SIGNAL PROCESSING EDUCATION THROUGH CONCEPT DISCOVERY AND RESOURCE SELECTION PRACTICE

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ABSTRACT

In this paper, we describe an on-line learning platform that enables students to develop conceptual knowledge, organize related concepts around supporting resources, and test their conceptual knowledge and its organization through numerous practice problems. We present these ideas in the context of our ongoing web-based educational platform ITS which we have deployed since 2010 for an introductory Signal Processing course at Georgia Tech. Specifically, we discuss the addition of two new features: the "Concept Browser" and the "Resource Selector". These tools provide a user interface that explicitly fosters a concept oriented learning environment.

***Index Terms*—** educational software, concept learning, data-mining

1. INTRODUCTION

Education is gained through successive and often repetitive opportunities that allow students to explore and expand their expertise of a specific knowledge domain. Learners build onto their existing knowledge by *incrementally acquiring* new related concepts to obtain a deeper understanding of the subject matter. To become an expert, one must not only acquire the necessary concepts, but also know when to apply them. Furthermore, experts tend to chunk information into hierarchical concepts for contextual retrieval, which enables them to efficiently retrieve relevant knowledge during problem solving.

Developers of educational software strive to capture the learning process by attempting to make students thinking visible. We are guided by this design principle where educational "software creates a record of thought that learners can use to reflect on their work and teachers can use to assess student progress" [1]. In this paper, we present an interactive educational platform that aims to log student conceptual development during a sequence of problem solving activities. Specifically, we limit the scope of learning to concepts, where students are given the opportunity to explore concepts, explain and extend conceptual organization, and finally evaluate their conceptual comprehension.

Education often involves a trade-off between breadth of knowledge versus the development of in-depth understanding. Knowledge is acquired by learning about concepts and building on them to form a collection of concepts linked by context and association. Students initially gain a superficial understanding of a topic often denoted by disparate concepts which are of limited value due to lack of proper organization and structure. "Novices not only have more sparse knowledge organizations compared to experts, but the basis for their organizational structures also tends to be superficial. This affects their ability to remember, and use what they learn effectively" [2]. In fact, problem solving is rooted in building a descriptive internal representation of the corresponding knowledge domain, since its success is dependent on properly characterizing and classifying the problem into a known structure or pattern.

In order for students to gain a deeper understanding of any subject matter, they need to develop organizing skills that enable them to chunk knowledge into hierarchies. Given that problem solving "occurs in short term memory, which is limited to four or nine chunks of information at a time" [3], this grouping or clustering of concepts allows for knowledge to be hierarchically stored in memory. "Experts tend to automatically process information in coherent chunks based on their prior knowledge and then use these chunks to build larger, more interconnected knowledge structures" [2]. Furthermore, chunking enables learners to access and retrieve known structures which are linked to existing knowledge with cues. This is akin to performing a tree-based search instead of an exhaustive search during problem solving activity.

In addition to conceptual exploration and organization through chunking, the amount of practice (and repetition) contributes greatly to a learner's conceptual development. "Knowledge representations are built up through many opportunities for observing similarities and differences across diverse events" [1]. During problem solving, learners test their conceptual understanding by recalling the necessary

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cues which are relevant in the context of the problem to be selectively retrieved. This process of repetitive selection, revision, and successive pattern matching builds the foundation for the generalization of knowledge. In turn, it also allows learners to chunk knowledge, build cues, and expand their existing conceptual comprehension by imposing new patterns on organization. In essence learning becomes a process of conceptual reorganization that leads to abstraction.

Mastery of a subject is predicated on how well what has been learned transfers to new problems where concepts must be efficiently retrieved and applied in a variety of novel contexts. In this paper, we present a system that enables learners to build "conditionalized" knowledge through their own extensive practice of selecting, associating, and revising concept-based resources during concept-centered problem solving activities. Conceptual comprehension is assessed through tests of "conditions" of applicability whereby learners are required to not only provide the correct answer but also to correctly identify supporting concepts through judicious association of resources.

2. ITS EDUCATIONAL PLATFORM

At Georgia Tech, we have been developing a web-based question-response system called ITS [4] [5], which we have deployed as part of the homework component in the introductory DSP course. Over the past four semesters, more than 1700 students have used the system for problem solving activities on thousands of questions. ITS consists of a database of DSP related questions along with a variety of supporting resources. The system supports multiple-choice, matching, and calculated questions which can include images and LaTeX-generated math. The questions can be created and edited within ITS, and also exported to and imported from other systems.

ITS operates in two basic modes. The "Concept" mode allows students to browse concepts, search for and assign concept-based resources, and answer concept-centered practice questions. The "Assignment" mode consists of an online set of graded homework problems which are grouped by textbook chapters and released to students based on a schedule. Recently, we have added two new features, a "Concept Browser" and a "Resource Selector" in order to implement additional data-mining capabilities for the following 3-stage concept learning process: (1) concept discovery, (2) conceptual organization, and (3) concept applicability and feedback.

2.1. Conceptual Knowledge Domain

Students build knowledge by learning about concepts which are associated with a topic of interest. In Fig. 1, the "Concept Browser" is shown which depicts all the concepts associated with the "Introduction to DSP" course. These concepts are presented as an alphabetical list which has been constructed from the index of the course textbook [6]. There are over 500 concepts; each corresponding to salient topics covered in each chapter. As students progress through the course, the list of concepts grows with the addition of subsequent textbook chapters. In addition, each concept can be associated with a number of textbook resources which enables students to search for a conceptual representation in the form of corresponding images, equations, textbook paragraphs, or examples. In Fig. 1, a "sampling" concept is selected enabling the user to search for related resources by clicking on the "Text", "Equation", "Image", or "Example" button via the "Resource Selector".

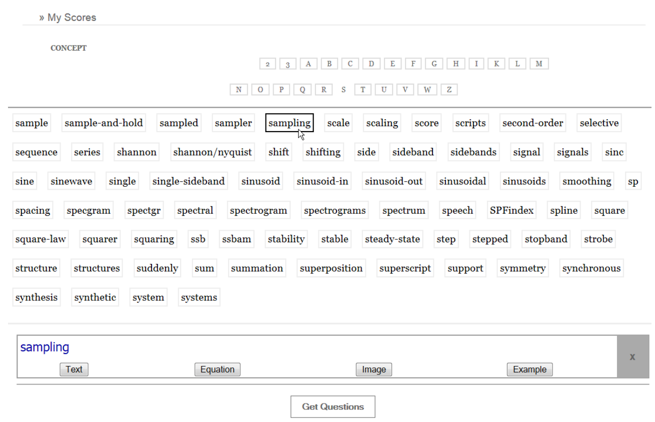

Fig. 1. ITS "Concept Browser" under letter "S"

2.2. Conceptual Organization and Resource Assignment

The first step in solving a problem is to understand what the problem is about. "The problem we solve is our mental internal representation of the situation. The creation of the internal representation seems to be a most challenging task" [3]. During a problem solving activity, experts rely on correctly characterizing the problem by examining its structure with the intent of possibly matching it onto the previously seen structures. Furthermore, experts are guided by inquiry procedures, which enable them to seek out patterns that can be revised and adapted to the existing problem at hand. "The ability to think and solve problems requires well-organized knowledge that is accessible in appropriate contexts" [1].

In ITS, the concept-based "Resource Selector" feature allows students to select and save a number of salient resources to be associated with a given concept. ITS attempts to scaffold a student's conceptual development by enabling users to first explicitly link concepts with the content of the textbook. In fact, by doing so, students begin to create an internal representation of the concept by building links and "cues" to the subject domain. This initial assignment activity may lead to superficial linking, however, it allows students to explore and expand their understanding of a specific concept. The objective is for users to first explore possible conceptual features,

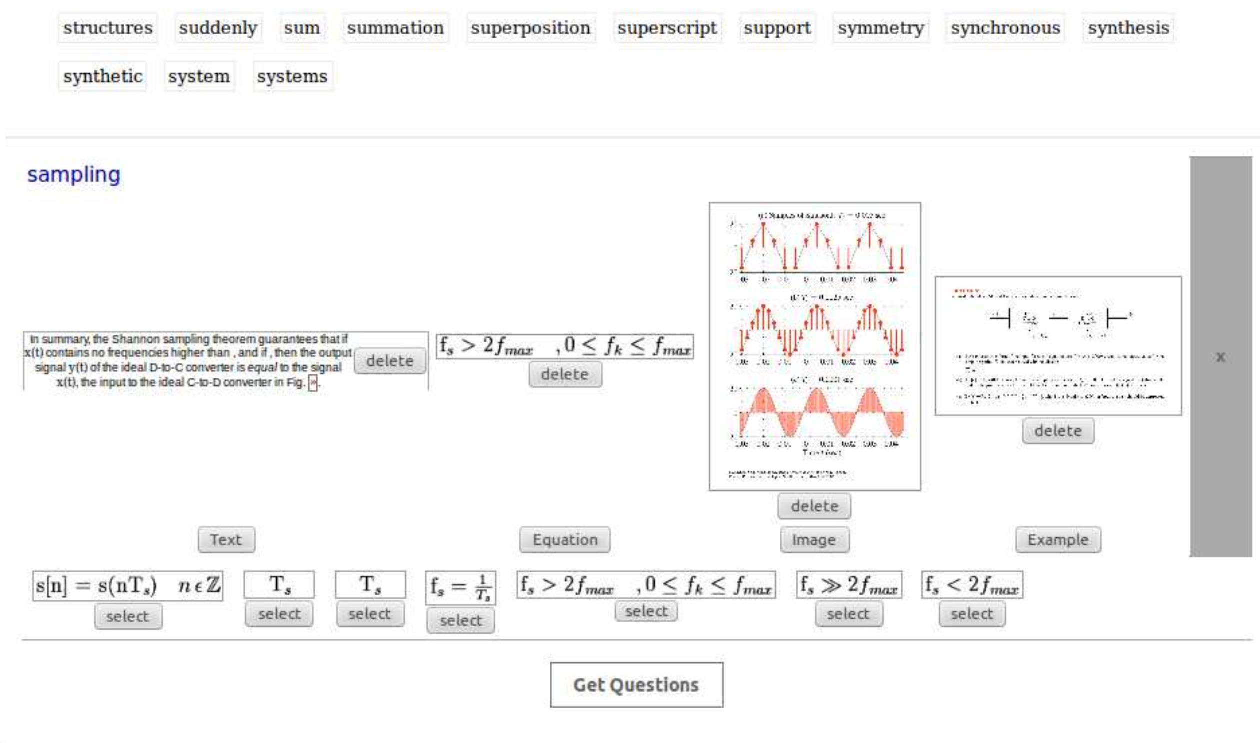

Fig. 2. ITS ”Resource Selector” with conceptual search results

and then to structure their conceptual thinking through a number of accessible resources. Currently, the ITS database consists of 450+ book passages, 300+ equations, 400+ images, and over 1,500 worked out problems.

In Fig. 2, the “Resource Selector” is shown for the concept “sampling”. This example depicts one possible resource assignment where a textbook passage labelled “Shannon Sampling Theorem” is cited, along with a corresponding equation, an image, and a previously worked problem example. A list of search results of possible “Equation” resources for the concept ”sampling” is shown at the bottom. Upon selecting the desired concepts for self-study and optionally associating resources with them, the “Get Questions” button directs users to a bank of questions targeting those concepts. In fact, the intent of the “Resource Selector” is to create and maintain a digital crib-sheet that students themselves create as a reference, and later revise based on problem context and applicability.

2.3. Concept Application and Knowledge Revision

Learning is an iterative process whereby through practice knowledge is rehearsed through selection and revision. Through concept application, learners partake in an inquiry cycle prompting students to obtain feedback, reflect on their answers, and revise their understanding and application of concepts. In effect they make a judgement of plausibility.

In the “Concept” mode, ITS presents a set of questions keyed to a specific concept. This allows students to practice solving problems with a known conceptual foundation. There are over 800 available questions which have been tagged with one or multiple concepts. Fig. 3 shows a problem associated with the “sampling” concept. In addition, the “Resource Selector” is shown below, which references the resources which might be applicable to the problem. Initially, ITS presents concept-specific resources that have been previously referenced by the user. ITS prompts students to search for more applicable resources and revise their prior resource selections in the context of each new problem.

In the “Assignment” mode, shown in Fig. 4, ITS enables students to reference the “Resource Selector” as an aide during problem solving activity for problems corresponding to concept-centered questions. In this mode, the concepts associated with the resources are not stated explicitly, but must be recalled. Furthermore, students have the option of revising their resource assignment in the context of the problem.

3. FUTURE WORK AND CONCLUSION

By data-mining student activity the system could develop adaptive assistance for learners during the concept discovery process. We hope to build from the collected data a student model along with an expert model to infer student activities and guide problem solving sessions through concepts along chapter hierarchies. In addition, we aim to provide students

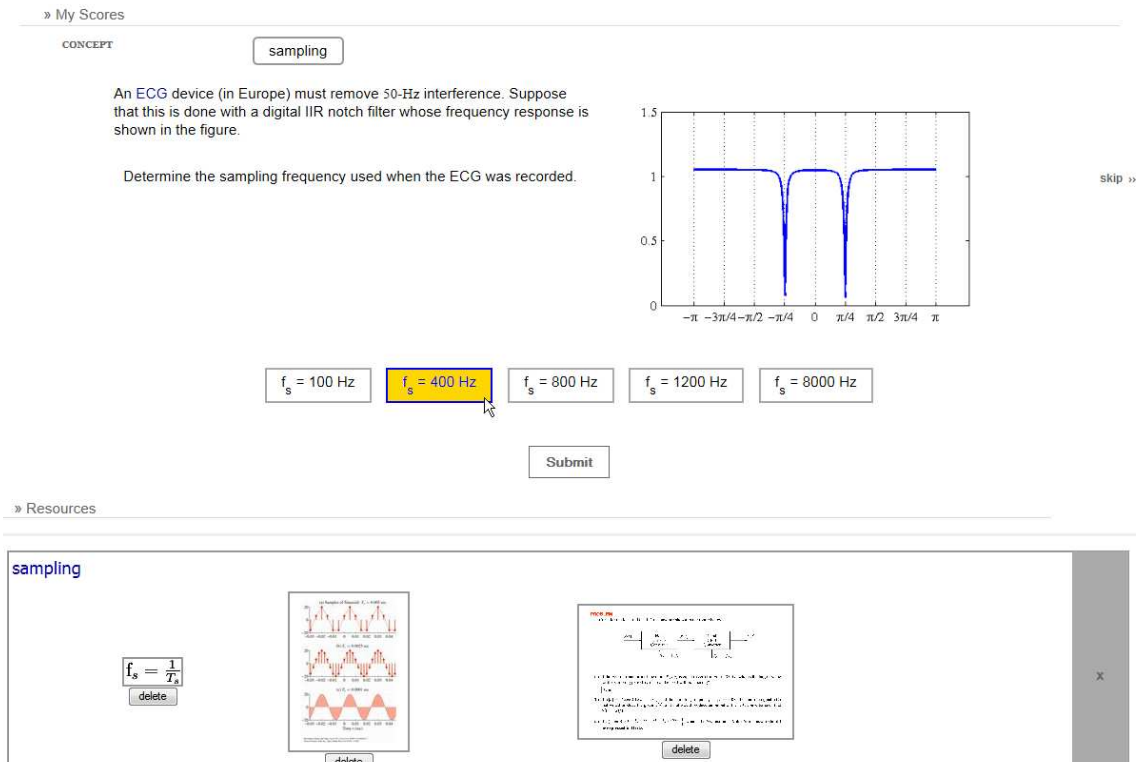

Fig. 3. ITS Problem Solving in the "Concept" mode

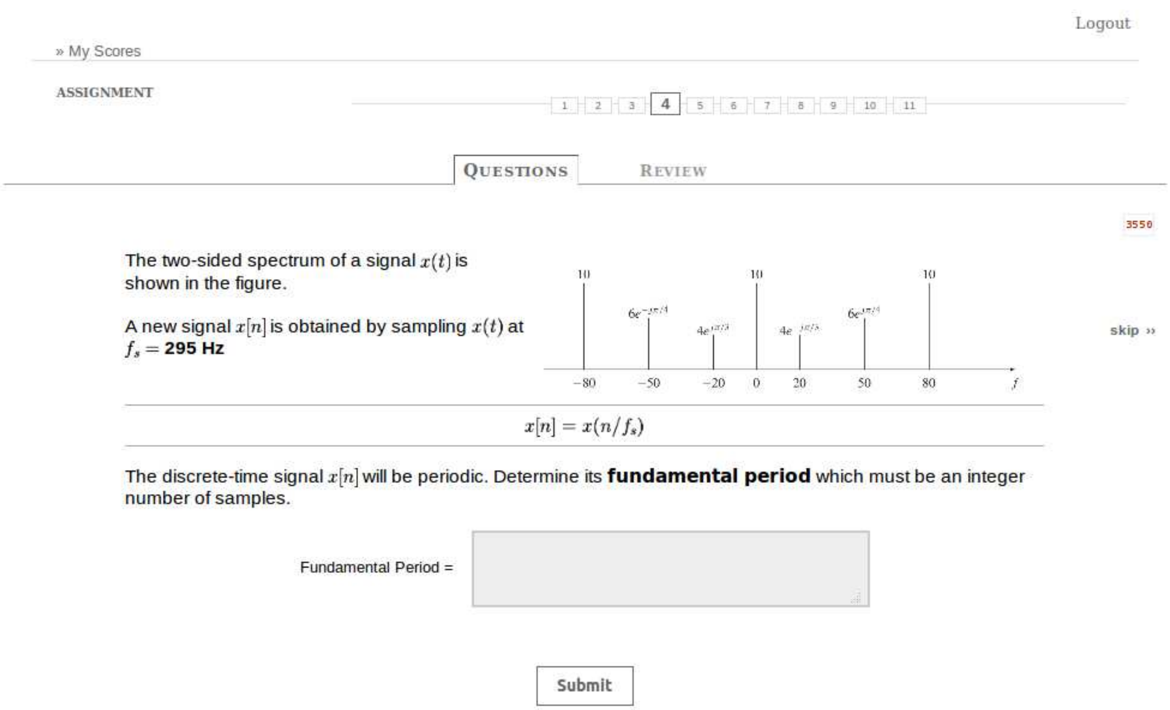

Fig. 4. ITS Problem Solving in the "Assignment" mode with chapter Questions and Review

with a concept map which can be used to navigate across concepts and further structure student learning through concept association, resource selection, and problem searches.

4. REFERENCES

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