Int. J. Engng Ed. Vol. 8, No. 6, pp. 446–450, 1992
Printed in Great Britain.

0742–0269/91 $3.00+0.00

A Graduate Course on Intelligence Engineering*

M. RAO
Department of Chemical Engineering, University of Alberta, Edmonton, Alberta, Canada, T6G 2G6

A new engineering graduate course on intelligence engineering has been developed, which includes technical survey, fundamental instruction, seminar presentation, and a course project. It provides basic concepts of intelligence engineering and technology, introduces students to the newest developments, and trains them with practical hands-on experience of developing intelligence systems. This course is intensive and effective, and helps students gain a deeper insight into intelligence engineering. It serves as an advanced technology transfer vehicle to train our next generation into highly qualified engineers for the upcoming knowledge-intensive industry.

INTRODUCTION

TO FACE the challenge of the upcoming knowledge-intensive industry, the current state of the art of engineering education contents cannot fully satisfy the requirements of training our next generation to be highly qualified technical personnel for industry. The development of industry may be divided into four stages in terms of automation [1]. The first stage, the labor-intensive stage, mainly relies on the skills of human operators using simple non-automatic machines. At the second stage, the equipment-intensive stage, automatic instrumentation plays a dominant role in the competitive productivity, and processes data that is individual sensor measurements. As a result of more powerful and affordable computing facilities on factory floors, and the increasing use of sensors due to decreased cost and higher reliability, our industry is now moving into the third stage, the information-intensive stage.

Information describes the relationship among the correlated data. Similarly, knowledge represents the relationship of the correlated information. The next final stage is the knowledge-intensive industry which relies on artificial intelligence (AI) technology. With the advance of AI technology and its application to engineering, it has become more and more apparent that in the future, industry will require process engineers to have considerable information-processing knowledge, especially, using AI techniques.

As a new, advanced technology frontier, AI has been widely applied to various disciplines, including the chemical industry [2]. This study examines the processing of non-numerical information, using heuristics and simulating an engineer's capability in problem-solving. In fact, a much better terminology for this field is 'Complex Information Processing Systems', rather than 'Artificial Intelligence'. Today, instead of arguing which terminology is better, we concentrate on investigating the use of powerful computation technology in AI research. Traditionally, expert system development relied mainly on the knowledge engineer who, by definition, was a computer scientist and had knowledge of artificial intelligence and computer programming [3]. Knowledge engineers interview domain experts to acquire basic information, then build expert systems. With the much cheaper, but more powerful hardware platforms, and a more user-friendly programming environment, as well as the increased computation capability of our engineering students, a new era of AI applications is coming, which will enable engineers to program expert systems to handle any problems they encounter. During the development of expert systems, knowledge acquisition is the most important, but most difficult task. Even with the help of knowledge engineers, some private knowledge (such as heuristics and personal experience) may still be difficult to transfer. A new generation of engineers, namely intelligence engineers, are to be trained to meet the needs of this area. The title of intelligence engineer was devised to distinguish from knowledge engineer, but other suggested terminologies exist [3]. Intelligence engineering is a new engineering and technology field [1]. Interdisciplinary in nature, it allows the learning from artificial intelligence and computer science, to be extensively applied to engineering disciplines. Intelligence engineering involves applying AI techniques to engineering problem-solving, and investigating AI theoretical

* Paper accepted 12 December 1992.

fundamentals and techniques, based on engineering methodologies. Distinguished from knowledge engineering, intelligence engineering emphasizes integrating knowledge from different application domains to solve problems of the real world. An intelligence engineer is a domain engineer (for instance, a chemical engineer) who has a certain domain knowledge in a related application area. After a comparatively short period of training, she/he can learn basic AI techniques, get some hands-on experience on programming expert systems. Then, the intelligence engineer can build much better expert systems for solving his/her domain problem, and so extend AI applications successfully. This raises a key issue: what kind of AI techniques should be provided to intelligence engineers?

Historically, AI courses were taught in Computer Science Departments to their own students. Usually, engineering students find this area very difficult. For example, when I was a graduate student, I spent two terms studying 'Programming Languages'. In this time, I learned how to design languages and compilers. However, engineering students only need about two hours to review the features of these languages. They need to know how to select and use these languages, rather than design compilers. In the past years, several chemical engineering departments have reported teaching AI courses to chemical engineering graduate students [3, 4], or combining AI content in chemical engineering courses [5]. CACHE organized a special task force to address AI education in chemical engineering curricula [6]. This paper reports on the development and construction of a new graduate course on intelligence engineering, at the Department of Chemical Engineering, the University of Alberta, in the spring semester of 1991.

COURSE CONTENT AND ORGANIZATION

'Intelligence Engineering' is different from AI courses offered by the Computing Science Departments. This course emphasizes engineering application aspects of AI techniques, and provides necessary AI theoretical fundamentals to engineering students. The course was organized as three hours instruction, plus an hour seminar per week. The instruction content of this course is listed below.

Part One: Introduction

What is Artificial Intelligence (AI) and its History?, Knowledge Engineering, Intelligence Engineering.

Part Two: Fundamental Knowledge Processing Techniques

Basic Problem-Solving Methods, Resolution Techniques, Refutation, Knowledge Representation (production systems, first-order logic, predicate calculus, frame, semantic network, object-oriented programming, imprecise knowledge representation), Knowledge Acquisition, Sampling Expertise, Search and Inference Control Methods.

Part Three: Expert Systems

What is an Expert System?, Expert System Components (database, knowledge base and inference engine).

How to Develop Expert Systems (how to identify project, how to acquire knowledge, how to organize knowledge base, how to implement expert system, how to evaluate expert system), Overview of Programming Languages, How to Select AI Languages and Expert System Development Tools, Human Factor Issue.

Part Four: Integrated Distributed Artificial Intelligence

Coupling Reasoning System, Qualitative Reasoning and Quantitative Computing, Multi-objective Environment, Blackboard Architecture, Integrated Distributed Intelligent System, Meta-system Functions and Its Implementations Multi-media Interface.

Part Five: Application of Case Studies

From the contents above, we know that this is an intensive instruction course. It attempts to provide basic AI techniques with an emphasis on expert system technology and practical development experience, as well as new research frontiers in this field, to graduate students. It was also recognized by Professor Sorenson, the Department Chairman of Computing Science at Alberta, that the materials of this new graduate course could be significantly covered by four courses in his department [4]. However, teaching philosophy and emphasis are quite different.

The first part of the course was a survey-type instruction which instilled basic concepts about AI and intelligence engineering. The second part was based on selective theoretical materials that were, I believed, the most important to our students who needed a sound understanding of knowledge processing techniques. The third and fourth part were the key contents of the course, in which expert system technology was introduced. Included were problem definition, knowledge acquisition, technical interview skills, sampling expertise, knowledge representation, control methods for inference engine, knowledge-base organization, system development, programming languages and AI tools survey, implementation environment selection, integrated distributed artificial intelligence, meta-system, and multimediam interface. Several application cases were also studied. For example, in the expert system development section, I presented five stages that constituted the development process of an expert system. I first analyzed the function of each of these five stages, the identification stage, the conceptualization stage, the formalization stage, the implementation stage, and the evaluation stage. Then, I examined their relationship between different stages. Finally, I used an example to illustrate how this five-stage method worked in a real engineering problem-solving process. Besides AI and software engineering contents, I extensively addressed human factor issues in my instruction which is very critical in constructing an expert system, but rarely taught by computer science departments. At the time of offering the course, no single text was found which could meet the demands of this new graduate course. Two books were recommended as references, one was *Artificial Intelligence and the Design of Expert Systems* by Luger and Stubblefield [8] and *Artificial Intelligence in Process Systems Engineering* developed by CACHE [9]. *Engineering Application of Artificial Intelligencee*, a Pergamon journal was recommended to students as another reference [10].

Along with the progress of the course instruction, an AI seminar series was organized which included eleven presentation topics. The speakers at the seminars were from different disciplines. Among them, two were my graduate students, two were from industrial companies, two were from professional research institutes, and four were academic professors. Their talks covered a variety of different AI applications, gave our students a deep insight into AI as well as a wide overview of AI applications in the real world. These topics are listed as follows:

1. 'An Expert Advisory System for Safe Refinery Plant Start-up' Randy Dong (Chemical Engineering Department, graduate student), 17 January 1991.
2. 'Neural Network and its Application to Chemical Engineering' Professor Peter Crickmore (Chemical Engineering Department), 29 January.
3. 'Considerations for the Successful Implementation of an Expert System' Jim Zurcher (Process Information Department Manager, Proctor and Gamble Cellulose), 13 February.
4. 'Intelligent Operation Support System for a Batch Chemical Pulping Process' Jean Corbin (Chemical Engineering Department, graduate student), 14 February.
5. 'What Engineers Should Know to Use Artificial Intelligence' Professor Randy Goebel (Computing Science Department), 12 March.
6. 'The Use of Expert Systems in Iron and Steel Industry' Professor Hani Henein (Mining, Metallurgical and Petroleum Engineering Department), 20 March.
7. 'Research and Development of an Expert System at Syncrude' Eb Mueller (Senior Research Scientist, Syncrude Research Center), 27 March.
8. 'Genetic Algorithms-Based Machine Learning' Dr Lingyan Shu (Bell Northern Research Company), 3 April.
9. 'Logic Programming: A Wrong Road for AI' (video presentation), Professor Herbert Simon (Computer Science Department, Carnegie-Mellon University), 9 April.
10. 'Scientific Discovery as Computation' (video presentation), Professor Herbert Simon (Computer Science Department, Carnegie-Mellon University), 9 April.
11. 'AI Application Development at Alberta Research Council' Breen Liblong (Manager, Advanced Computing Department, Alberta Research Council), 24 April.

GRADING SYSTEM AND COURSE PROJECT

The course grading system was based on the following scheme: 20% on homework assignments, 30% on a middle term examination and 50% on a course project. Homework assignments help students review the technical contents of course instruction, while the middle term exam was a closed book test to examine students' understanding of the important concepts and techniques, such as what are the objectives of AI, what are the main components in problem-solving, and theory and calculation on first-order logic, predicate calculus, heuristic search, and unit refutation resolution. The project was an important component in this course. My objective was to direct our engineering students towards the frontier of advanced information processing technology through teaching such a research-oriented graduate course. This one-semester course should provide students with basic concepts about fundamental AI techniques, as well as help them to be familiar with programming expert systems. To achieve such a challenging objective, I took a different course organization schedule, and let students learn by doing.

At the beginning of the course, all attendants (twelve students and four auditors) filled in a questionnaire to describe their knowledge on both AI and computer programming techniques. From the survey, I found most of the attendants had only very limited knowledge of computer programming techniques, nothing about AI. For example, over two-thirds of the students only knew how to program in BASIC or FORTRAN on IBM PC or compatible computers. They did not even know what the relationship was between AI and an expert system! With an understanding of students' background, I began talking individually with every student to help her/him define project. Meanwhile, the course instruction was so well organized that students could immediately apply their learning into the course projects. For example, when the instruction of frame knowledge presentation technique was finished, the students were required to submit an assignment in which they showed how to select their own course projects, how to define problems, where to acquire knowledge, how to organize knowledge by using a frame-rule representation technique

Twelve different prototype expert systems were developed in this course by using seven different languages and AI tools that were available. In order for students to understand more about implementation tools through instruction, projects and evaluation, I did not select a unique AI tool or language for the course project. Students selected programming tools, and learnt to use the tools during their projects. To help students better understand software tools, an overview and summary about both computer programming languages and AI-developing tools was given. Also, I believe, the best way to learn software tools is 'learning by doing'. Two expert systems were implemented for characterizing bitumen/heavy oils; two systems were built for selecting chemical process equipment in design; three were generated to diagnose process operation faults, two for operation support in metallurgical processes; one for HVAC (Heating, Ventilation and Air Conditioning) process control; and one for multivariable control system design. An expert system was developed for diagnosing heart disease in the field of medical consultation. The following lines briefly describe these projects:

1. 'An Expert System for Selecting Viscosity Correlation and Predicting Viscosity' Murray Stevenson (PC Plus on a personal computer).
2. 'Design of an Expert System for Mixing Model Selection for V–L–E Property Prediction' Ravindra Gudi (PC Plus on a personal computer).
3. 'An Expert System for Selecting Solid–Liquid Separation Equipment' Albert Wong (PC Plus on a personal computer).
4. 'A Heat-Exchanger Selection Expert System' Harry Frangogiannopoulos (Modula-2 on a personal computer).
5. 'A Blackboard-Based Integrated System Structure for Building Fault Diagnosis Knowledge Bases' Zhihua Qi (G2 on a HP 9000 workstation).
6. 'Process Supervisory Expert System' S. Dhaliwal (G2 on HP 9000 workstation).
7. 'An Expert System for Distillation Column Problem Diagnosis' Richard Broenink (PASCAL on a personal computer).
8. 'A diagnostic Expert System for Continuous Caster Breakout Analysis' Norman Hanson (VP-Expert on a personal computer).
9. 'Determination of Cooling Parameter During Solidification by Microstructure for Al–Cu Alloys' Ding Yuan (VP-Expert on a personal computer).
10. 'An Expert System for Energy Saving Operation Planning in HVAC Process' Hong Zhou (PC Plus on a personal computer).
11. 'An Expert System for Linear Multivariable Control System Design' Heon Chang Kim (SFPACK on SUN SPARCstation).
12. 'A Computer-Assisted Medical Consultation System' Pradeep Modur (Turbo Prolog on a personal computer).

The evaluation of course projects consisted of four parts. The students were organized into two groups. Each had six members plus two auditors. The first evaluation was assigned as homework in which students were required to present the knowledge-base organization for their expert systems, and each student evaluated the assignments of the other five members. The second evaluation occurred in the latter part of the course when the projects were finished. Then students presented their projects in their groups with a time duration of thirty minutes for each member (20 minutes for presentation, and 10 minutes for questions). Students evaluated each other, based on technical criteria such as project objectives, problem definition, knowledge acquisition, function classification, knowledge-base organization, implementation skills, technology merits and application illustration. The professional technical presentation was also an evaluation factor. Then, a public demonstration of expert systems was held by each group. During a demonstration, each student had to run her/his expert system for an examination period of 30 minutes. The main evaluation criteria here was to examine the implementation techniques and operation effectiveness of expert systems, such as system implementation, user interface, human factor considerations, field testing, and the advanced features (such as calling numerical computing routines into an expert system environment, using meta-system architecture [11, 12] to implement intelligent systems, and so on). Every student evaluated their colleagues' projects, from which they also gained a further study into AI and its applications. Finally, they submitted a project report to present their work. The organization of the course was significantly more beneficial to students who learned, from the instruction process, how to do independent research through literature search and review, research topic selection, learning to use AI tools, project implementation, oral presentation, technical writing and project evaluation [13]. A course evaluation was conducted at the end of the instruction. Students expressed their satisfaction of this new engineering graduate course, appreciated the knowledge they learned and the new teaching methodology I used. This course has been finally approved by the university as a regular course offered to engineering graduate students.

Although there still remains an argument on whether engineering departments should offer such an AI course, it is similar to the situation more than 20 years ago when people questioned whether a numerical computation course should be offered in engineering departments or not. As an educational institute, our mission is to produce well-trained personnel for tomorrow's society, not for yesterday's. Current students will be the important driving force for our future economic development. To meet the need of this important task, we should provide the newest technological developments to our next generation through education. Dr Hani Henein, who is a metallurgical engineering professor at the University of Alberta and works on expert system applications to the iron and steel industrial processes, pointed out that in order to be ready for this challenge, all of his graduate students have to take 'Intelligence Engineering' as one of the requirements for graduation.

CONCLUSIONS

A new graduate course on intelligence engineering has been successfully developed at the University of Alberta. It is composed of technical survey, fundamental instruction, seminar presentation, and a course project. It provides engineering students with basic AI concepts and fundamentals, introduces the most recent developments in intelligent systems, and trains them with practical hands-on experience of developing expert systems. Such an instruction methodology is intensive and effective, helping students gain a deep insight into AI fundamentals, as well as a broad overview of AI applications. It serves as an advanced technology transfer vehicle to train our next generation into highly qualified engineers for the up-coming knowledge-intensive industry.

REFERENCES

1. M. Rao, J. Cha and J. Zhou, PHIIS: parallel hierarchical integrated intelligent system for engineering design automation, *Eng. Applic. AI*, **4**, 145 (1991).
2. G. Stephanopoulos, The future of expert systems in chemical engineering, *Chem. Eng. Prog.*, **83**, 44 (1987).
3. V. Venkatasubramanian, A course in artificial intelligence in processing engineering, *Chem. Eng. Ed.*, **23**, 120 (1986).
4. P. R. Roberge, Transferring knowledge: a parallel between teaching chemical engineering and developing expert systems, *Chem. Eng. Ed.*, **24**, 228 (1990).
5. J. M. Douglas and R. L. Kirkwood, Design education in chemical engineeering, *Chem. Eng. Ed.*, **23**, 120 (1989).
6. J. F. Davies and G. Stephanopoulos, CACHE artificial intelligence in processing engineering task force, *CACHE News*, **29**, 4 (1989).
7. P. Sorenson, Supporting letter for Dr M. Rao's new graduate course on artificial intelligence, March (1991).
8. G. Luger and W. Stubblefield, *Artificial Intelligence and Design of Expert Systems*, Benjamin/Cummings, New York (1989).
9. G. Stephanopoulos and J. Davis (eds) *Artificial Intelligence in Process Systems Engineering*, CACHE Corporation (1990).
10. M. G. Rodd (Editor-in-Chief), *Engineering Applications of Artificial Intelligence*, a Pergamon journal.
11. M. Rao, *Integrated System for Intelligent Control*, Springer-Verlag, Berlin (1991).
12. M. Rao, Q. Wang and J. Cha, *Integrated Distributed Intelligent Systems in Manufacturing*, Chapman & Hall, London (1992).
13. M. Rao, Secrets of my success in graduate study, *Chem. Eng. Ed.*, **23**, 256 (1989).

Dr Rao is an Associate Professor of Chemical Engineering/Computing Science, and the Director of Intelligence Engineering Laboratory at the University of Alberta. He received his BS in Chemical Engineering from Kunming Institute of Technology, MS in Computer Science from the University of Illinois, and Ph.D. in Interdisciplinary Engineering from Rutgers University. He had five years' experience at industry, and is a consultant for several industrial companies. In 1989 he worked in FAA (Federal Aviation Administration, U.S.A.) Technical Center on intelligent control. So far, Dr Rao has published two books and over 100 technical papers in international journals and conference proceedings. Dr Rao is the guest editor of 'Intelligent Process Control' published in *Engineering Applications of Artificial Intelligence*, a Pergamon journal. He is also an associate editor of this journal. He was the program committee member and the session chairman in several international conferences, and was invited to give seminars at many universities and research institutes. He is a member of AAAI, AIChE, CPPA, CSChE, IEEE, Sigma Xi and Tau Beta Pi.