

Developing a Design System into an Intelligent Tutoring System*

B. T. CHEOK

CAE/CAD/CAM Centre, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260

A. Y. C. NEE

Department of Mechanical and Manufacturing Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260

As the techniques of artificial intelligence become more widely used, an increasing number of knowledge-based design systems has been developed to handle problems that cannot be solved by traditional computational-based systems. Knowledge-based design systems are embedded with a wealth of design rules and heuristics. In addition, the architecture of knowledge-based system has features such as symbolic and structured programming, objects, rules manipulation, and rule-tracing and explanation. Therefore, they are ideal candidates for development into intelligent tutoring systems (ITS). This paper explains how a knowledge-based design prototype system for progressive die design is developed into an ITS that can be used to teach authentic design activities both in the classroom and on-the-job. It illustrates how the flexibility offered in the trainee-system interaction facilitates the exploration of design alternatives and case studies to tackle open-ended design problems. The ITS uses a computer-aided design and drafting (CADD) system as the front-end and automates many of the tedious drafting, measurement, shape recognition and manipulation tasks associated with progressive die planning and design. Therefore, it promises to be a more effective training aid which can help shorten the traditionally long period of apprenticeship training program which a trainee has to follow.

INTRODUCTION

THE SKILL involved in die design is traditionally acquired through a long period of apprenticeship which includes classroom and on-the-job training. The trainee usually starts by understanding the fundamental mathematics and engineering knowledge used to support design decisions. The subject of design is usually taught using good case studies where the various engineering concepts and principles are applied to achieve the design are explained to the trainee. The trainee would then reinforce his design knowledge by designing products which are similar to the case studies taught to him. This form of learning continues until the trainee graduates from the training institution and joins a company as an apprentice. He will be involved in authentic projects under supervision. Over the years, the apprentice will continue to acquire design knowledge and skills in this manner until he is competent enough to apply the knowledge confidently to design new products within his trade.

The use of CAD/CAM equipment helps to automate the tedious tasks such as modelling, drafting and annotation. However, the cognitive tasks (or the decision-making and problem-solving process) which are skill, experience and knowledge dependent are still performed by the designer. Knowledge-based design systems are now increasingly being introduced to assist designers to make decisions

and solve problems in their work. It is obvious that there is similarity between knowledge-based systems and intelligent tutoring systems (ITS) where expertise developed in the expert systems can be used to improve teaching of design knowledge.

USE OF KNOWLEDGE-BASED SYSTEMS AS INTELLIGENT TUTORING AIDS

Knowledge-based systems have many characteristics that make them suitable for development into ITS. For example, GUIDON [1], an intelligent computer-assisted instruction program that teaches medical diagnosis was developed from MYCIN [2], a diagnostic expert system. Some of the characteristics:

- a knowledge base about a specific domain;
- an inference engine which in some way mimics the way humans makes decisions;
- a facility to trace the rules and explain how they arrived at a conclusion;
- provide structured symbolic programming facilities that make it easier for further development into ITS.

Vivet [3] explained that expert system techniques offer three interesting characteristics when it comes to writing tutoring systems:

- an expert system can be used simply as a problem solver in the particular domain in which we want to train a learner;

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- an expert system can 'explain' the solution it has obtained for a given problem;
- an expert system can conduct a session following a plan which forms a scenario reflecting a pedagogical strategy.

The Department of Mechanical and Production Engineering and the CAE/CAD/CAM Centre of the National University of Singapore has researched and developed IAPDie, a knowledge-based prototype program for the design of progressive dies [4, 5]. It was observed that the design system exhibits many of the characteristics explained earlier. This paper explains how the design program was further developed into an ITS using a cognitive apprenticeship approach explained by Brown and Collins [6].

LEARNING DIE DESIGN THROUGH THE COGNITIVE APPRENTICESHIP APPROACH

Brown and Collins have argued that authentic activities are important for learners, because they

are activities that shape or hone their skills. Activity also provides experience. Authentic activities cannot be easily (or perhaps not at all) represented by description. However, traditionally, die design subjects are mostly taught using a descriptive approach both in the classroom and in most die design textbooks [7, 8]. This is inadequate. This explains why there is a need for a reasonably long period of apprenticeship during which a trainee learns by participating in authentic die design activities. Brown and Collins defined the development of concepts out of and through continuing authentic activities as the cognitive apprenticeship approach. This approach supports learning in a domain by enabling trainees to acquire, develop, and use cognitive tools in authentic domain activities.

There are several characteristics of IAPDie which make it suitable for development into an ITS for teaching progressive die design through the cognitive apprenticeship approach:

- IAPDie is a practical system that can be used to design progressive dies, it is most suitable for use

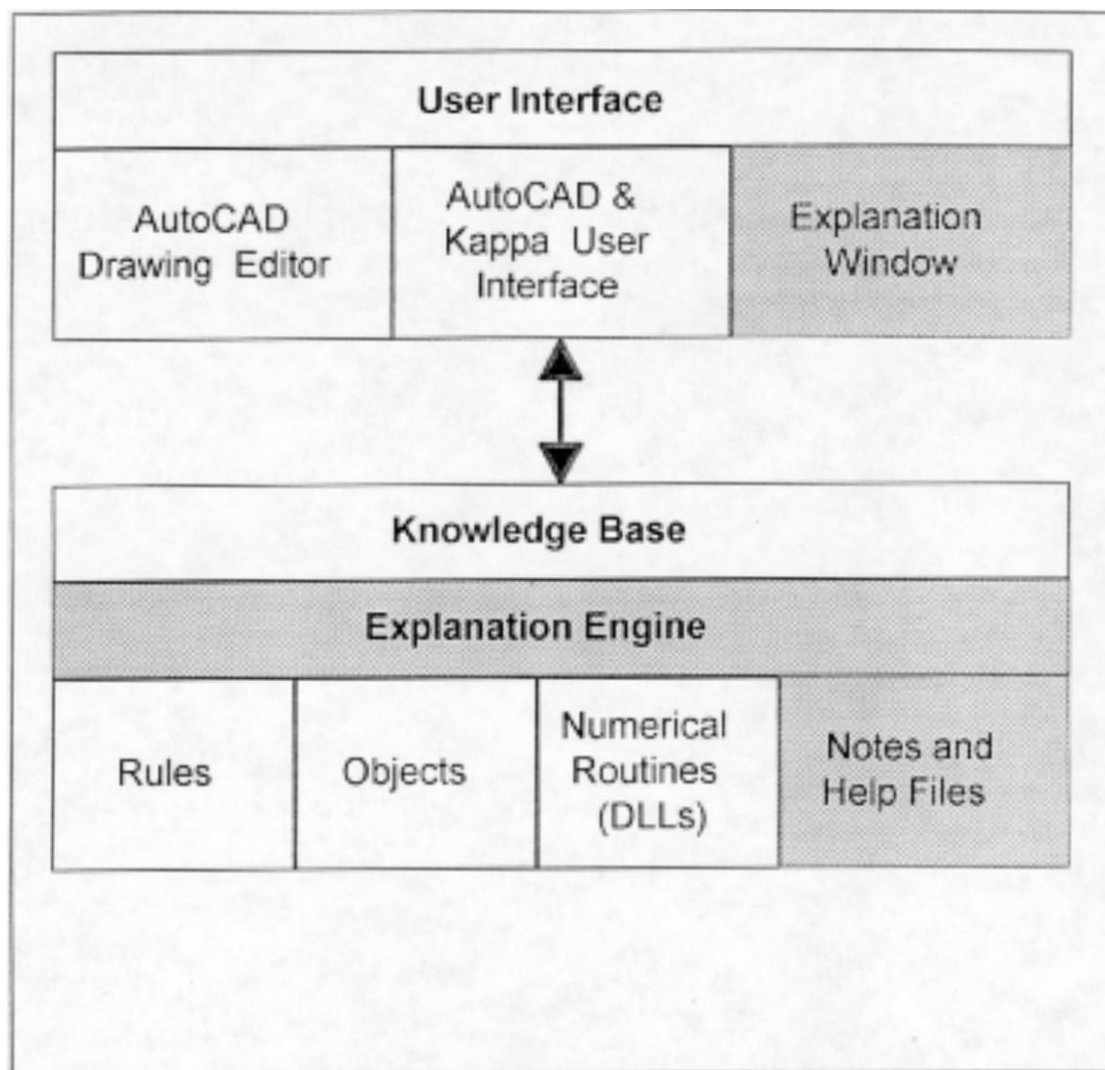


Fig. 1. Architecture of IAPDie-Learn.

as a tool to provide structured authentic design activities for the trainees.

- IAPDie recognises that die design is an iterative process and is designed such that the entire planning and design process is separated into distinct sub-tasks that allow the user to generate their solution path as they progress.
- The system is developed using a computer-aided design and drafting (CADD) program as the interface to the user. This provides powerful interactive graphics tools for the user to control the design process.
- The system treats each and every design problem as a separate knowledge-base. This permits the trainer to structure a set of progressively more difficult problems for the apprentice.

In other words, IAPDie can be developed into an ITS which provides a flexible and interactive learning environment which will encourage greater cognitive exploration and generate better trainee interest on the subject. It is anticipated that this new approach will offer dramatic improvements in learning and provide a new perspective to die designer training.

THE DESIGN OF IAPDIE-LEARN

IAPDie-Learn is the tutoring module of IAPDie. The architecture of the system is shown in Fig. 1. The design program of IAPDie is developed by dynamically linking a CADD package, AutoCAD with a knowledge-base development system, Kappa-PC. All the objects, functions and rules associated with die design are stored in the Kappa's knowledge-base. In addition, computationally intensive shape processing and shape recognition C++ routines are compiled as dynamic link libraries (DLLs) in Kappa. As the product drawing, strip layout and die models are geometrical in nature, AutoCAD is used to provide the graphics aids required for man-machine interaction. The tutoring facilities are developed by adding a layer of functions to form the explanation engine in the knowledge-based system. It is supported by a collection of text files containing 'static' explanatory notes and help instructions on progressive die design and rules used by the system. An explanation window is also provided to handle user interaction when using the learning module.

IAPDie adopts a procedural design methodology as defined by Boyle [7] in the sense it recognizes that the die design process is iterative in nature and provides a series of check points at each design step to allow the user to generate his own solution path by exploring and studying design alternatives. This provides the flexibility for the user to evaluate different design alternatives by either selecting alternative die configuration (for example, by choosing a different system of carrying the strip), or by selecting alternative

strategy within a selected configuration (for example, by selecting different piloting schemes, different punch combination or by re-staging the sequence of punch operation), or by modifying the built-in design constraint factors (for example, by reducing the factor controlling the distances between holes on a punch plate to overcome the space problem). In other words, IAPDie offers a more comprehensive learning tool than the descriptive approach provided by textbooks or classroom learning which only proposes what the author or instructor purports to be the optimum solution. This is because it allows the trainee to generate many different solutions and can compare them before identifying the optimum solution. By creating poor designs as well as good designs during the early stages of the training program, the trainee could be trained to intuitively reject poor solution paths at the early stages of design.

As many of the tedious drafting, measurement, and shape processing and recognition tasks associated with die design are automatically accomplished by the system, IAPDie-learn allows the trainee to concentrate wholly on the thinking and decision-making tasks associated with die design. Hence, the learning activity is very focused and more stimulating as the mundane and time-consuming tasks are attended to by the system. This also helps to dramatically shorten the time it takes for the trainee to study a design.

EXPLANATION AND GUIDING FEATURES OF IAPDIE-LEARN

The key functions which IAPDie-Learn adds to the basic design program are the explanation and guidance capabilities. Vivet [3] has stressed that the mere tracing of applied rules to reach a solution does not suffice to produce good explanation. Instead, it will probably confuse the trainee as the information provided by the rule-tracing functions of most expert systems are presented in such a manner that only software developers would understand. Therefore one cannot use the word 'explanation' if there is no reformation of the design system to change the context of interaction. IAPDie-learn provides three types of explanation and guidance to the trainee: static explanation, dynamic explanation and dynamic guidance.

Static explanation

The static explanation is used to explain design rules and heuristics adopted by IAPDie and guide the trainee in the use of the system. It is independent of the status of the design model in the knowledge base. It includes the following:

- Explaining the rules and heuristics used by the system at the various stages of the planning process.

- Explaining the metal stamping processes supported by the system (i.e. lesson notes).
- Explaining the commands supported by the system.

Static explanation and guidance instructions are stored as text files for retrieval by the system as and when requested by the user. These instructions serve several purposes. Firstly, it can be used to explain the appropriate die design rules and principles to the trainee at the most opportune time. For example, after the trainee has used the system to automatically generate the strip layout for a die, the notes pertaining to staging the die operations can be viewed to reinforce understanding of the related rules. Secondly, the notes and instructions can be viewed as complementary reference materials for the trainee to revise understanding of the subject. Finally, the help files explain the function of each and every command provided by IAPDie. Hence, the learning activity is not distracted by the need to refer to instruction manuals or textbooks.

Dynamic explanation

Dynamic tutoring represents explanations and guidance offered to the trainee which are dependent on the status of the model. Dynamic explanation informs the trainee why a solution is offered at a particular stage of the design process.

For example, after the system automatically configures the punch plate assembly and presents the solution as a 3D geometrical model to the trainee, he may have noticed that a particular punch is mounted on the punch plate with a slotted key while others are not.

The rule related to the retaining of punches is produced:

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If a punch is non-circular
Then insert a slotted key.
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The rule-tracing function of the knowledge-based system will just print out this rule to the trainee. However, a trainee requires deeper explanation to the solution. In this case, the explanation offered to the trainee by IAPDie-Learn is:

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The selected punch is non-circular.
A slotted key is inserted.
This is to retain the punch in the required
orientation during operation.
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Dynamic explanation is a very effective form of tutoring as it offers deep explanation on decisions made by the system as and when they are presented to the trainee during the design activity. An explanation is only offered when the trainee is interested in finding more about why a decision is made by the system and makes a deliberate effort to ask for it, hence the system answers directly to a trainee's question at the most appropriate time without distraction. This is far superior to textbook and classroom descriptive explanation as they offer all the available recommendations without consideration whether the trainee needs them or is interested in them.

Dynamic guidance

Dynamic guidance is different from explanation because it not only offers explanation, but also suggests actions that can be taken to help the trainee proceed along a particular design path. In other words, dynamic guidance attempts to provide answers to the following questions at a particular stage of the design process:

- Why can't a certain goal be achieved?
- What actions are needed (if any) to help achieve the desired goal?
- For each recommended action, what is the implication?

As the user interacts with the knowledge base via the geometrical model presented in the CADD system, many of the non-geometrical factors affecting the plan developed by the system may not be obvious to him, e.g. a hole is too close to the edge of the workpiece for selection as a pilot hole. To the novice die-designer, he may be confused by the answer given by the system, e.g. why a certain punch is not selected (or recommended) by the system for use as a parting punch. The explanation engine provides functions to interpret the geometrical and topological data stored in the knowledge base and provides the answers to the trainee's query. The explanation engine can further provide tutoring advice to the user to indicate what type of action(s) he can take to achieve his goal(s) and what are the implications.

For example, a trainee may have intended to use a particular hole as a pilot hole (the goal). However, the system has tagged it as unsuitable for use as a pilot hole (i.e. goal cannot be achieved). He can first use the explanation engine to list out the pilot selection rules which the hole has violated (i.e. why the goal cannot be achieved). He can further ask for advice as to what constraint condition(s) he has to relax, or what changes to design he has to implement, to overcome the violation (i.e. actions recommended by the system to achieve the goal).

The explanation engine will explain each recommendation and its implications. In this case, the guidance from the tutor can be in the following form:

```
Hole1 is NOT SUITABLE for use as a PILOT
HOLE because:
1. It is ON A FOLDED PORTION of the
workpiece
2. It is TOO CLOSE to edge of workpiece
Recommended action(s) to make Hole1
suitable for use as a PILOT HOLE:
1. It is ON A FOLDED PORTION of the
workpiece
Seek design changes from the Product
Designer
2. It is TOO CLOSE to edge of workpiece
Reduce the FACTOR for Minimum Distance
Between Centre of Hole and Edge of Part
for Direct Pilot Hole selection, or
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Seek design changes from the Product Designer

If desired, the trainee can further use the static explanation commands to find out the implications of reducing the factor for minimum distance between centre of hole and edge of part for direct hole selection or reasons why a hole located on the folded portion of a workpiece cannot be used as a piloting hole.

Dynamic guidance contributes greatly to the development of cognitive skills in die design. This is because during the design process, the constraints are explained, and alternatives and recommendations are offered to the trainee at the time when the decision is made.

Dynamic explanation and guidance are implemented in the knowledge base by using functions to scan the relevant slots of the object in question to extract its geometrical and topological status. The state of each condition is checked with the relevant rules. The explanation and recommendations are pre-stored as text slots in the subclass one level higher and as the objects are created, they will inherit these properties. For each explanation or guidance demanded by the trainee, the system will fire monitors to check the status of the rules and display the relevant text slots in the explanation window.

IAPDIE-LEARN AS AN ITS

In addition to the explanation capabilities of IAPDie-Learn described above, the iterative procedural design approach adopted by the design system helps to reinforce the cognitive apprenticeship learning approach for die design. Case studies illustrating how the software can be used to examine design alternatives can be found in References 5 and 10.

IAPDie-learn offers many features that would enhance the effectiveness of the learning of progress die design. They are:

- It provides a structured approach for the learning of die process planning and design. By splitting up the planning and design process into discrete steps, the software allows the trainee to concentrate on one problem at a time. At the same time, the interactions between decisions made at one stage of the decision process and the down-stream design steps will be immediately realised when he moves from one step to another.
- It provides immediate feedback to the trainees in the form of appropriate 2D (strip-layout) and 3D (die assembly) models. The way in which actions taken by the trainee that would affect the design model are immediately updated on the CADD model in front of him.
- It is based on authentic design activities. One major criticism against classroom training is that it is usually too abstract and bears little

resemblance to the real work environment and is therefore unable to motivate the trainee.

- It allows a trainee to try out more exercises within a given period of time hence improve his design skill via repeated practices. This is because the most time-consuming component of die design, i.e. the drafting tasks are virtually eliminated.
- It offers the instructor a very flexible teaching tool. It can be used as a self-paced tutoring aid to complement classroom and laboratory instructions. Alternatively, it can be use like a 'story-book' where the instructor scripts the preferred solution path for the trainee to follow.
- It is most suitable for use as an in-house company-based training aid to introduce new staff or apprentice to the design philosophy of the company. The software can be used to show new staff past products manufactured by the company and explain the standards and design philosophy applied.
- It makes the task of learning progressive die process planning and design more focused and enjoyable and is therefore more likely to motivate the trainee.

Furthermore, it fosters procedures which are characteristics of the cognitive apprenticeship approach:

- As the trainee experiments with familiar design tasks, it reinforces the legitimacy of the implicit knowledge acquired and how it can be used as framework when solving problems in apparently unfamiliar tasks.
- By offering the trainee a tool to study alternative design configurations and strategies, it stresses that heuristics is not absolute, but assessed with respect to a particular task.
- By allowing trainees to generate their own solution path, it helps to make them conscious, creative members of the tool-making trade. This provides them a means to discuss, reflect upon, evaluate, and validate group procedures in the collaborative design process.

CONCLUSIONS

This paper had discussed the suitability of developing a knowledge-based design system into an ITS which supports the cognitive apprenticeship approach which has been recognised as most suitable for development of skills and experience as it involves authentic activities. It also stresses that developing an ITS from a knowledge-based design system is not merely rule-tracing. It involves a deliberate effort to reformulate the rules into contexts meaningful to the trainee.

It must be noted that IAPDie-Learn lacks one key component of an ITS, that is the ability to model and rate the trainee's performance when he

is using the software. At the moment, this is a very difficult task as die design is an open-ended problem. In addition, there are no facilities in the software to monitor the trainee's performance and to trap the trainee's mistakes.

In both developing and developed countries, young people tend to shy away from professions which involve long periods of training and

apprenticeship. It is expected that when more and more cognitive apprenticeship ITS becomes available, there will be a need to re-structure and shorten the training and apprenticeship training programme to take advantage of the new technology. Hopefully, the shortened qualifying period will attract more young people to join such skill-oriented trades.

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B. T. Cheok received his B.Sc. from the University of Southampton in 1979 and M. Sc. from the University of Strathclyde in 1981. He is presently a Senior CAD/CAM Specialist in the CAE/CAD/CAM Centre, National University of Singapore. He has published over 25 papers. His present research interests include CAD/CAM, knowledge-based systems and sheet metal working.

A. Y. C. Nee received his Ph.D. from UMIST in 1973. He is presently a professor in the Department of Mechanical and Production Engineering and Dean of Engineering, National University of Singapore. He has published over 270 papers and is editorial member of 6 international journals. He is an Active Member of CIRP and a Fellow of the Society of Manufacturing Engineers. His present research interests include knowledge-based systems, computer-aided fixturing, sheet metal working and process planning.