STUDY-FLOW: STUDYING EFFECTIVE STUDENT-CONTENT INTERACTION IN SIGNAL PROCESSING EDUCATION

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ABSTRACT

Throughout a semester students use textbooks to reference key fragments especially in response to assigned homework problems. We present an extension to an existing web-based Question and Answer (Q&A) system by incorporating the course textbook as a collection of annotated and chunked resources in a website. To characterize student interaction with the textbook contents, we capture the progress of each student's self-study through their content usage and construct a map of conceptual understanding which defines an individual's organization of course information into relevant concept hierarchies for efficient recall. This process consists of a sequence of enhancing learning activities, or *study-flow*.

Index Terms— tutoring system, self-study, educational data-mining, personalized learning, concept maps

1. INTRODUCTION

Institutional learning has been transformed by the speed and ease with which knowledge is accessible and widely available. As a result, educational goals have pivoted from acquiring enough material necessary for knowledge construction to identifying useful content from a universe of data readily available to an inquiring mind. This age of abundance has altered the educational experience by promoting independent learning through self-directed study on any trivial or in-depth topic of interest. The learning process has transformed from navigating the well defined content of a textbook to searching for and constructing knowledge through referencing fragments in pursuit of deeper understanding.

2. MOTIVATION

Students' approach to homework assignments increasingly reflect their web-based habits, whereby knowledge is acquired and constructed by referencing the textbook sporadically, and only when needed, usually in pursuit of a specific short-term goal. Learning activity then takes the form of periodic sampling of the content by students in short duration intervals, yet detailed in nature to allow for exploration of the intended chunk of information. This process characterizes a learner's relationship with content by identifying how knowledge is incrementally acquired over time, how understanding is reconstructed through context, and to what extent learning activity can be enhanced through a sequence of additional interactive steps. The study of the learning process is a *study* of learner–knowledge interaction through the *flow* of knowledge between a student and content, an activity that we term as *study-flow*.

2.1. Mind and Media

How knowledge develops, and more importantly how this process can be aided, has traditionally resided in the epistemic realm of mind, behavior, and culture. From Thorndike's behaviorist designs of a *teaching machine* to Papert's constructivist dream of a *knowledge machine*, ultimately the goal is to understand the *flow* of knowledge that *does* the teaching. Papert prognosticated this development by remarking that "in the past, education adapted the mind to a very restricted set of available media; in the future, it will adapt media to serve the needs and tastes of each individual mind" [1].

Although personalized learning has been unleashed, much of today's high quality content is well-structured and curated to reflect the representation of knowledge as organized by domain experts, and its best examples are found in university textbooks. This expert presentation is valuable precisely due to its expert structure, however its scope and availability can be intractable to future learner's needs. So, what are user's needs and what does the educational experience demand of students in a digital signal processing course?

2.2. Papert's Principle

Educational researchers have recognized that expertise stems from highly structured knowledge efficiently organized by conceptual descriptions or mental schemas. Learning is based on interpretation of new knowledge and its re-interpretation within the existing mental framework, as it leads to active and deliberate conceptual change. The educational experience demands are epitomized by *Papert's principle* [2]:

> Some of the most crucial steps in mental growth are based not simply on acquiring new skills, but on acquiring new administrative ways to use what one already knows.

Papert asserts that knowledge structure and its formation are key to understanding how learners organize and use existing mental schemas to further knowledge prioritization and application during problem solving activity.

3. STUDY-FLOW

In this paper we present an enhancement to the web-based Q&A system that has been deployed in an ECE undergraduate course, *Introduction to Signal Processing*, and designed specifically to capture the *study-flow* of learners pursuing signal processing education. This system named ITS [3, 4, 5] presents problems from a bank of questions based on signal processing concepts and incorporates course textbook *Signal Processing First* (SP-First) [6], as a reference-based resource. A screen-shot of ITS detailing its user interface is shown in Fig. 1, where a concept-based problem serves to motivate *study-flow* by aiding the learning process through a list of selected links to pertinent textbook resources.

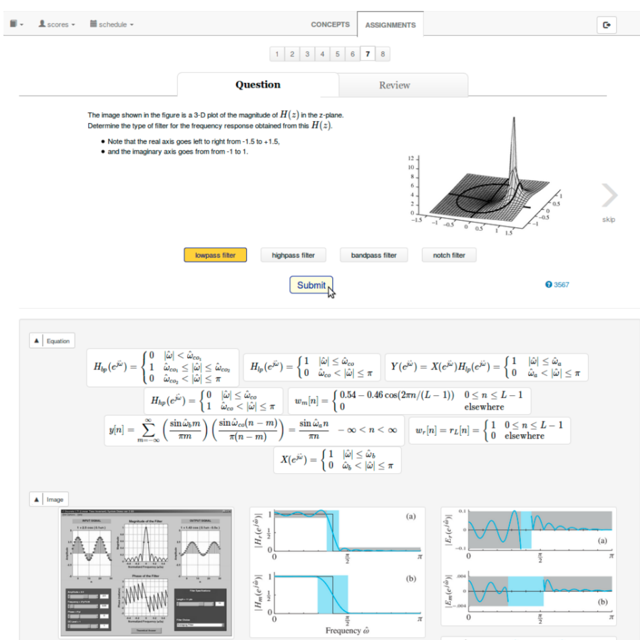

Fig. 1: ITS screen-shot: multiple-choice problem (top) with textbook resource links (bottom).

4. ITS SYSTEM

4.1. Prior Usage and Related Systems

The core Q&A component of the ITS system has been fully deployed since 2011, serving as an automated homework companion to the written assignments and labs. Throughout the semester, ITS presents to the user sub-groupings of questions in the form of assignments. In general, each assignment covers content from a textbook chapter that becomes available to the student based on a schedule, thus giving students ample time to work on more than 40 questions within each assignment. There are 7 designated *pre*-test assignments consisting of 542 questions in total, along with a final *review* assignment designated as the *post*-test consisting of the same 542 bank of questions, administered for comparison.

In many ways, ITS is similar to other Q&A systems that have been recently deployed across university campuses, most notable of these in the signal processing community is the OpenStax tutor that strives to optimize student's progress by building personalized learning pathways [7].

4.2. Data Collection

Concepts often describe complex and abstract knowledge. Within ITS, the conceptual lexicon is derived from the textbook's index, with each individual keyword forming a tag. All ITS resources have been annotated based on these 328 concept-based tags.

A question bank consisting of 542 questions constitutes the core of ITS assignments. Each question is annotated with one or more tags to specify its conceptual foundation. For ease of grading, ITS questions are either of multiple-choice, matching, or computed type, where computed questions are randomly parameterized to inhibit collaboration. Questions are presented to the user within each assignment at random, with the possibility of skipping questions and each question can only be answered once within the *pre* or *post* assignments.

ITS has been deployed in an *Introduction to Signal Processing* course since 2011, serving on average around 440 students each year. As of 2016, approximately 3600 students have used the system producing a user database with more than 844,000 question records.

5. STUDY-FLOW FOR ITS

ITS personalizes learning by tracking how students interact with structured learning material and whether these exchanges are educationally beneficial. In pursuit of expertise, learners rely on experts for guidance and feedback. Textbooks offer highly structured content, promoting expert insights organized in an appropriate conceptual order. Although the notion of *intelligent textbooks* has been criticized as educationally expedient and driven by the demands of *monster ed-tech* efficiencies [8], there exists an established relationship between a learner and a well organized medium, such as a textbook. Intelligent textbooks not only offer the opportunity for feedback, but also provide a window into *time on task* learning. "Expertise only comes with the investment of a great deal of time to learn the patterns, the problem-solving rules, and the appropriate problem-solving organization for a domain" [9].

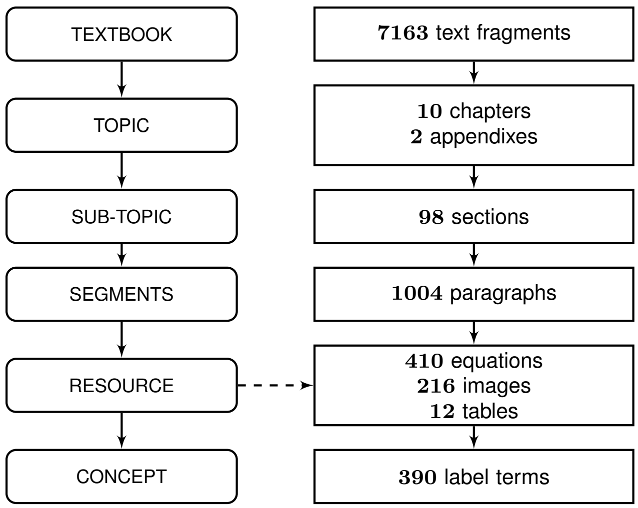

Fig. 2: SP-First resource hierarchy (left) and decomposition of the textbook (right).

5.1. Textbook Hierarchy

Students must construct knowledge for themselves by first understanding smaller pieces of information and later broadening content knowledge to group related concepts under higher-level abstract concepts. This abstraction leads to a hierarchy of the conceptual knowledge that structures content for application through efficient search and recall. This process of learning a structure refines with deliberate practice by identifying domain-specific and general-purpose knowledge. "Higher order knowledge produces new knowledge, which in turn gradually becomes more automated. Automatization, in turn, introduces new ... elements, allowing the process to repeat at higher levels of learning" [10]. The fragmentation of

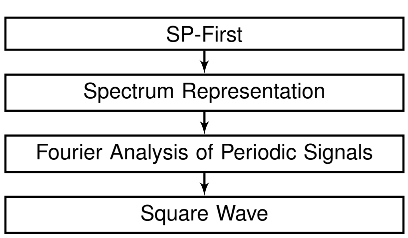

Fig. 3: SP-First *study-flow* example.

the textbook into a hierarchical structure is shown in Fig. 2. Each level represents a conceptual grouping that localizes content knowledge with a designated scope. Structure learning proceeds in a bottom-up fashion, by initially becoming familiar with the meaning of basic concepts, such as terms and definitions, and later associating those with higher-level constructs such as equations, images, tables, or figures identified as learning resources. For resource constructs to be useful, learners need to place these *helper* constructs within a larger context, as specified by sub-topics, which in turn, belong to more general topics.

5.2. *Study-flow* Example

Incorporating the course textbook into ITS allows for a study measuring a student's investment spent in developing expertise through problem-solving tasks. More importantly, an individual's domain-specific knowledge and conceptual organization can be *traced* through their exploration and usage, via *learning paths*. For instance, when a user is presented with a question that explicitly mentions *Square Wave*, whose conceptual hierarchy is shown in Fig. 3, within ITS there are three *learning paths* available:

Concept Path

The implementation of SP-First is shown in Fig. 4, where users are initially presented with a limited and domain-localized list of concepts relevant to the problem-domain. This pathway often represents introductory steps as learners grapple with concept definitions and seek to acquire general conceptual knowledge. *Study-flow* transpires as learners look for "an instructional strategy that presents clear cases of the concept, along with directions to compare a best example with additional expository examples and information on the critical attributes, provides the most effective means for abstracting information to form conceptual knowledge" [11].

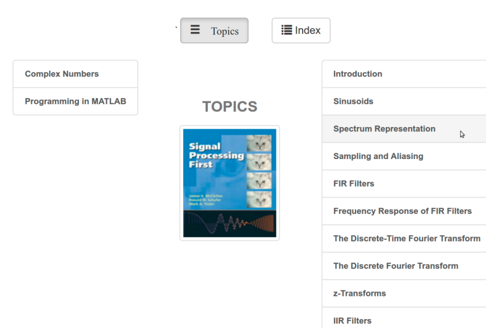

Fig. 4: SP-First list of topics shown in the ITS interface.

Resource Path

ITS presents to users selected *resources* along with each question, as depicted at the bottom of Fig. 1. These resources serve as conceptual cues that link users to content-specific concepts within the textbook. In effect, learners hypothesize about correct resource classification by identifying concept attributes. This path leads to the "development of procedural knowledge through the practice of comparing and contrasting the coded conceptual knowledge with newly encountered interrogatory

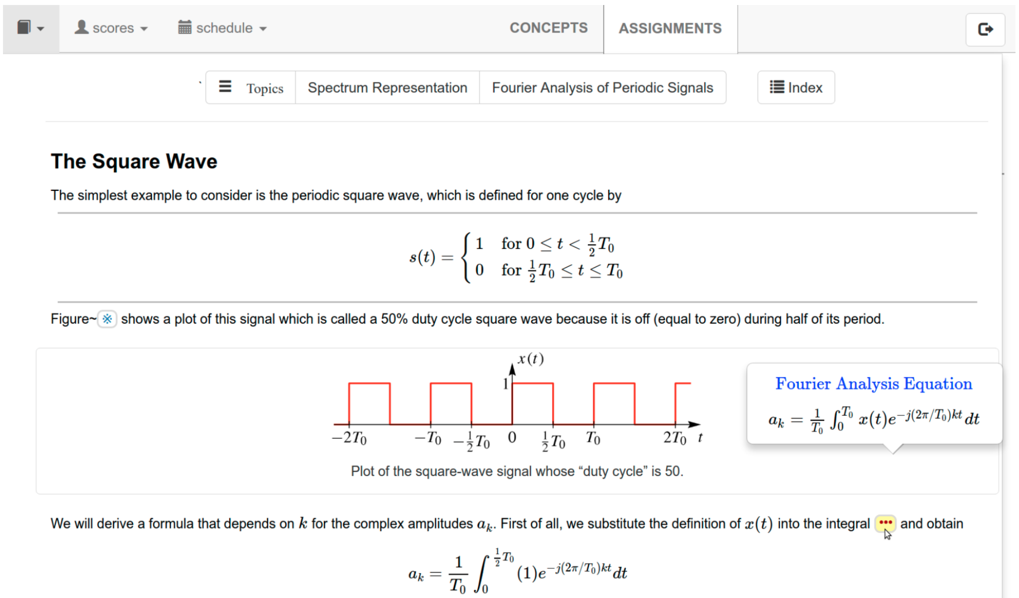

Fig. 5: SP-First concept-based resources for the *Square Wave* concept along with equations, images, tables, and sub-section references. A user interaction with a conceptually dependent equation reference is shown as a popup.

instances" [11]. This *study-flow* option allows users to self-label useful conceptual constructs by constructing *local* associations and contextual groupings.

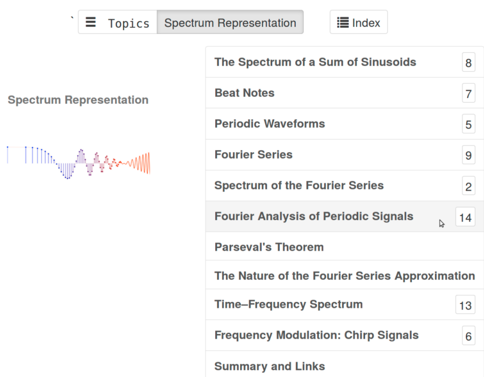

Fig. 6: SP-First *Spectrum Representation* sub-topics.

Hierarchical Concept Path

The development of expertise is gained through generalization of concepts and its ability to efficiently access needed information from within a high-level context. In motivating structure learning, ITS presents the outline of the SP-First topics corresponding to the textbook's chapters (Fig. 4).

Fig. 6 depicts the subsequent user navigation through subtopics within the ITS textbook environment. This interface prompts users to engage in successive *conceptual judgment calls*, akin to descending down a hierarchical concept map, from a broad conceptual plane into specific concept-centric regions, as outlined in Fig. 3. Each navigational junction necessitates a proper *decision* along a chosen *branch* towards the most beneficial targeted conceptual domain. The ITS resource search and selection process is reinforced with a list of concepts available for the chosen conceptual path, as shown in Fig. 7, whereupon users are presented with a paragraph from the textbook containing the targeted concept (Fig. 5).

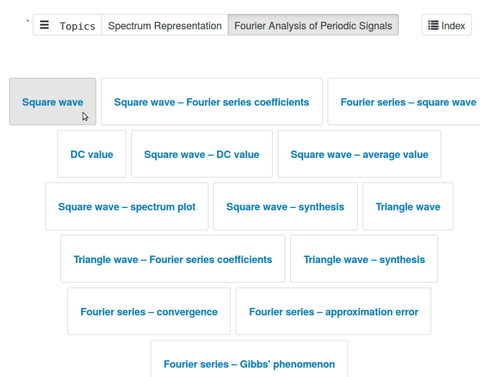

Fig. 7: SP-First *Fourier Analysis of Periodic Signals* subtopic concepts.

6. CONCLUSION AND FUTURE WORK

Educational technologies capable of delivering new types of experiences that students find beneficial must be based on better understanding of learning strategies. In this paper, we present a *study-flow* system that exploits the existing paper-based infrastructure with the goal of studying how students approach educational content, in order to understand their ways of developing mastery through effective engagement.

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