QUESTION MODEL FOR INTELLIGENT QUESTIONING SYSTEMS IN ENGINEERING EDUCATION

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Abstract *¾ This paper describes the development of a question model to be used with an intelligent questioning system. The purpose of the intelligent questioning system is to improve the educational process in engineering courses by allowing students to learn more in less time, to understand more deeply, and to enjoy their learning experience. Key elements of this system are a question model and an adaptive question management system that uses a hierarchical knowledge map to direct the learning process based on the student's degree of understanding of individual or grouped concepts. Although there are several online computer-based questioning systems, they typically have no built-in help, no guidance if questions are answered incorrectly, no method for selecting questions based on the students needs, and no comprehensive monitoring of a student's progress through a knowledge map not only of the course but also of the curriculum.*

Index Terms ¾ Intelligent Questioning System, Question Model, Knowledge Map

INTRODUCTION

Over the past several years, considerable effort has been devoted to research in the area of technology-enhanced education. Progress has been made, addressing a variety of educational needs, ranging from supplements to existing "traditional" courses, to complete on-line courses, to complete on-line programs. Despite all this effort, hype, and even product development, most of the courseware material available for use at the college level is still not judged to be as effective as a professor lecturing and leading discussions with students. Most of the work is driven more by convenience factors in continuing education due to the increasingly mobile student population ("anytime, anyplace, anywhere," education), perceived economies of scale (some educational administrators envision that a few "super star" faculty could each teach thousands of students), and to a certain extent just because the technology is available. Nevertheless, faculty working on a daily basis with students continue to pursue the dream of using technology to improve the educational process, allowing students to learn more in less time, to understand more deeply, and to enjoy their learning experience more.

The present state of affairs in cyber education leads us to the conclusion that focused, long-term research is needed to move forward. The particular focus of our research is to develop a methodology for an intelligent computer-based questioning system to be used in engineering programs. One of the unique aspects of the engineering field is the need for questions of many types---basic information, analytical problem solving, design techniques, and finally open-ended design problems. These different types of problems will be addressed in our methodology.

The primary goal of this paper is to present the question model that will be a core component in the overall questioning system. Key aspects of the question model include an intelligent questioning engine, a question/answer interface tool, an answer interpreter, feedback to the user, and connections to a knowledge data base to monitor student progress. Note that the overall questioning system is under development and has not yet been fully built and tested. This paper describes the theory and basic format of the question model which is under continued development as this paper is written.

The question model is a formal representation of the question database to be used for a specific program of study. Each question is characterized by type (true false, multiple-choice, numerical answer, open ended), classification in terms of correspondence to the knowledge map, types of numerical input variables needed, difficulty level, and scope. In addition each question has links to various types of help ranging from basic hints to partial solutions to complete solutions. The question model is also developed to allow convenient integration with mathematical software tools such as MathCAD. The "side" information included in the database for each question is used by the adaptive questioning system, together with student input and current state of knowledge, to determine which question should next be posed to the student. After each question is answered, either incorrectly, partially correctly, or correctly, the question management system then updates the student's progress through a knowledge map, again taking in account the question characteristics.

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BACKGROUND

This paper is a companion paper to another paper by Leathrum et al. [1] (June 2001 ASEE conference). Whereas the paper by Leathrum et al. focuses on the knowledge map component of the intelligent questioning system, the current paper focuses on the question model. However, the background and introductions to both papers are essentially the same.

The potential for computer-based questioning systems has been recognized and commercial products are already available (see, for example, WebAssign [2] and WebCT [3]). Such systems are well developed for courses with large audiences such as freshman physics classes. Primary benefits include immediate feedback given on every question attempted, the options to easily vary parameter values for each question, and automated record-keeping options. Typically higher-achieving students prefer these systems for homework questions to more conventional methods. However, most current systems are little more than a computerized version of homework problems found in a typical textbook. The only feedback given to the student is "correct" or "incorrect" for each question answered. There is no built-in help, no guidance if questions are answered incorrectly, no individual student-centered method for selecting questions based on a students needs and background, no accompanying simulations to illustrate key concepts, and no comprehensive monitoring of a student's progress through a concept map of the material. The intelligent questioning system under development will address these deficiencies by adding to the "intelligence" underlying automated questioning systems. The goal is to determine how to build a questioning system, which will appeal to and benefit a wide range of learners with a large range of capabilities.

A very good intelligent on-line physics homework system is Andes [4]. This work-in-progress is being developed by personnel of the Physics Department of the United States Naval Academy and of Computer Science from the University of Pittsburgh. In the Andes system, the students can solve the problems directly in the web browser. The solution steps consist of defining the variables, drawing free body diagrams, writing and solving the equations. If the instructor allows it, Andes will inform the students of problems with a free body diagram and equations, and even solve the set of equations. Andes can find the mistakes because its knowledge base consists of a set of rules to solve the physics problems. Andes is smart enough to determine multiple solution paths, if they exist. One of Andes' strengths is the tutor system. Depending on the instructor's options and the student's past experience the tutor can explain the mistakes and can assist with the solution. Andes' also has a very good student assessor system. By observing the students use of rules, the assessor forms a modified Bayesian net, computes probabilities of the student's knowledge, proper use of rules, and expected solution [5]. This information is used by the assessor to tell the tutor system how to help the student. Two intelligent tutor systems for electrical circuits were reported by Ahmed and Bayoumi [6] and Yoshikawa, et al. [7]. These tutors do not develop a student model and only provide limited feedback to the students.

INTELLIGENT QUESTIONING SYSTEM OVERVIEW

The Intelligent Questioning System is comprised of three basic components: the User, the Knowledge System and the Question System as shown in Figure 1. Figure 2 gives an overview of the overall architecture for the system. An appropriate user model drives the system. The Knowledge System presents the user with his or her current status in the system by use of a graphical map. This gives the user a set of options of concept areas that he or she may work on. The selection of a concept area defines a knowledge key that is presented to the Questioning System. The Questioning System then identifies an appropriate set of questions within the concept area based on the student's past history. A question is then randomly selected and presented to the user with random parameters. After answering the question, the user is provided immediate feedback. Should the Questioning System identify that the user needs some help, it initiates this process. Help may come in several forms:

- links to material for review,
- suggestions, and
- breaking down the problem into smaller steps.

When the user completes or chooses to leave the concept area, the Questioning System provides an assessment measure to the Knowledge System. The Knowledge System then updates the user's status in the system, potentially identifying a new set of concepts that the user may work on.

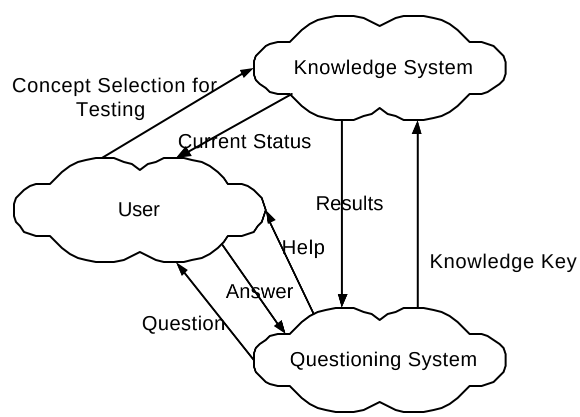

FIGURE 1

INTELLIGENT QUESTIONING SYSTEM CONCEPT

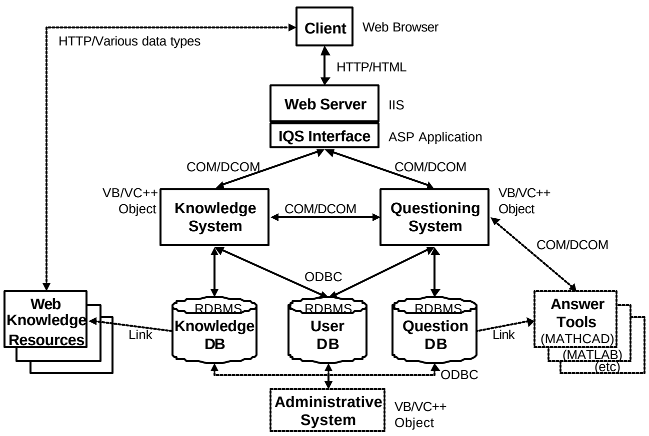

FIGURE 2
. INTELLIGENT QUESTIONING SYSTEM ARCHITECTURE OVERVIEW.

To implement this system, several databases are required as illustrated in Figure 2. The question database contains the complete set of questions. The student system database encapsulates a model of the student's progress, maintaining information about which questions (and associated parameters) the student has attempted and the assessment measure for each question. The knowledge system database maintains the structure of knowledge flow in the form of knowledge maps for the whole curriculum. The question system database is the primary topic of this paper. The complete database model is presented in Figure 3.

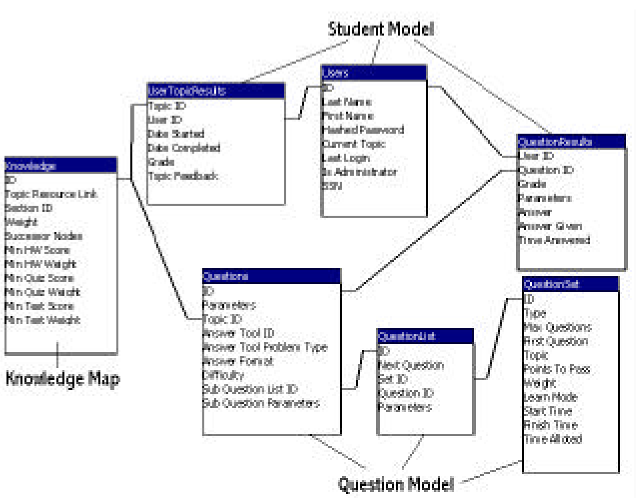

FIGURE 3
DATABASE MODEL

THE QUESTIONING SYSTEM

The question model is a formal representation of the question database that is developed for each module in a course for a program of study. Each question is mainly characterized by type (true/false, multiple-choice, numerical, graphical, open ended), types of numerical input variables needed, weight, as determined by the difficulty level, and a knowledge key that defines the scope of the question and its coverage of the knowledge map. The assessment system uses the weight of the question to provide the incremental score contributed by the answer to this question. The score also takes into consideration other issues such as the number of attempts and the length of time needed to submit the final solution. If an answer is incorrect, the guidance system selects links built into the question that provide various types of help ranging from basic hints to partial solutions to complete solutions. The question model is also developed to allow convenient integration with mathematical software tools such as MathCAD. The "knowledge key" information about each question is used by the adaptive questioning system, together with student input and the current state of knowledge, to determine which question to pose next. After each question is answered, either incorrectly, partially correctly, or correctly, the question management system updates the knowledge map, again taking in account the question characteristics. Figure 4 depicts the questioning system architecture.

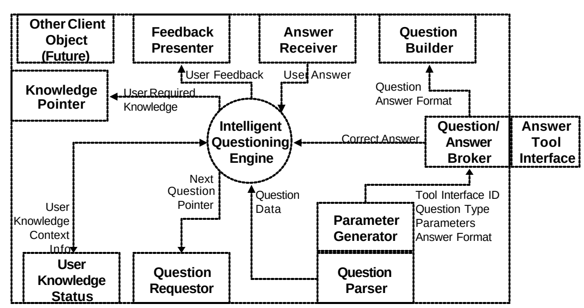

FIGURE 4
QUESTIONING SYSTEM ARCHITECTURE

The goal of the question model is to create a formal set of guidelines for the construction of questions and solutions to meet topic and difficulty requirements. Questions must also be well integrated with lectures to enhance student learning. The questions not only consist of text and figures, but technology to make them highly interactive and engaging. To insure that questions are "good" engineering questions, the state-of-the-art on engineering problem solving research is made use of. For example, Donald Woods [8] has developed guidelines to create assignments that teach as well as reinforce lecture concepts. Wankat and Oreovicz [9] introduce a problem-solving taxonomy [10] and dedicate a chapter to teach problem solving strategies.

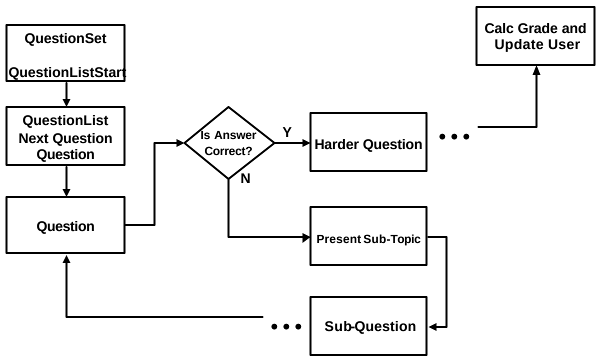

FIGURE 5
FLOW DIAGRAM FOR HOMEWORK/PRACTICE QUESTIONING MODE

The question model insures that a topic of the knowledge map is covered at various difficulty levels, that learner help is provided, and that a measure of learner's level of understanding is provided. The "dimensions" quantified for each question include:

1. Content Area—Graphical specification of which portion or portions of the knowledge map the question "covers".

2. Difficulty level—A five point scale is used to rate each question from 1 (very easy) to 5 (most difficult).

3. Category — Questions fall into three categories to support engineering disciplines:

Informational: questions that simply measure the learner's knowledge of the topic area basics. Questions would be of the multiple choice and true/false format.

Analytical: questions that involve computations. Answers to these questions would vary based on randomly selected parameters.

Design: questions that measure the learner's ability to make design decisions.

4. Scope— A five point scale is used to rank each question from 1 (very narrow focus) to 5 (broad focus). Typically questions with a rating of 1 in scope covers only a single content area in the concept map, whereas questions with a rating of 5 covers several areas in the concept map, which help the students apply their skills in different contexts.

Another part of the question model is a solution map, used to formally specify the solution, to provide intelligent help, and to improve the learner assessment. The solution map consists of an index of concepts needed to solve the problem, specific equations or rules which are needed to solve the problem, and links to simulations, which can be used to help illustrate the solution. A simulation can be a simple set of equations or a complex simulation system developed in numerous tools (Matlab, MathCad, PSpice, and Macromedia) or languages (Java and VRML).

A key aspect of the questioning model is the "intelligence to provide meaningful feedback to the user. That is, the questioning process itself should be interactive and instructional to the student. The system under development at present is based on the flowchart depicted in Figure 5. In this homework/practice mode, if questions are answered correctly, the student is immediately informed of the result, the user data is updated, and the next question is generated. If, however, the answer is incorrect, some tutorial information is presented, and a set of less complex questions is posed to the student, drawn from the sub-topics contained in the original question.

Questions of like content and level of difficulty are grouped into a Question Set. The questioning process involves: randomly selecting a question from the set, completing the question, gathering assessment information, and providing a measure of the *degree of understanding* back to the knowledge model for use in knowledge assessment. Besides selecting and asking a question, the Question Set also provides a mechanism to quantify *degree of understanding*. This is used to assist in assessing the student's level of competence in each topic to determine if he/she requires further work.

Two primary modes of built-in tutoring are anticipated when the learning mode is turned on.

Basic Model. The basic model simply identifies a right/wrong result. If the answer is wrong, the question model also refers the student to specific reference material to be reviewed prior to continuing. Reference material could include online material (organized in a module structure), textbooks, etc.

Advanced Model. The advanced model attempts to more closely identify the problem area for the student. Once a wrong answer is found, the solution map is used to pose a series of intermediate questions leading to the final answer. In this manner, the model can attempt to specifically identify if there is a math problem, conceptual problem, or another potential problem area. The student will then be given reference material to address that specific problem. On completion, the same question can be asked again with new parameters to determine if the problem is overcome. A *degree of understanding* (0 to 100) is then passed back to the knowledge model along with the *focus area of concern* where the problem lies (if the student continually has errors in the same *focus area of concern*, he will be sent back to previous material, along with assessment, to ensure understanding of that subtopic). The integration of the Bayesian net used in the Andes system with the curriculum's concept map will be investigated as the primary means of student assessment.

EXAMPLE

To use the intelligent questioning system (IQS), a student would use a web browser to access the IQS web server. The student would first have to enter a user name and password. Then the student would select a course from a list of courses the student is currently enrolled in as part of his or her overal program of study. The next screen would present a graphical view of the course partitioned into modules. The image would clearly show the degree of understanding that the student has earned for each module. For each module a graphical image of the concepts that form the module is given together with the degree of understanding for each concept. If the student selects nodal analysis and this is the first time the student has attempted a question on this concept, a possible question that is selected by the IQS could be as shown in Figure 6.

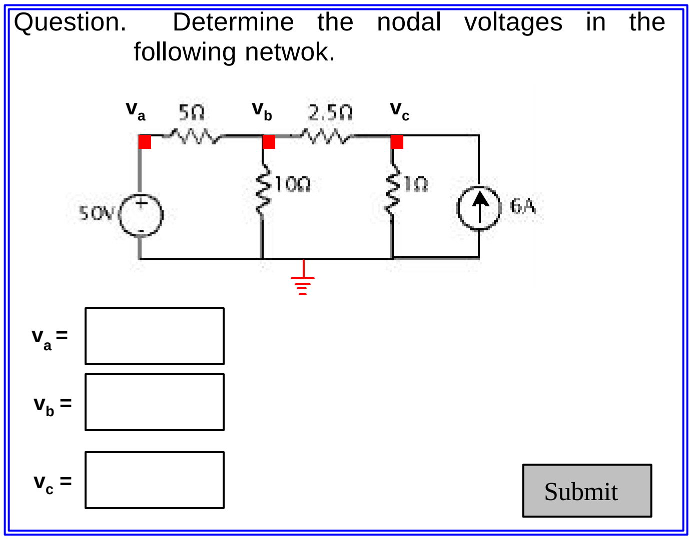

FIGURE. 6
EXAMPLE OF QUESTION POSED BY THE INTELLIGENT QUESTIONING SYSTEM

Some of the "dimensions" maintained in the question database for this question are given in Table I.

TABLE I
DIMENSIONS ASSOCIATED WITH THE QUESTION IN FIGURE 5

Dimension	Value	Explanation
Content Area	201.3.01	A key that points to the introduction to nodal voltages concept. This is the first concept in module 3 of the 201 course.
Difficulty level	1	Very easy
Category	2	Analytical
Scope	1	Very narrow focus

For each question, the question database contains the text of the question, the dimensions from Table I, a link to a plain network as seen in Figure 7, a listing of objects and parameters that need to be defined, their relative positions, the passing score, a question weight, a SPICE script or a set of mathematical expressions of the plain network, and a list of steps that form the solution. The plain network in Figure 7 facilitates its reuse in other questions. Not only can the values of all the parameters be chosen by the IQS, but also the source type and the polarity or current direction. Since this is one of the first questions in nodal analysis, an academic set of parameters for the sources and resistors was chosen that lead to integer values for all the nodal voltages. The Question Builder block in Figure 4 creates and assembles the html code for the question together with the necessary images. This information is then passed to the web server using an ASP script as shown in Figure 2. The Question Broker block computes the answers with the assistance of an external application such as PSpice, MathCAD or Matlab. If the answers are correct within a specified tolerance, the student record is updated and the option for another harder question is given as shown in Figure 5. If the answer is incorrect and the basic tutoring mode is on, the student is only told which answers are incorrect and is given a list of links to get more help. If the answer is incorrect and the advanced tutoring mode is on, a possible sequence of steps is given. In this problem, there are two main steps in the solution:

1. Solve for $\mathbf{v_a}$
2. Solve for $\mathbf{v_b}$ and $\mathbf{v_c}$

The student must first solve for $\mathbf{v_a}$. To help the student, links to very specific reference material are given. Once $\mathbf{v_a}$ is correctly solved the student is given the chance to type the answers for $\mathbf{v_b}$ and $\mathbf{v_c}$. If the answers are incorrect, a new sequence of possible steps is presented:

3. Write the KCL equation at node **b**.
   - 3.1. Define reference directions for the currents through the 5Ω, 2.5Ω, and 10Ω resistors.
   - 3.2. Write and simplify the KCL equation at node b.

A similar sequence of steps is given to write the KCL equation at node **c**. Finally, the student is asked to write the set of two equations in two unknowns in matrix form and to solve them using Cramer's rule. At each step the student's intermediate answers are checked and links to specific reference material are given if the answer is incorrect. This detailed tutoring has been made possible by decomposing the solution into smaller steps for which an automated tutoring wizard has already been developed. With careful planning it should be possible to reuse portions of the wizards to develop new for more complex operations.

Once the student has correctly answered the question, the assesment of the degree of understanding of the concept as well as a measure of the areas of concern is formed and the student database is updated. The student would then be given the choice to try the same problem with different parameters or another similar problem before trying a more difficult one.

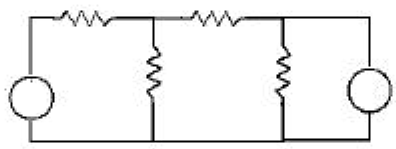

FIGURE. 7
SCHEMATIC OF NETWORK TEMPLATE USED IN FIGURE 6.

FUTURE WORK

As of the time of this writing (May 2001), work is ongoing to complete devlopment of the vaious databases mentioned in this paper, and to create the needed script codes for the required logic and processing. The goal is to create a system such that questions can be "easily" created and entred by an instructor. Nevertheless, the generation of questions with intelligent help is likely to be a big concern in terms of the amount of effort needed for question/help authoring. The objective is to build a protype system, and then to to evaluate it with students and faculty, as applied to fundamental concepts in circuit theory.

CONCLUSIONS

A critical component in computer based education and training systems are good questioning and assessment tools. Computer-based systems which rely on instructors for all grading and assessment cannot be scaled to accommodate large numbers of students. Computer-based systems which give only non-interactive assessment measures are not satisfying to the student nor likely to promote effective learning. This paper presents an overview of the architecture and data structures necessary to create an interactive questioning system with considerable feedback to the user. This questioning system is closely linked with a knowledge system which monitors student learning and progress.

The goal of this work is to support a web-based Computer Engineering curriculum, both domestic and international, as well as to improve the learning process for on-campus students. The system will give immediate feedback and assistance to the student, an improvement over the delays required with classical assessment measures such as homework. Thus, while this questioning system is still a work in progress (see also [11],[12]), it is believed that the success of this project will provide an improved learning environment and the capability to support distance learning.

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