DESIGNING SOFTWARE SUPPORT FOR A COMPLEX COGNITIVE TASK

Denise Kirkpatrick and Martyn Wild
Edith Cowan University, Perth WA

Paper presented at the Australian Association for Research in Education Conference, University of Newcastle, November 1994

Abstract

This paper will report the design and development of a User Performance Support System (UPSS) to enhance lesson planning skills in first year teacher education students. This is part of a larger study investigating the development and implementation of a UPSS to facilitate lesson planning. Much conventional software has been criticised for its failure to acknowledge the cognitive proceses involved in the task. A UPSS is interactive software that is intended to both train and support the novice user in the performance of complex tasks. This paper will focus on the features of a UPSS which support the performance of a complex cognitive task (lesson planning) and report the design process involved in the development of the software.

Designing Software Support For A Complex Cognitive Task

Introduction

This paper will report the design and development of a User Performance Support System (UPSS) to enhance lesson planning skills in first year teacher education students. This is part of a larger study investigating the development and implementation of a UPSS to facilitate students' lesson planning. The larger study includes the investigation of the effectiveness of the system, the cognitive strategies employed by students when interacting with the UPSS and assessment of students' responses to the system.

Much of the design and development of the UPSS is already complete. However, this paper does not distinguish between software features that are planned and those that are already implemented. The larger investigation into the effectiveness of the UPSS has not been carried out to date and will be the subject of a future paper; however, this paper offers a brief description of the research methods to be used in the investigation .

Aims of the research

The aims of the research project are to:

- develop a highly interactive, hyper-media learning environment to facilitate enhanced lesson planning skills in first year Bachelor of Arts (Education) students;
- investigate the effectiveness of the UPSS compared with current methods and practices of teaching lesson planning;
- identify the cognitive strategies that students employ as they interact with the UPSS;
- assess students’ use of and responses to the UPSS.

User Performance Support Systems

A User Performance Support System (UPSS) is interactive software that is intended to both train and support the novice user in the performance of complex tasks. Such software are being used successfully in training situations in medicine (e.g. medical diagnostic systems), engineering (e.g. computer assisted design systems) and management (e.g. decision support systems). It would seem that there is value in using similar software in educational situations (Gustafson & Reeves, 1990; Reeves, 1993*a*).

A UPSS is being developed for use by first year Education students in the academic setting and in the classroom. This UPSS will facilitate the development of student skills in the area of lesson planning. The Lesson Planning UPSS (LPS) is intended to (i) be instructional software that will teach students the skills involved in lesson planning and, (ii) provide support in the concurrent and subsequent performance of the lesson planning task. To date, instructional materials based on interactive technologies, have tended to focus on only the instructional aspect of task performance (Jih & Reeves, 1993; Brown, 1991). It is also intended that student use of the LPS in the school and university setting will facilitate the transfer of cognitive strategies and minimise the distinction between "learning" and "doing".

The design of the LPS

The LPS will incorporate the model of lesson planning required by Edith Cowan University. This will include essential components of lesson planning such as writing learning objectives, developing learning experiences and planning evaluation. Each component will be supported by activities that will instruct the user about the task (e.g. provision of information relating to reasons why objectives are necessary, criteria for quality objectives), and which will also assist the user in performing the task (e.g. provision of a database of verbs to assist in writing quality learning objectives). A set of software tools will be available to support each activity. One of these, for example, will be an expert knowledge base system, to provide students with the ability to evaluate the effectiveness of their completed lesson plan. This will work by prompting students to analyse and reflect upon the appropriateness of evaluation processes in relation to lesson objectives.

The design of the instructional aspects of the software is based on the principles of instructional psychology described by Glaser (1987), incorporating traditional instructional design and intelligent tutoring systems design. These principles acknowledge the importance of considering human cognition, using current learning theories to suggest teaching strategies. Implicit in this approach is the role of "expert" and "novice" knowledge in effective task performance. This approach clearly identifies the focus of instruction, not just the description of content, but also the relationships between topics or how they should be known (Laurilliard, 1993). This approach also considers the task conditions that improve performance and which can be used to suggest instructional strategies.

The task of lesson planning can be viewed as an exercise in problem solving. An important factor in solving problems is domain specific comprehension. Glaser (1984) has suggested that one of the features distinguishing a novice from an expert is the incompleteness of the novice's knowledge base, rather than limitations in their processing capabilities. It has been suggested that the transition from novice to expert performance is largely provided for by the acquisition of a suitable knowledge base (Glaser, 1982). A knowledge base consists of both descriptive and heuristic components. Descriptive knowledge is the shared knowledge of experts and practitioners that is usually found in text books, while the heuristic component includes the knowledge of good practice and judgement constructed over years of experience. It is suggested that the description of expert performance should include two related aspects: the information structures and declarative knowledge that are required for performance and the cognitive strategies and procedural knowledge that are required by the task.

Lesson planning is an essential cognitive skill for teachers. Effective lesson planners possess declarative knowledge about themselves as planners, about the task of lesson planning and about ways of going about the task. They also possess domain specific knowledge, such as the criteria for creating instructional objectives, the most appropriate strategies to achieve particular objectives and the range and relevance of evaluation techniques. They know how to plan lessons in the appropriate way, what is required of them in planning a lesson and they know when and why to perform particular aspects of lesson planning. In addition to this knowledge they have the skills to regulate their own performance, checking and monitoring to ensure they are meeting certain criteria. They also possess the skills and knowledge to allow themselves to correct errors. These characteristics of the lesson planner, the task and the interaction of both, are addressed in the design of the LPS.

Stages in the design process

The design of the instructional dimension of the LPS was composed of two main stages. The first is the identification of the cognitive skill that is to be the focus of instruction. In this case the skill is that of lesson planning according to the criteria described in the lesson planning model prescribed for Education students. While Laurilliard (1993) has argued that instructional design should consider the students' representations of the topic and incorporate these representations into the instruction we decided that in the initial design stages the focus of design should be on expert representations. As students were to be assessed against pre-determined (expert)

criteria which were out of our control, we believed that we had a responsibility to instruct students within this framework. However, we acknowledged that at some stage in the design we should take account of learners' representations of the topic of lesson planning and that these should be incorporated in the instructional design aspects of the LPS. If we understand how the learner constructs the topic of lesson planning then we can design software that works with, rather than against the learner. Our first step was to clarify our intended outcomes. Our design of the instruction was to be guided by our desire to teach students how to plan lessons effectively, and in accordance with the prescribed guidelines. Our objectives were to

- encourage students to see the "big picture" of teaching and learning and to understand how lesson planning fits into the teaching-learning process,
- promote general problem solving heuristics. To teach students to use general problem strategies such as analysing the problem, identifying possible solutions, planning responses and monitoring their own performance.

Having established our desired outcome the next stage was to articulate the knowledge base that expert learners possess. Knowledge bases are composed of descriptive or declarative knowledge that describes the facts relating to the subject domain and the information structures, and heuristic or procedural knowledge about how to go about performing the various strategies. In experts this may be derived from years of practice and experience. We asked expert lesson planners, those who taught the topic, to describe what they knew about lesson planning and then to describe the ways in which they saw the various pieces fitting together. This resulted in an extensive list of topics including the components of lesson planning such as learning objectives, teaching strategies and evaluation techniques. It also resulted in the description of cognitive tasks such as planning, analysing, deciding, selecting, matching, checking and monitoring, and stated principles and procedures. From these descriptions we could construct the knowledge base required for lesson planning.

To confirm the relevance and completeness of this knowledge base we then asked experts to think aloud as they went about the task of planning the types of lessons that first year students would be required to perform on teaching practice. They were encouraged to talk about the ways in which they made decisions about aspects of the task such as the selection of learning objectives, relevant content, teaching strategies and evaluation. The descriptions which resulted, allowed us to refine the knowledge base particularly with relation to the strategies that experts used to monitor and check their task performance.

For example, as the expert talked through the sub-task of planning the evaluation component of the lesson plan she described thinking back to the original learning objectives, considering the desired outcomes, and the type of information that she required to inform her of the extent to which the learning objectives had been achieved. She also called to mind the age and capabilities of the learners, the amount of time available, the place of the individual lesson in the sequence and the purpose of evaluation in the specific lesson. She checked that her proposed evaluation techniques were suitable for her purpose and that they were appropriate for the learners involved, and particularly, that they would provide the necessary information that would inform the teacher of the extent to which objectives had been achieved.

This process of identifying the outcome which we wanted the learner to achieve and construction of an expert description of the knowledge base involved provided us with the framework for the design of the instructional dimension of the LPS.

Multimedia developments

As Oliver suggests, the term multimedia is not a new one and has only received currency of late with the advent of computer based technological advancements and in particular, interactive technologies (Oliver, 1994). Perhaps the most notable if not the most distinguishing feature of interactive multimedia software in terms of its educational significance, is its facility to allow non-hierarchical representation of information - that is, it allows declarative representation of information with semantic and other links made between items to create a knowledge base. The educational value of knowledge representation in this way was first highlighted by those working with the computer language Prolog who suggested that computer based semantic representation of knowledge perhaps best mirrored the behaviour of certain higher order cognitive activities (Nichol, 1990; Nichol, 1988; Nichol, et al, 1988). This notion found some theoretical basis in Minsky's theory of cognitive frame representation (Minsky, 1975).

To date, much of the software developed as interactive multimedia can be characterised as presentation, instruction or information systems. For education, the most widely applied multimedia software are of the latter types - instructional and information systems (Oliver, 1994). The LPS provides a new departure for multimedia development by providing software that encourages problem solving through cognitive modelling, that is the building and exploring of qualitative models. In this sense, users of the LPS are encouraged to create models of lesson plans and to explore and test those models.

Modelling

Models are important in education since they provide vehicles by which the learner can arrive at an understanding of an expert representation of a particular domain. In this case, the domain is lesson planning. The modelling environment needs to be accurate and structural but not necessarily complete. By interacting with such a model, the learner may move from their own mental model of lesson planning to the conceptual model of that process required by an expert.

It is generally agreed that although a modelling environment should not be complete it is important that it remains functional; that is, it must provide the learner with some expert knowledge and it must facilitate learner predictions (LMMG, 1988). It is the incompleteness of the model that provides the opportunity for construction, reflection and change. In this sense, the LPS provides an environment for learners to externalise their own understanding of the lesson planning process, to identify inaccuracies or insufficiencies in their thinking and to reflect on their cognitive models without expressing a commitment to any one in particular.

Transfer

The LPS is based on the premise that by using the LPS to model the lesson plan process, students will come to understand that process and be able to plan lessons effectively both through their use of the LPS and also by other means (e.g. pen and paper). A significant finding in transfer of learning research is that where there are common factors in the content or procedures in carrying out two tasks, transfer is more likely (Child, 1981, p 127). To facilitate transfer of learning here, the metaphor that guides the design of the human-computer interface is provided by traditional lesson planning: the LPS environment in which students plan their lessons uses similar terms and has similar elements to those encountered in the paper and pen process. Students describe lesson objectives, associated teaching materials, methods of realising the objectives and evaluation processes. At each stage, students can access examples, gain information from an appropriate knowledge base, obtain a critical analysis of their lesson based on an expert knowledge base and be prompted to reflect on their model of the lesson. The amount and type of human-computer interaction expected by use of the LPS is intended to approximate that between learner and human tutor in a pen and paper context.

Navigation

The problems usually associated with navigating hypermedia are described by Collis (1991) and include:

- disorientation (i.e. difficulty knowing where one is in the software environment);
- navigation inefficiency (i.e. difficulty in moving intentionally from point to another);
- cognitive overload (i.e. exposure to more information than is required by the user).

In particular, these problems can be expected to be encountered more by naive users who are not aware of the design metaphors built into the interface than by more experienced users. Without recognition of the design metaphor, users can be expected to access information inefficiently, for example, by following information browsing techniques (Trumball, et al, 1992).

It is intended that the pen and paper lesson planning metaphor that guides the design of the human-computer interface will support learners in their interactions with the LPS. This interface is intended to facilitate efficient navigation through the use of the tools necessary to build and evaluate lessons and the associated hypermedia environments that provide information in the form of text and graphics.

Cognitive load

The greater the availability and accessibility of information within a given computer environment, the more likely users will flounder as a result of excessive cognitive load or cognitive overload and consequently fail to learn. According to Jih and Reeves (1992), learners using a hypermedia system must cope with and integrate three types of cognitive load: the content of the information, the structure of the program and the response strategies available. How learners cope with such a load depends largely on the human-computer interface. For example, cognitive load can be reduced by (i) reducing the number of options at any one point in the program; (ii) by encouraging users to externalise their thinking, by use, for example, of text annotations and place-marking; (iii) by 'hiding' program options not likely to be needed by most users; (iv) by providing strong visual cues to aid navigation; and (v) by reducing the number of hypermedia links between information nodes (Oren, 1990).

The means by which users deal with the cognitive load imposed by the LPS will largely be a function of their conception of the lesson planning task as well as that of the software interface. Software features such as on-line help (i.e. help, for example, in planning the task) and dynamic structure maps (i.e. maps to show a user's position in the hypermedia environment at any one point), will be included in the design of the LPS to encourage students to build strong conceptualisations (what Johnson-Laird (1983), Jih and Reeves (1992) and others have termed mental models) of the task itself, the structure of the LPS and the information and response options available in the software.

Learner control

Learner control is a reference to that dimension in computer based education that describes the level of control exercised by the learner when interacting with a given software item. Despite the fact that learner control has been one of the most heavily researched dimensions of computer based education in recent years (Steinberg, 1989), Reeves (1993b) has pointed out that many of the research studies are flawed both in their theoretical and methodological bases. It seems to be popularly assumed that the greater the control exercised by the learner (as opposed to that exercised by the software) within a given software environment, the greater the level of learning will be. This assumption is a product of cognitivist learning perspectives, in which learners are shown as active processors of information and that knowledge is constructed when learners have control over the learning process (Rowe, 1993, pp 96-106). However, the evidence about learner control is at best contradictory and at worst negative (Steinberg, 1989; Reeves, 1993b). In particular, Oliver draws attention to research that suggests that unskilled learners fare especially badly in terms of performance outcomes when the degree of learner control is high and external control (e.g. control by the program) is low (Oliver, 1993).

The LPS provides for significant learner control over a range of learning processes, including: task perception, information retrieval and processing, problem-solving, knowledge construction, revision, reflection and cognitive modelling. The research program to investigate the effectiveness of the LPS will, in part, consider whether the high degree of learner control invested in the software system effects performance outcomes.

References

Brown, M. (1991). An investigation of the development process and costs of CBT in Australia (pp 43-54). In Godfrey, R. (Ed.). Simulation and Academic Gaming in Tertiary Education: the Proceedings of the 8th Annual Conference of the Australian Society for Computers in Learning in Tertiary Education, Launceston, Tasmania, December 1991. Launceston: University of Tasmania.

Child, D. (1981). Psychology and the teacher. Third edition. London: Holt, Rinehart and Winston.

Collis, B. (1991). The evaluation of electronic books. Education and Training Technology International, 28, (4), 355-363.

Glaser, R. (1982). Instructional psychology: past, present and future. American Psychologist, 37, 292-305.

Glaser, R. (1984). Education and thinking: the role of knowledge. American Psychologist, 39, 93-104.

Glaser, R. (1987). (ed.) Advances in instructional psychology volume 3, Hillsdale, NJ: Lawrence Erlbaum Associates.

Gustafson, K. L. & Reeves, T. (1990). IDioM: a platform for a course development expert system. Educational Technology, 30, (3), 19-25.

Jih, H. J. & Reeves, T. (1992). Mental models: a research focus for interactive learning systems. Educational Technology Research and Development, 40, (3), 39-53.

Johnson-Laird, P. N. (1983). Mental models: toward a cognitive science of language, influence and consciousness. Cambridge: Cambridge University Press.

Kulik, J. A. & Kulik, C. C. (1988). 'Computer based instruction: what 200 evaluations say'. Occasional paper, Centre for Research and Teaching, University of Michigan.

Laurilliard, D. (1993). Rethinking university teaching. London: Routledge.

London Mental Models Group (1988). Tools for exploratory learning. Occasional paper, InTER/5/88, University of Lancaster.

Minsky, M. (1975). A framework for representing knowledge. In Winston, P. H., (Ed). The Psychology of computer vision. New York: McGraw Hill.

Nichol, J. (1988). Models, micro-worlds and minds. In Nichol, J., Briggs, J. and Dean, J. (Eds). Prolog, children and students. London: Kogan Page.

Nichol, J. (1990). Peg: a way of thinking about things. In McDougall, A. and Dowling, C. (Eds). Proceedings of the IFIP TC 3 fifth world conference on computers in education, pp 1061-1066. Amsterdam: Elsevier Science Publishers BV.

Nichol, J., Briggs, J. and Dean, J. (Eds). (1988). Prolog, children and students. London: Kogan Page.

Oliver, R. (1993). Interactive multimedia applications in education. Unpublished manuscript, Edith Cowan University, Perth, February 1994.

Oliver, R. (1994). Measuring learning outcomes using IMM systems. Proceedings of the Second International Interactive Multimedia Symposium, Perth, WA, pp 377-382.

Oren, T. (1990). Cognitive load in hypermedia: designing for the exploratory learner. In Ambron, S. and Hooper, K. (Eds). Learning with interactive multimedia, 126-136. Washington: Microsoft Press.

Reeves, T. (1993a). Research support for interactive multimedia: existing foundations and new directions (pp 79-96). In Latcham, C., Williamson, J. & Henderson-Lancett, L. (Eds.). Interactive Multimedia: Practice and Problems. London: Kogan Page.

Reeves, T. (1993b). Pseudoscience in computer based instruction: the case of learner control research. Journal of Computer Based Instruction, 20, (2), 39-46.

Rowe, H. A. H. (1993). Learning with personal computers: issues, observations and perspectives. Hawthorn: ACER.

Steinberg, E. R. (1989). Cognition and learner control: a literature review, 1977-88. Journal of Computer Based Instruction, 3, (3), 84-90.

Trumball, D., Gay, G. and Mazur, J. (1992). Students' actual and perceived use of navigational and guidance tools in a hypermedia program. Journal of Research on Computing in Education, (24), 3, 315-328.