An Expert System to Aid in Model Conceptualization

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Abstract

Using interviews and a Delphi exercise, valuable information was collected from experts concerning the problem definition and model conceptualization stages of system dynamics studies. This research examined when to select and use various knowledge acquisition techniques and knowledge representation structures. Now this information is being incorporated into a comprehensive expert system for training novice SD analysts. A teacher model and a student model are being incorporated into the expert system to provide pedagogical flexibility and intelligent tutoring. This paper reports on the initial work on the prototype instructional expert system, and plans to extend this prototype.

THE PROBLEM

The problem definition and model conceptualization stages of SD are most difficult for students and novice practitioners. The effective implementation of these stages are considered to require both art and science. There is a need for educational materials to train novice SD analysts in conducting problem definition and model conceptualization. Most system dynamics textbooks, articles, and courses concentrate on model formulation, verification, and simulation. The development of training material dealing with problem formulation and model conceptualization is a very practical research endeavor. Any such material will be most effective if the experience of expert practitioners is incorporated. Effectively exposing analysts to the diverse options in applying the SD methodology requires capturing and replaying the experiences of a range of expert SD practitioners. This can be done best through an automated training package such as an expert system. Any pedagogical package to teach these stages should allow for flexibility in teaching approaches and diversity in student background.

Traditional computer aided instruction (CAI) and computer based tutoring (CBT) allows no flexibility in adjusting the teacher model or student model. Various intelligent computer aided instruction (ICAI) packages allow for diverse student situations and dynamic adjustment of student models but do little to allow flexibility in teacher models. Often CAI models are not derived from knowledge obtained from leading experts in the selected domain.

Instructional expert systems incorporate the experience of highly qualified experts. However, these systems generally pay little attention to the student model.

This ongoing research is focused on developing a comprehensive instructional expert system that incorporates a flexible instructor model and a flexible student model.

This expert system will serve as a training tool for students to learn the concepts, philosophy, and structures involved in SD. This system will also address

the approaches and methodologies required to interact with system participants in conducting a SD study.

An expert system for training problem definition and model conceptualization provides portability and standardization. The portability allows it to be used in settings that have no access to experts. The standardization provides the SD community a model to be checked for validity. After extensive testing and validation, the revised expert system could serve as a benchmark for SD practitioners. The combination of portability and standardization contribute to make this expert system a useful tool for SD courses.

RESEARCH APPROACH

This is a significant problem which requires considerable resources. It has been divided into segments. This current paper addresses: (1) the development of a generic instructional expert system (IES) with flexible teacher and student models, (2) utilization of expert knowledge from Trimble (1992) to establish a domain specific teacher model, (3) construction of a skeletal prototype IES that addresses selected concepts and methods critical to problem definition and model conceptualization and (4) future enhancements to the prototype expert system.

The research on ICAI was examined. The focus was on the structure and components of various ICAI packages. The developments in teacher and student models were studied in detail. The philosophy of education is researched to gain a basic understanding of how philosophy relates to teaching methods. Several computer based tools that aid SD analysts were studied.

After examining ICAI and SD literature a generic IES was developed that provided flexibility in the teaching process and the student model. Knowledge elicited from novice practitioners is used in developing the student model. The teacher model is based on information obtained from the interviews with experts and the delphi exercise. The conclusions of SD analysts regarding knowledge acquisition in SD from Trimble (1992) were examined. Protocol analysis was performed on the transcripts of experts interviewed. These activities generated a domain specific knowledge base that helped define the teacher model of the IES.

A key subset of SD concepts was selected to develop the initial prototype. This was done to allow for testing the flexibility of the IES before constructing an extensive set of tutoring modules. The knowledge base was enhanced to handle test development and student errors. Finally, the knowledge base was expanded to use student errors to adjust the student model.

INVESTIGATING PREVIOUS RESEARCH

Pigford and Baur (1990) identify three basic components for any expert system: inference engine, user interface, and knowledge base. The inference engine is responsible for deciding when and how knowledge from the knowledge base is applied to make decisions. The user interface is the communication link between the user and the expert system software. It takes on added significance with instructional expert systems since the form of communication between user and machine has a significant impact on the success of the pedagogical process. The knowledge base contains the domain knowledge, which can be represented using a variety of knowledge structures. The knowledge base can be subdivided by the type of knowledge representation structures such as facts, rules, and frames. Alternatively, the knowledge base could be subdivided along topical lines. In the case of an

instructional expert system the knowledge base could be divided into knowledge related to student, teacher, pedagogical process, and instructional domain.

Corben and Wolstenholme (1992) developed a computer based Delphi method to assist the development of SD models by providing the ability to create consensus influence diagrams. Adjustments could make this an innovative group based learning tool. Kaupe (1992) describes a German-language computer-based tutorial SDAQUIRE developed at Mannheim University. This tutorial consists of twelve lessons and is oriented to SD model building. The tutorial starts with the basic concepts of systems research, and steps through the model building process all the way through validation of model structure, parameter values and model behavior. While providing an good orientation to SD, this tutorial does not allow for adjustments in the pedagogical process, or account for student diversity.

Rickel (1989) in surveying research in ICAI identified eight possible components of an ICAI package. They are learning scenarios, domain knowledge representation, student model, student diagnosis, pedagogical knowledge, discourse management, problem generation, and user interface. A learning scenario is the circumstances under which the student's learning is to take place. The balance of control between student and tutor is critical. Knowledge representation can vary from canned presentations to complex causal relationships, scripts, or semantic networks. The student model maintains information of the student's knowledge and capabilities. It is adjusted based on the student's actions and responses. The student diagnosis component evaluates student errors to establish the basis for the misconception. Pedagogical knowledge deals with instructional strategies. This includes choosing an effective presentation method and determining how to deal with student errors. Discourse management is concerned with the determination of what the tutor and student need to communicate. Problem generation should allow flexibility in testing the student's competency. The user interface involves the presentation of text, graphics, audio and video, as well as acceptance of user input. In many ICAI packages some of these components are combined.

Vassileva (1990) surveys student modeling techniques and presents a classification of student models. This paper classifies student models based on representing student domain knowledge versus general characteristics of the student, and the techniques used to update the student model. An approach is presented that includes a model of the student's domain knowledge that is updated by comparison, and a model of student features, such as learning rate, level of concentration, and preferred style of presenting material.

Chen (1991) examines teaching in the context of a three layer framework. The three layers are: (1) bottom layer (physical layer) consisting of various physical media, (2) middle layer (layer of logical contents) consisting of the materials of a particular learning unit, and (3) top layer (external view) addressing the teacher's cognition, selecting from different views indicating different patterns of the teaching behavior.

Educators have studied the relationship between philosophy, teaching methods and curriculum. In Smith (1990) six schools of philosophy are discussed: idealism, realism, pragmatism, existentialism, essentialism, and perennialism. Idealists feel students should learn through contemplation or the dialectic, and the curriculum focuses on teaching students to think as opposed to memorizing facts. The instructional methods of realists include a wide repertoire of traditional approaches, such as lecture, discussion, and experiential activities. Pragmatists apply a problem centered learning approach. The focus in on problem solving, personal experiences, and interaction between student and environment. Because the philosophy of existentialism is unique and individualized, it opposes the standardization of schools.

The curriculum emphasizes skills and subjects that explain physical reality and social reality, and depict human choices. Essentialism emphasizes discipline, and diligence on the part of the student. The main teaching methodology is drill and rote memorization. In perennialism the key purpose of education is to promote intellectualism, as opposed to learning through problem solving. Teaching methods include well organized narratives, coaching in basic skills, and selected use of the Socratic model of probing questions. Experts in most domains do not isolate their teaching strategy to a single educational philosophy. The SD experts that participated in this study frequently applied different teaching approaches under different conditions. The approach in developing the teaching model is to emulate different experts not the idealized teaching philosophies and corresponding methodologies.

A GENERIC INSTRUCTIONAL EXPERT SYSTEM

The instructional expert system in this research consist of five components: student model, teacher model, domain knowledge model, user interface and inference engine. The inference engine is established by the expert system development tool used. Problem generation is handled by the domain knowledge model. The pedagogical approach and philosophy is embedded in the teacher model. Discourse management is handled by the user interface, and student diagnosis is incorporated into the student model. The learning scenario is developed by the student and teacher models.

For the prototype expert system in this research a three layer framework of the teacher model is constructed. It is somewhat different from Chen (1991). The bottom layer is the philosophical perspective of the teacher regarding the domain subject. For example, how does one regard SD - simply as one of many tools for displaying causality, a simulation language, or a broad paradigm that explains how the world operates.

The second layer is the relevant skills base of the teacher. The skills level of the teacher model consist of general and domain specific skills. The general level addresses the knowledge level of each resource (none, novice, experienced, expert), and the teaching level (elementary, HS, freshmen, advanced undergraduate, and graduate level). The domain specific skills information should indicate the teacher experience regarding studying SD, teaching SD, and practicing SD.. The third layer in this framework is the resources available. This would include literature, experts, computer resources, group tools, etc..

In interactively constructing the teacher model the user responses to questions, establishing a knowledge base regarding the model teacher. This process starts with the bottom layer and proceeds to the top layer. Each layer establishes direction and constraints for subsequent layers.

In constructing the teacher model, the user is in part establishing the student model. The resources available layer is identical for student and teacher. This layer is the basis for communication between student and teacher. The general information in the resources layer of the teacher and student models consist of an availability list indicating the availability of interactive multimedia, video clips, audio clips, group decision making software, interpretive structural modeling, electronic mail contact with experts, non-computer group sessions and group techniques, and direct contact with experts. The domain specific resource availability list indicates the level of availability of Stella models and microworld models.

Additional inquiries of the user are needed to further establish the philosophical perspective of the student (layer 1), and the skills level (layer 2) of the student model.

The philosophical perspective layer of the student model addresses the student's view toward learning using ICAI. Is the student optimistic or pessimistic?, the preferred style of presenting material, and the level of concentration of the student are aspects of this layer.

The skills level establishes the skills of the prospective user. This corresponds to the same two dimensions this layer has in the teacher model: (1) knowledge regarding the instructional domain, and (2) general knowledge regarding knowledge acquisition, conveyance, and representation. If the teacher model prescribes the use of certain resources that the student model has little or no skills, the IES must first provide training regarding the learning resource, before using it in instruction of the domain subject. The student model skills level has general information that indicates the student's general knowledge level (elementary, HS, freshman, advance undergraduate, and graduate). The domain level student model indicates the student's knowledge level in SD, problem solving, causal loops, and differential equations

Layer 3 allows extension of the teaching and learning process beyond the expert system. This implies interrupting the IES with a partially constructed knowledge base and returning to this exact point. The IES could activate software that could aid the learning process, such as a simulation program, a Stella model, or a short video clip. Upon completion of this external computation, control should automatically be returned to the IES. Additionally knowledge may be made available to the IES as a result of the interrupting program. A non-programmed interruption requires leaving the IES to complete learning tasks unattached to the IES. It may involve a literature search, group interaction, correspondence, or experimentation. It may take hours, days or weeks. The state of the IES is saved when the IES is exited, and maintained until reactivated by the user.

This layered approach to establishing teacher and student models allows one user (instructor) to establish certain aspects of the environment and other users (students) to establish other environmental perspectives. Alternately a single user could construct both student and teacher models. All this is done in advance of the actual tutorial sessions.

INITIAL PROTOTYPE DEVELOPMENT

The initial prototype is based on the generic three layer structure. This initial prototype will be concerned with teaching: (1) components of problem definition and model conceptualization, (2) the process of eliciting knowledge from system participants, and (3) select knowledge representation structures. This early version will be developed to train users with general knowledge at the level of college students, and basic knowledge of SD equivalent to a 8-10 week course. Level 5 by Information Builders Inc. is the expert system development tool used to create the initial prototype. Level 5 generates an expert system with an inference process of backward chaining, and a rule based knowledge representation structure.

For the initial prototype the interactive computer based access to information in the resources layer of the teacher and student models will be limited to text and simple graphics. The rule based system will include limited hypertext capabilities. This hypertext feature is recognized as a critical interactive learning feature. It allows the user to inspect information in a non linear fashion. The user can decide when to view more information on select features. External learning tools such as electronic mail contact with experts, non-computer group sessions and group techniques, and direct contact with experts are available.

In the initial prototype the teaching level and student model skills will correspond to the advance undergraduate level.

To simplify the prototype, the student philosophical perspective is limited to the level of concentration of the student (high, medium, low). The philosophical level of the teacher model focuses on the significance of the subject matter. In our prototype it addresses whether the teacher views SD as (1) one of many tools/techniques for simulating and forecasting, the SD model is just a theory about a system, a simulation language, (2) one of a few paradigms that explains socioeconomic reality, the best tool for medium to long range planning, or (3) the single most important paradigm for explaining and understanding how the world operates.

The information related to an SD concept that an expert feels is significant is based on his/her view of SD. Evaluation of the transcripts from expert interviews and the Delphi results from Trimble (1992) led to the identification of a list of information to be used to convey each concept. This information is used to construct the various scenarios. Table 1 summarizes, by teacher model philosophy, the key information used to construct the set of scenarios that convey the components of problem definition and model conceptualization.

Table 1: Summary of features for 'components of conceptualization' scenario

PHILOSOPHY	COMPONENTS OF CONCEPTUALIZATION
SD is the main paradigm for explaining how the world functions	-talking with clients about the problem without using feedback and closed system terminology. -first identify the objectives and clarify the problem -the analyst identifies time histories of related variables, and then identify feedback related causes. -presents the truth & discrepancies to the client, clarifies client objectives, historical conditions and client attitude toward conditions.
SD is the most powerful tool for medium to long range planning	-start with time histories and develop verbal scenarios which explain the relationships in the time histories. -draw the model out on paper -identify variable you have data for those you do not have data for (not collected or uncollectable) -determine how to deal with missing information. -formalize causal loop by starting with very broad relationships, key levels , then key rates, then add auxiliaries.
SD is one of many tools, A SD model is just a theory about a system.	-identify system or aspect of the system to be studied by using interviews, interactive modeling and detailed questionnaires -develop the final conceptualization model using causal diagrams.

The student and teacher model knowledge bases determines how to construct the instructional scenario which consist of a series of screens responsible for conveying a key concept. The student and teaching model are also the basis for constructing the tests of the concepts conveyed.

Table 2: Summary of features for 'components of knowledge acquisition' scenarios

PHILOSOPHY	COMPONENTS OF KNOWLEDGE ACQUISITION APPROACHES
SD is the main paradigm for explaining how the world functions	-talking with clients without using feedback and closed system terminology, in an unstructured interview. -Observations of the system or situation and its participants. Tour facilities, sit in on meetings, and record if feasible. -Check time histories against each other and responses from system participants interviewed.
SD is the most powerful tool for medium to long range planning	-Unstructured and semi structured interviews -Academic perspective: read about the problem, what does the literature say about the problem -Talk to system participants to get information and for the good of the group.
SD is one of many tools, A SD model is just a theory about a system.	-Interviews -Interactive modeling -Detailed questionnaires

Table 3: Summary of features for 'components of knowledge representation' scenarios

PHILOSOPHY	COMPONENTS OF SELECT KNOWLEDGE REPRESENTATION
SD is the main paradigm for explaining how the world functions	-Most important knowledge structure is the choice of verbal expression used in communication with client and other system participants. -Time histories are identified and presented to clients. -The use of knowledge representation structures and tools vary with the background of the clients. -The central focus is to capture how people feel and how control is exercised.
SD is the most powerful tool for medium to long range planning	-In problem formulation, time histories are most useful. Time histories are linked to flow diagrams. -Only after generating and/or simulating time histories are they linked to causal loops, as a way of explaining the model.
SD is one of many tools, A SD model is just a theory about a system.	-The main forms of knowledge representation are causal diagrams and structure diagrams -Initially difficult to go from causal diagrams to structured diagrams. Once this is mastered one can easily go from causal diagrams to equations. -Causal diagrams may be divided into sectors.

Tables 2 and 3 indicate various components of scenarios conveying knowledge acquisition approaches and knowledge representation structures as they correspond to the different philosophies. These components are expanded as determined necessary by the student and teacher models. The selection of which components to include in a given scenario is also determined by the state of the student and teacher models.

After an instructional scenario is completed, the student is tested. The student's responses to the test are used to update the student model. Incorrect responses as well as correct responses to the concept test provide information about the student's skill level. Also these responses can provide insights on certain student philosophical characteristics such as preferred learning style and level of concentration. This revised student model in conjunction with the teacher model are used to construct the next instructional scenario. If errors were made on the previous concept test, the new instructional scenario is used to convey the same concept. If the student successfully completed the concept test, the instructional scenario corresponds to a new concept.

The student's responses to concept tests does not alter the teacher model. The teacher model is established by responding to questions at the beginning of the session. The teaching approach can be altered during the instructional session by invoking the module which establishes the three layers of the teacher model. While this is not the usual mode of operation it is an available option.

There are two techniques for generating a variety of instructional scenarios for the same concept. Scenarios can be constructed from a library of preformatted paragraphs and clips. The variety in scenarios is directly dependent on the size of the library. The second technique employs natural language generation to construct a scenario when needed based on the user's natural language input and the current state of the teacher and student models. This prototype system uses the first technique.

CONCLUSIONS

Results of this research to date indicate that the knowledge elicitation process in SD studies centers on the interview, with data gathering, identifying time histories and direct observation close behind. However, the degree of complexity and sophistication employed in interviews varies as do the processes used to complement the interviews. Those more versed on elicitation techniques tend to use more complex interviews and various group processes and techniques.

There was a strong indication that analysts adjust their approach based on problem domain, decision making constraints, and analysts' preferences. Experts most committed to SD as the most significant paradigm view knowledge acquisition in SD as a complex feedback control process. This process involves eliciting information from people, gathering information from data bases (which may be fed by people), getting information from direct observation, and generating information from inferred logic or theory. This control process is conducted until there is satisfaction with the results or there is a realization that the additional information attainable is insignificant.

SD experts indicated it was very important to use and develop knowledge representation structures relevant to system participants and based on the problem domain. This supports the conclusion that there is a need for a more comprehensive set of options for generating knowledge structures in the instructional expert system (IES).

The extensive nature of this project was underestimated. To thoroughly cover the domain, using a range of teacher and student models requires enumerating an

extremely large number of teaching scenarios. To address this problem other approaches to elaborating scenarios will be investigated.

Level 5 had limitations as a tool to develop an IES. A tool or development language for a more comprehensive IES should be geared more toward intelligent computer aided instruction (ICAI). It should provide more flexibility in knowledge representation, better output and display capabilities, and an easier interface to other software.

An increasing number of computerized learning environments utilize multimedia, distance learning, and computerized group communication. These three techniques must be incorporated in future ICAI to maximize the benefits to users.

This research is useful to SD practitioners, instructors, and students. Since the teacher model and instructional scenarios are based on the practice of experienced SD analysts, a more completely developed IES can serve as a benchmark and source for new techniques for practitioners and instructors. The IES will be a useful enhancement to existing curriculum in SD.

The process of having experts review, refine, and validate this instructional expert system will be a crucial aspect of the continuation of the knowledge acquisition process. It will also serve as a basis for the refinement of this instructional expert system. An initial test version of the prototype will be available the summer of 1993.

FUTURE DEVELOPMENTS

The prototype will be extended by expanding the computerized learning resources and expanding the teacher and student knowledge bases. The fully developed prototype instructional expert system will include a range of topics. It will be designed to cover the elementary concepts in SD as well as details of several knowledge representation structures, and knowledge acquisition approaches and techniques. It will allow graphics, video, and audio in addition to text in the scenarios.

The teacher model will be extended based on additional interviews and surveys of SD practitioners and teachers. As the prototype is extended student users will help determine the most effective student diagnosis and discourse management. This information will be used to revise the student model and the user interface.

The cost effectiveness of different multimedia, distance learning, and computerized group software and hardware will be investigated. This effort will look at both the short and long term potential impact these technologies can have on instructional tools for SD.

The instructional domain will be expanded. Additional concepts will be added to more thoroughly cover the problem definition and model conceptualization phases of SD. Concepts that are dependent on the SD study domain will be examined and possibly added to the IES. The additional educational levels mentioned in the generic IES will be added. Test generation will be expanded to complement developments in student diagnosis and discourse management.

Further research in educational philosophy coupled with interviews and group sessions with SD practitioners and students will be the basis of enhancing the philosophical perspective layer of both the student and teacher models.

A more comprehensive version of the prototype IES is scheduled for completion by first quarter 1994. The degree to which the future developments listed above are included in the 1Q94 release will be based on the funding support received.

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