*
1) On the surface 2) Underground

Q3. *Is the rock:*
1) Hard (compressive strength > 100,000 MPa)?
2) Soft (compressive strength < 100,000 MPa)?

Q4. *Is the bench height (or blasthole length) less than or equal to 50 feet?*
1) Yes 2) No

Q5. *Is the borehole drill capable of drilling a 2″ to 4″ blasthole?*
1) Yes 2) No

Q6. *Is the charge density of the explosive in the blasthole:*
1) High (> 1.1 g/cc)? 2) Low (< 1.1 g/cc)?

Q7. *Is the rock mass:*
1) Stratified with the proposed face parallel to the plane of the dominant fabric elements, or not stratified but heavily jointed?
2) Stratified and/or heavily jointed with the proposed face not parallel to the plane of the dominant fabric element?
3) Jointed or fractured such that the blasting will create loose, blocky conditions on the face?

Q8. *Are the static field stresses:*
1) Low (<10 MPa) with the principal stresses parallel to the proposed face?
2) Low (<10MPa) with the principal stresses not parallel to the proposed face?
3) High (>10 MPa)?

The list of rules follows:

Rule 1.

If Q1 answer 2
Then Decision 4 is valid.

Rule 2.

If Q1 answer 1
and Q2 answer 2
Then Decision 3 is valid.

Rule 3.

If Q1 answer 1
and Q2 answer 1
and Q3 answer 2
Then Decision 5 is valid.

Rule 4.

If Q1 answer 1
and Q2 answer 1
and Q3 answer 1
and Q4 answer 2
Then Decision 4 is valid.

Rule 5.

If Q1 answer 1
and Q2 answer 1
and Q3 answer 1
and Q4 answer 1
and Q5 answer 2
Then Decision 5 is valid.

Rule 6.

If Q1 answer 1
and Q2 answer 1
and Q3 answer 1
and Q4 answer 1
and Q5 answer 1
Then Intermediate conclusion A is valid.

Rule 7.

If Intermediate conclusion A is valid
and Q6 answer 1
Then Decision 5 is valid.

Rule 8.

If Intermediate conclusion A is valid
and Q6 answer 2
and Q7 answer 1
and Q8 answer 1
Then Decision 1 is valid.

Rule 9.

If Intermediate conclusion A is valid
and Q6 answer 2
and Q7 answer 1
and Q8 answer 2
Then Decision 2 is valid.

Rule 10.

If Intermediate condition A is valid
and Q6 answer 2
and Q7 answer 1
and Q8 answer 3
Then Decision 3 is valid.

Rule 11.

If Intermediate condition A is valid
and Q6 answer 2
and Q7 answer 2
Then Decision 4 is valid.

Rule 12.

If Intermediate decision A is valid
and Q6 answer 2
and Q7 answer 3
Then Decision 3 is valid.

"The results of developing an expert system are similar to obtaining practical experience of the subject matter while still in a classroom setting." Another said, "The student is essentially gaining work-related experience while integrating coursework and correct problem-solving procedures."

Students were especially positive about expert system-building as an alternative to essays or term papers on similar subjects. The formal structure of the expert system imposes a discipline that:

1) Clearly defines what is expected of students;

2) Forces them to identify and concentrate on the essential features of the subject;

3) Requires them to search for, evaluate and synthesize specific information, i.e., they are forced to read the literature purposefully;

4) Encourages them to interact with faculty and ask carefully prepared questions;

5) Encourages them to interact productively with each other in a group effort (students were required to work in groups of two or three);

6) Eliminates much of the busywork involved in writing a paper.

The instructors noticed that student enthusiasm depended on the topics the students chose to pursue. The most effective were complex but clearly defined topics in which expertise was within their reach. Faculty members noted several other points:

1) Student assignments are easier to grade and evaluate than, for example, term papers.

2) Students learn to approach heuristic information with care and become acutely aware of exceptions to and limitations on empirical rules.

3) If computer programs are indeed available for implementing the student exercises, a further important and qualitatively different learning process can take place as students in one group attempt to use an expert system built by students in another group.

In conclusion, as one student wrote, "This analysis involved a thoroughness not often experienced in my engineering education and required clarity of purpose, complete understanding and a logical, ordered examination of all conceivable solutions to the problem studied." Few would disagree that these are important components of engineering education; expert system-building appears to be an effective way of introducing such elements into the curriculum.

References

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