160 CONCEPT-BASED TUTORING SYSTEM FOR ON-LINE PROBLEM CENTERED LEARNING

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ABSTRACT

Among different theories of learning, the importance of repeated retrieval advocated by Karpicke and Roediger is appealing for teaching and learning in core engineering subjects. Recent research proposes a model for the time-spacing needed when doing repeated retrievals. These ideas are relevant for on-line systems that are being developed and marketed for tutoring, testing and homework in core science, math and engineering subjects. We have been developing a web-based Intelligent Tutoring System (ITS) for an introductory signal processing (SP) course built around the concepts needed in this Electrical and Computer Engineering foundation course. ITS features two databases: one holding all the questions tagged by concepts, the second containing measurements of student interactions. The student interface is minimalist with a question mode and a review mode. The instructor interface has tools for monitoring the total scores of an entire class and reviewing the answers of individual students on each question. The designer interface provides a capability for creating and editing questions, as well as making assignments by grouping sets of related questions. Two modes are available: a self-guided self-paced practice mode where all questions are presented by concept name, and a scoring mode where question sets are presented usually with a deadline due date. ITS has been used for four semesters in the second-year undergraduate SP course at Georgia Tech – more than 100,000 questions have been answered by over 400 students. Student feedback has been generally positive because we have typically created assignments that amount to quiz-review by offering the multiple retrieval approach when studying.

Keywords: Concept Based Learning, Tutoring Systems.

1 INTRODUCTION

In [1], tutoring is described as a sequence of learning opportunities where students encounter episodes with the goal of increasing their understanding of a specific concept, also referred to as a "principle". Naturally, a full mastery of a concept requires many learning opportunities whereby the underlying structure of a concept can be appropriately understood. The benefits of sustained practice, emblazoned by the "Power Law of Practice" curves, [2] demonstrate the relationship between repeated trials and reaction time, namely stating that with linearly increasing trials, the task related reaction times decrease somewhat exponentially. Studies on memory formation and recall [3] [4] have led to similar observations about retention, captured by the "forgetting curve", empirically establishing that acquired knowledge degrades and exponentially fades with time, often as memory cues become inaccessible. Hence, with greater experience learning becomes easier on related tasks, often summarized by the proverbial education motto – "practice makes perfect", however knowledge needs to be revisited to cement educational gains.

Perfection aside, educators have a stake in student progress on all given concepts, via assignments, the final exam, or other exercises that demand the student to recall and correctly apply the newly acquired knowledge. Progress is often measured by the degree with which a student is able to apply the knowledge to unseen, but related, problems or to work a problem backwards (reverse engineering), or to arrive at a solution with different underlying assumptions. These demonstrations of knowledge transfer serve to illicit an impasse in learners which occurs when a student realizes to possess incomplete understanding of a specific piece of knowledge and hence is motivated to take an active role in constructing a better conceptual understanding.

Different concepts will demand formulating different structures; hence multiple learning opportunities that encourage the formation of useful associations of reinforcing concepts ought to ultimately lead to deeper learning. Although the "read more – know more" dictum is well entrenched in today's engineering curriculum, recent research [5] [6] on repeated testing suggests a more effective learning style with the retrieval practice strategy preferred over encoding, e.g. studying. "Retrieval practice is a powerful way to promote meaningful learning of complex concepts commonly found in science education." [6] During testing, a student's knowledge is impromptu assessed and prompted for recall, and conceptually relevant information must be selected and retrieved. Learners themselves are forced to reason about the problem and in the process reconstruct and consolidate knowledge which itself enhances learning.

In fact, retrieval practice has been found to be more effective in conceptual learning than the act of constructing concept maps as part of a learning activity. Whereas concept map building encourages the learner to increase the number of known concepts and form associations among them, repeated testing has the added benefit of promoting cue building required for retrieval and selection. "In free recall, subjects must establish an organizational retrieval structure and then discriminate and recover individual concepts within that structure. Retrieval practice likely enhances the diagnostic value of retrieval cues, which refers to how well a cue specifies a particular piece of knowledge to the exclusion of other potential candidates." [6] It is this repeated conceptual search and retrieval process which educators hope to foster that will lead to a student's long-term recall and retention of the subject material.

Traditionally, human tutoring has provided extensive educational scaffolding by guiding students through problem solving activity. Tutoring is most effective when tutors help students to stay on a correct path, but allow students to provide their own explanations. Studies of human tutors indicate that guided explanations by tutors themselves may not be as helpful as once thought, but instead "tutorial behaviour that gets students to think, such as generating opportunities for impasses or giving zero-content prompts, may be the key to why tutoring is so effective." [1] These findings are corroborated by the self-explanation effect, which stress the importance of prompting the student for inferring and integrating possible solutions to a given problem, similar to recall retrieval practice.

Testing is a repetitive task best handled by computers; hence supplementing education with computer-based tutors is a way of providing ample learning opportunities for students. Developers of computerized tutors have grappled with the task of "how to choose what is taught, how to present it, and how to sequence the material" [7]. Recent research has begun modelling student education by looking at the latter task, namely the scheduling of learning episodes and the constraints imposed by learning new material and reviewing what has already been studied. This sequencing problem lends itself to what is known as the spacing effect, which stipulates that studying is more effective when spread over time. The benefits of periodic review of the newly learned material through testing lead to re-organization and generalization of the student's knowledge essential for long term concept retention.

Ultimately, a computer driven tutor may also be suited for the task of student assessment, where the educational goal is "to get students familiar with a certain set of educational units by a particular point in time" [7]. Already a few schools have begun exploring the idea of issuing skill-based certificates, such as MIT's merit badges, to on-the-job adult learners seeking to upgrade and expand their skills. We are entering the era of algorithmic education with the promise of inexpensive computer-based tutoring sessions that adapt to each student's needs and abilities in real time. Intelligent tutoring systems are set to revolutionize the way students learn to solve problems and, therefore, carry serious implications for the future nature of formal engineering education.

2 ITS

At Georgia Tech, we have been developing a web-based tutoring system (see Figure 1) called the Intelligent Tutoring System (ITS) [8]. The underlying educational goal of the system is to foster conceptual learning through repetitive questioning keyed to a specific concept(s). ITS has been deployed as part of a second-year signal processing (SP) course in the School of Electrical Engineering whose content is based on the "Signal Processing First" textbook. The course material introduces abstract "signals and systems" concepts supported by mathematical equations and interrelated conceptual dependencies which are often difficult for students to grasp as they cannot be easily visualized. The required development of the conceptual proficiency is representative of and applicable to the broad engineering problem solving skills and hence has served as a direct and effective introduction of computerized tutoring into engineering education.

Systems like ITS must have two interfaces: one for students, another for instructors to support administrative and editorial tools. The design of the student interface is mini-malistic, with just four activities: navigation, question-response, scoring and review.

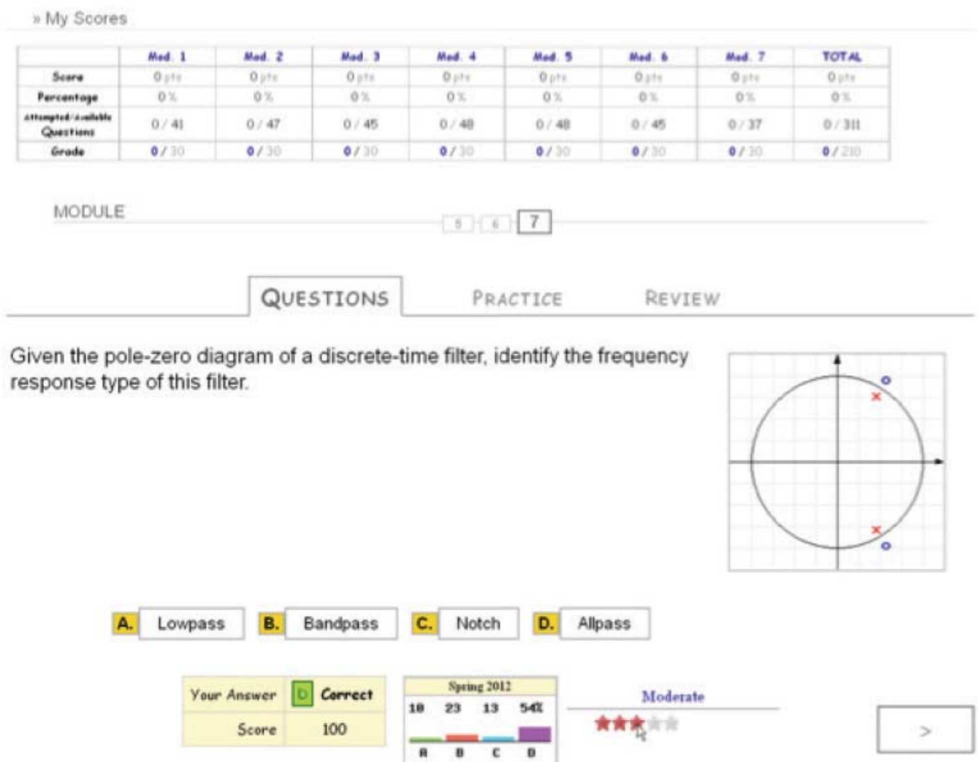

FIGURE 1. *ITS submitted multiple-choice question with My Scores tab.*

2.1 ITS – Student Interface

Navigation: At the top, students can select modules that group questions according to pre-selected tags or other criteria. At the moment, modules organize related questions in correspondence to textbook chapters, concepts, or specific class topics designated by the instructor. Modules provide a convenient way for structuring assignments that can be scheduled to open and close at desired times throughout the duration of a course.

Question-Response: Questions grouped within each module are shown under two different modes: the Practice tab and the Questions tab. In Practice mode students select question sets from a list of concepts for self-guided and self-paced study which might serve as preparation for the scoring mode. By design, each question becomes a learning opportunity targeting one particular concept, although multiple questions can address the same concept, multiple times. In effect, the pedagogical goal of ITS is to present the student with repeated conceptual tests, in order to motivate recall and cue selection required for matching and retrieving the designated concept. Learning through time-delayed repetitive practice is in stark contrast to a "single-shot" style, whereby students learn a concept, get tested, and are expected to remember.

Under the Questions tab, questions are presented in a random order where student answers are graded and must be completed by a deadline for scoring. Figure 1 illustrates the student view in Questions mode. An ITS assignment might contain many questions. For instance, over the past two semesters of the SP course, students were required to answer correctly 24 out of 40+ questions available per module to earn full credit. This strategy does not penalize students for making a few errors because the module typically contains several similar questions and these repeated questions offer later opportunities to be answered correctly. This approach allows students to take charge of their own learning, encouraging them to move on when failing to generate a correct self-explanation, and to retest their understanding unhindered by the potentially negative outcome. Students can learn at their own pace; those requiring many learning opportunities can build-up their knowledge from a larger sequence of questions, whereas quick learners may need to solve only the minimum number of problems in order to demonstrate their proficiency. Currently, there are over 2,000 questions in the database consisting of multiple choice, matching, and computed questions. Multiple choice and matching questions are presented in randomized states, while computed questions are parameterized to a range of variables. Module-specific questions are served at random from a pool of related questions and each question can be taken only once. Since conceptually unfamiliar or difficult questions will elicit an impasse during each problem solving session; ITS permits users to skip questions and return to them once they have constructed a better understanding of that concept.

Scoring: Upon answering a question, students are presented with a score ranging from 0 to 100, with a possibility of earning partial credit. In order to motivate self-explanations by students, ITS does not provide an answer for multiple choice or matching problems, but instead shows a class distribution of the submitted answers for each problem. For computed questions, ITS does provide an answer with an acceptable tolerance in the hopes of motivating students, if needed, to go back and retrace their calculations and arrive at the correct answer. In addition, students have the option of rating each question based on perceived difficulty. The rating is on a 1 – 5 Likert scale and provides a secondary indicator of student understanding of a particular concept. In addition, students can keep track of their progress via the My Scores tab, which tabulates module statistics. For each module – the scores, the number of attempted and available questions, percent completed, along with the projected grade are displayed.

Review: The Review tab allows students to review the already taken questions in each module. Questions are presented in the order answered, preserving the sequence of learning opportunities encountered by the student. With the aid of a slider users can quickly search and navigate across questions to review previously taken questions and also see how others in the class have answered. For the unrated questions, students have the option of rating the difficulty of the problem after revisiting it.

2.2 ITS – Instructor and Designer Tools

The instructor mode in ITS supports content creation, module creation, and allows educators to track student activity. Questions can be authored in ITS with the help of a web-based question editor and later grouped and associated with an assignment or a module. The profile view offers instructors the ability to monitor class participation and progress with a detailed view of each student's online activity.

Profile View: The profile view summarize ITS class activity by listing points earned and the fraction of students who have completed module assignments along with those who have reached full credit. A detailed profile of student activity is available for each student, where the sequence of questions answered is displayed (see Figure 2). In addition to recording student answers, ITS logs question scores, event time-stamps, duration spent answering each question, the configuration of the question, and the question difficulty ratings. The profiler is useful for instructors to keep track of student progress and in helping students reason about their submitted answers.

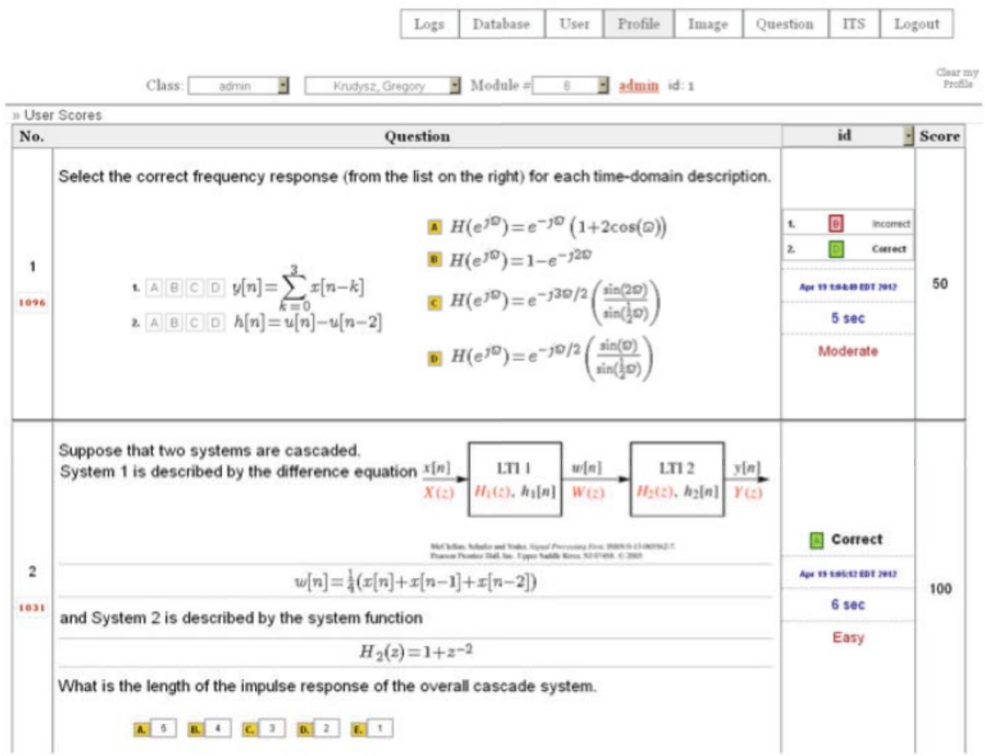

FIGURE 2. *Instructor view of a Student Profile.*

Question Editor: ITS is a question driven environment, hence its impact on learning outcomes is in large part based on the quality and applicability of the questions keyed to the course. The editor enables question authoring tools to create, clone, edit, publish, search, and share questions (see Figure 3). Currently, ITS supports the creation of five question types: multiple-choice, matching, calculated, short answer, and paragraph. Recently, calculated questions have been extended to support a multi-part format, where multiple sub-questions are associated with one question statement. Existing ITS questions can be easily cloned and modified to expedite the question creation process with the addition of revised versions. Question content is edited by either altering question parameters or by selecting the appropriate question fields and modifying the entries with HTML or LaTeX supported text. In addition, images can be uploaded either from the author's computer or from the ITS server-based image repository.

Tags: ITS links modules, concepts, and questions with a set of mutually supporting meta-data descriptors, or tags. The relevant content is labelled with tags to simplify and expedite the searching, selection, and extraction of information from the database. ITS distinguishes between two types of tags: conceptual tags which serve to describe the content, e.g. questions, images, or equations, and system tags which are associated with content organization and structure, e.g., a "chapter01" tag. Questions can be tagged in the question editor with the aid of a search window or by adding new tags to the system. In Figure 3, the z-transform tag is selected from the "z" search results.

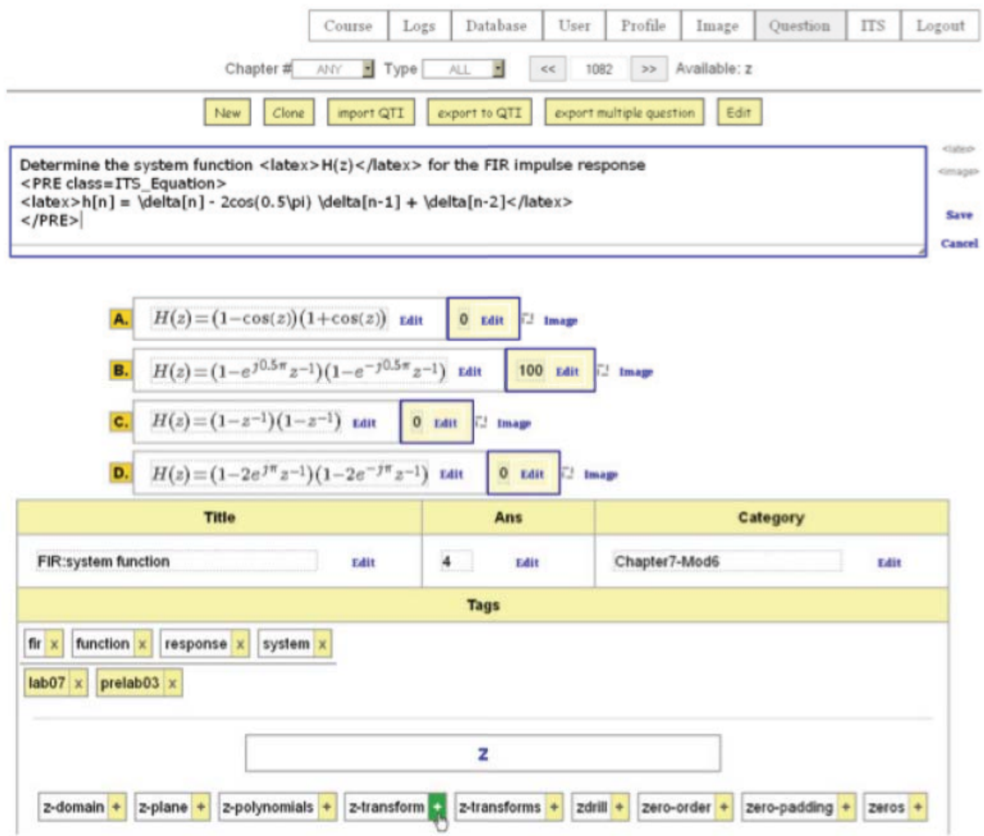

FIGURE 3. *ITS Question Editor: Multiple-choice question with the tag browser.*

Import-Export: ITS questions can be shared across different educational systems via the IMS Question and Test Interoperability specification (QTI). QTI is an XML based standard format for the representation, exchange, and delivery of question content in a neutral format. The ITS question editor supports importing and exporting of QTI questions as well as packaging ITS questions according to pre-selected filter criteria.

3 RESULTS AND DISCUSSION

Student Survey Feedback: Student reaction to ITS has been generally positive as many students use it as a mechanism to test their understanding and welcome the opportunity to practice and further enhance their skills. Asked during exit course survey consisting of 5-point Likert scale questions, to respond to the question "The ITS questions were helpful in my learning" – 81% of respondents agreed ("Strongly Agree","Agree") and 6% had an unfavourable opinion. Student sentiment was conveyed by the following comment – "The majority of the questions on ITS are very good and help with the actual working of problems; concepts are covered in class while the actual working of the problems are supported and solidified in recitation and ITS". When solicited for future improvements, students asked for more examples, hints and detailed solutions.

Data Collection & Usage: Over the past two semesters, over 400 students have collectively recorded over 100,000 question sessions, where approximately 15% of the questions were rated by students for difficulty. Each module consisted of questions grouped along textbook chapters and students were given a window of roughly three weeks to earn the required number of points. On average, students attempted 91% of the available questions, and 82% of the students managed to earn a full-credit. At present, ITS is a testing platform with data collection capabilities. To serve as an effective tutoring system, student responses must be used to adapt in real time using a student model based on statistical data-mining that infers the "learner-state". Currently, we are working to deploy ITS as an open-source project and building a national database of questions, through the Signal Processing Education Network project.

4. ACKNOWLEDGEMENTS

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REFERENCES

[1] K. VanLehn, S. Siler, C. Murray, T. Yamauchi and W. B. Baggett, "Why Do Only Some Events Cause Learning During Human Tutoring?", Cognition and Instruction, Vol. 21, No. 3, pp. 209-249, 2003.
[2] G. D. Logan, "Shapes of Reaction-Time Distributions and Shapes of Learning Curves: A Test of the Instance Theory of Automaticity", Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 18, No. 5, pp. 883-914, 1992.
[3] L. Averell and A. Heathcote, "The form of the forgetting curve and the fate of memories", Journal of Mathematical Psychology, Vol. 55, No. 1, February 2011.
[4] J. T. Wixted and E. B. Ebbesen, "On the form of forgetting", Psychological Science, No. 2 pp. 409-415, 1991.
[5] J. D. Karpicke and H. L. Roediger III, "The critical importance of retrieval for learning", Science, Vol. 319, No. 5865, pp. 966-968, February 2008.
[6] J. D. Karpicke and J. B. Blunt, "Retrieval practice produces more learning than elaborative studying with concept mapping", Science, Vol. 331, No. 6018, pp. 772-775, February 2011.
[7] T. P. Novikoff, J. M. Kleinberg and S. H. Strogatz, "Education of a Model Student", Proc. Natl. Acad. Science, January 2012.
[8] G. A. Krudysz and J. H. McClellan, "Collaborative System for Signal Processing Education," Proc. ICASSP-2011, Prague, CZ, 2011, pp. 2904-2907.