Work-in-Progress: DSP education through web-based selective concept retrieval

Mr. Gregory Augustus Krudysz, Georgia Institute of Technology

Gregory A. Krudysz is a Ph.D student in the School of Electrical Engineering at Georgia Institute of Technology, Atlanta, Ga. His interests are in learning, DSP education, and intelligent tutoring systems. Currently, he is developing an educational research platform which has been deployed in the "Introduction to DSP" course at Georgia Tech.

Work-in-Progress: DSP education through web-based selective concept retrieval

Abstract

In the age of user experience defined by big data, digital presence, and social media, education is increasingly pursued on-line where the cognitive footprint of each student can be easily tracked, analyzed, and assessed. In this environment, learners seek to personalize their education by focusing on concepts and skills which are of immediate interest or utility which is experienced tailored to specific tastes and needs. In this paper, we present a web-based concept-centered educational platform, which has been deployed in the sophomore-level introductory Digital Signal Processing (DSP) with the goal of developing DSP problem solving skills and comprehension. We discuss it in the context of recent research on learning which supports the importance of repeated concept retrieval practice, with an emphasis on relevance during problem solving. By data-mining student activity the system can develop assistance for learners during the concept discovery.

Introduction

In recent years, the nature of education has been undergoing a precipitous change largely due to technological advances enabling ubiquitous access to information, computation, and mobility. Today's learners seek personalized education where knowledge can be targeted to a specific interest or skill and administered at the learner's corresponding difficulty level, schedule, and pace. Teachers have an additional stake in timely monitoring student progress and decisively assessing student comprehension. Recent research on learning [1,2] has demonstrated the benefits of providing students with extensive learning opportunities through sustained concept-based practice and repeated testing. In fact, the act of successive retrieval practice has been shown to contribute to greater conceptualization and development of meta-cognitive skills than by simply studying.

Learning starts with knowledge gathering but also requires searching, organizing, and selecting conceptual tools that have the greatest relevance and potential. Within a course of study, education strives for students to demonstrate competence by knowing when, where, and why the selection of one concept over the other contributes to the solution of a given problem. During the duration of a course, students practice solving problems in order to refine their selective skills for retrieving the appropriate conceptual resources in the context of a problem. Incorrect concept selections lead to a buyer's remorse prompting for an opportunity to re-examine and revise.

Students build their understanding by gathering relevant pieces of information and form associations among them to construct an internal representation of the knowledge domain. These conceptual structures, often referred to as concept maps, dictate how knowledge is organized and ultimately accessed during problem solving activity. The difference between novice learners and experts in a given field is based on how knowledge is organized and utilized. Experts organize knowledge by chunking information into hierarchical structures which allow them to effortless and efficient access knowledge and search for a solution by pattern matching from the repertoire of existing known structures. During testing, student's knowledge is impromptu assessed and prompted to recall, and if possible, to select and retrieve conceptually relevant information. Learners are forced to reason for themselves about the problem and in the process reconstruct and consolidate knowledge which itself enhances learning.

Objectives

Educators often express a wish for their students to become life-long learners. Increasingly, this aspiration is becoming a necessity in today's knowledge oriented economy, as workers become both consumers and producers of knowledge. The ability to acquire, synthesize, and apply knowledge is the foundation of education. The hunter-gatherer instincts of this knowledge-based environment demand from learners to engage in self-directed study which expand cognitive options and enhance the probability of successfully obtaining a desired cognitive goal.

In this paper we present our on-going efforts in developing a data-mining educational platform whose aim is to foster problem solving skills through on-line concept-centric exercises and supporting resources. Specifically, our research attempts to study how students *organize and select* relevant knowledge during a self-directed problem solving activity and how knowledge is later *re-called and retrieved* under a testing condition of an assigned problem. Through data collection our objective is to build a conceptual profile of student's understanding in order to introduce an adaptive tutoring capability [3,4] in the form of timely [5,6] hints and conceptual resources.

Methods

Knowledge Selection

Knowledge does not merely consist of rote learning, but hinges on the development of higher mental processes which enables problem solving through reasoning, judgments, and decisions. Researchers on education have long recognized the importance of proper application of principles, analytical skills, and creativity. These processes are "retained and used long after the individual has forgotten the detailed specifics of the subject matter taught in the schools. These abilities are regarded as one set of essential characteristics needed to continue learning and to cope with a rapidly changing world" [7]. Higher mental processes are activated when learners engage in topic inquiry or reach an impasse during problem solving activity.

Inquiry is the first step in learning, whereby a conceptual understanding is developed through the process of acquiring pieces of information in order to build a representation of the environment. Self-directed learning allows students to take charge of their own learning by deciding on what type of skills they need to acquire and thus the types of experiences that are necessary for them to undertake. Essentially, learners engage in a sampling behavior where they control their own training experience by making sequential decisions of how to study. It is a type of selection process filled with decisions to access or gather specific pieces of information. These sequential acts are deliberate as learners explore the knowledge domain by preferentially selecting information that reduces student's knowledge uncertainty [8].

Effective and efficient selection of relevant knowledge is based on superior knowledge organization and synthesis. In order for learners to optimize experience and maximize topic retention, they need to be able 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" [9], 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" [10]. Furthermore, chunking enables learners to access and retrieve known structures which are linked to existing knowledge with cues.

In fact, the problem of selection leads to a buyer's dilemma, which in itself commits learners to a meta-cognitive activity. Students engage in hypothesis testing by attempting to activate background knowledge, predict and later explain outcomes, plan ahead, and apportion time and memory. Research studies have demonstrated that by simply "deciding what to study often relies on a meta-cognitive judgment about what has already been learned, an introspective process that can enhance memory independently of any further study" [11].

Knowledge Retrieval

Learning is a sequential decision process where knowledge is rehearsed through repeated selection and revision. Through concept application, learners partake in a process of sequential decision making where existing knowledge is consolidated, strategies are formed, and a prediction is formulated with an expected outcome [8,12]. It is a cycle of hypothesis testing, whereby students obtain feedback, reflect on their answers, and revise their understanding and application of concepts. "Feedback has its greatest effect when a learner expects a response to be correct and it turns out to be wrong" [13]. In effect learners are presented with a choice, requiring them to hypothesize by making a judgment of plausibility.

In addition to conceptual exploration and organization through chunking, the amount of practice through 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" [9]. During problem solving, learners test their conceptual understanding by recalling the necessary cues which are relevant in the context of the problem to be selectively retrieved. This process of repetitive selection, revision, and successive pattern matching lays 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 updating their belief models with a new pattern of organization. In essence, learning becomes a process of conceptual reorganization where knowledge is generalized – a process 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.

Results

At Georgia Tech, we have been developing a concept-centric problem oriented on-line system, called ITS [15,16], specifically designed for repeated concept selection and retrieval. ITS has been deployed in the sophomore-level introductory DSP course in the School of Electrical Engineering as a study aide and as an on-line supplement to the homework problems. ITS is essentially a question and answer system whose goal is to assist students in DSP concept discovery, organization, and testing. The system consists of over 1500 multiple-choice, matching, and calculated questions, each targeting a specific concept referencing a topic from the course textbook.

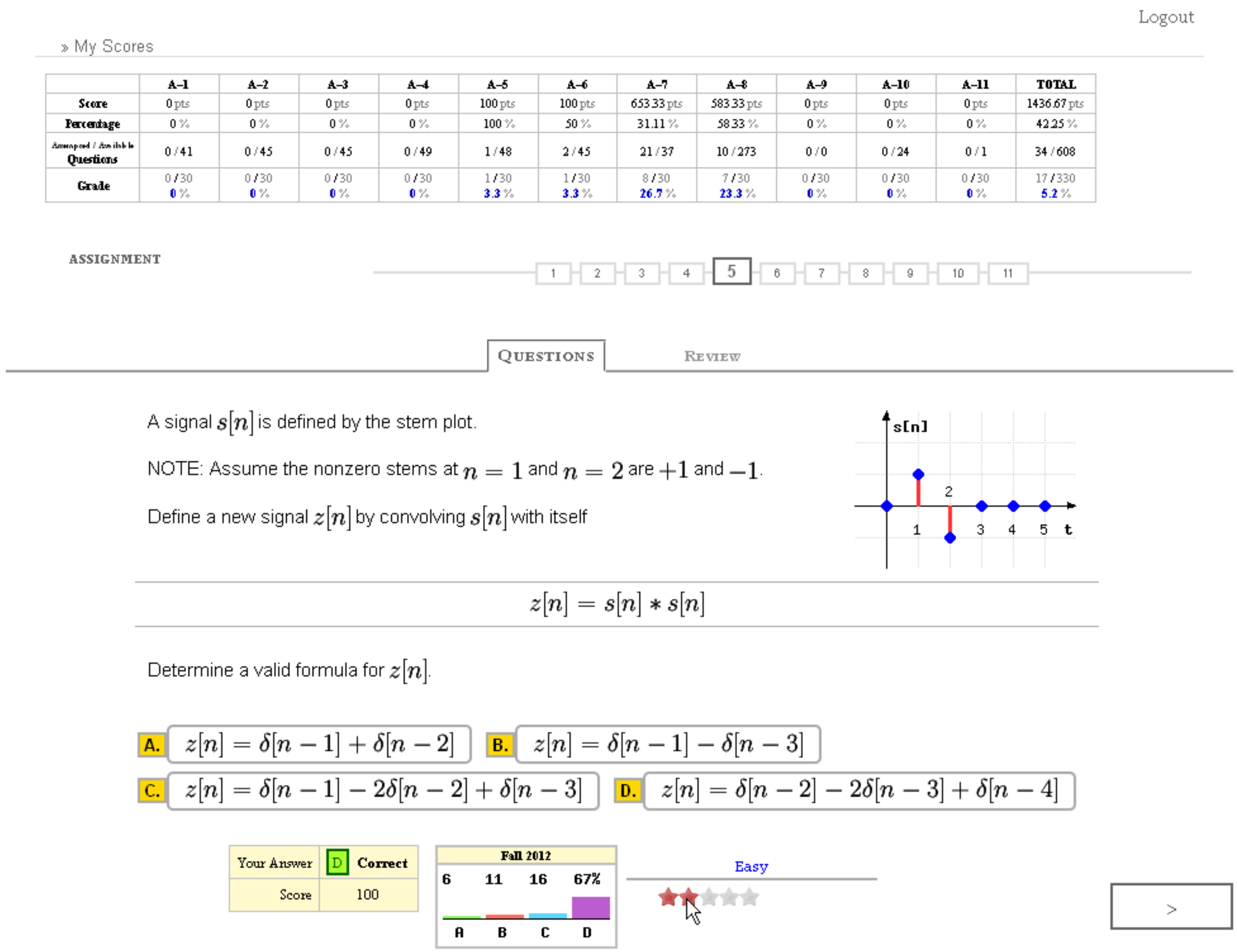

Figure 1. ITS student interface.

The system consists of two interfaces, one for the students, and an expanded version for the instructor. In the student view, there are two modal possibilities: the "Practice" mode and the "Assignment" mode. The practice mode presents learners with a list of concepts and directs users to create a plan of study. Students can select a desired textbook topic or a specific concept which enables them to engage in self-directed study by solving concept-centered question which are anchored in and target these specific concepts. The “Assignment” mode consists of on-line set of problems which are grouped by textbook chapters and graded as part of student’s homework. The instructor view enables question authoring tools to create, clone, edit, publish, search, and share questions. Figure 1 depicts a student view in the ITS "Assignment" mode, where student feedback is shown in the form of a grade assignment and a class distribution. In addition, students have the option of rating the perceived difficulty of the problem.

ITS – Resource Selector

In the “Practice” mode, ITS allows users to navigate across topics via the concept browser interface, which subsequently presents a bank of questions keyed to a specific concept. In this mode, students have the opportunity to practice solving problems with a known conceptual foundation. There are over 800 available practice questions which have been tagged with one or multiple concepts. In addition to the concept browser interface, ITS prompts users to compose a "crib-sheet" for each concept, and later for each question, by searching for and selecting relevant resources. Students have the option of associating resources from the textbook such as text passages, equations, images, and examples, which might be applicable during their problem solving activity. The "crib-sheet" was introduced specifically with the intent of fostering cue building to strengthen learner’s organization of knowledge and lead to greater fluency in selective retrieval.

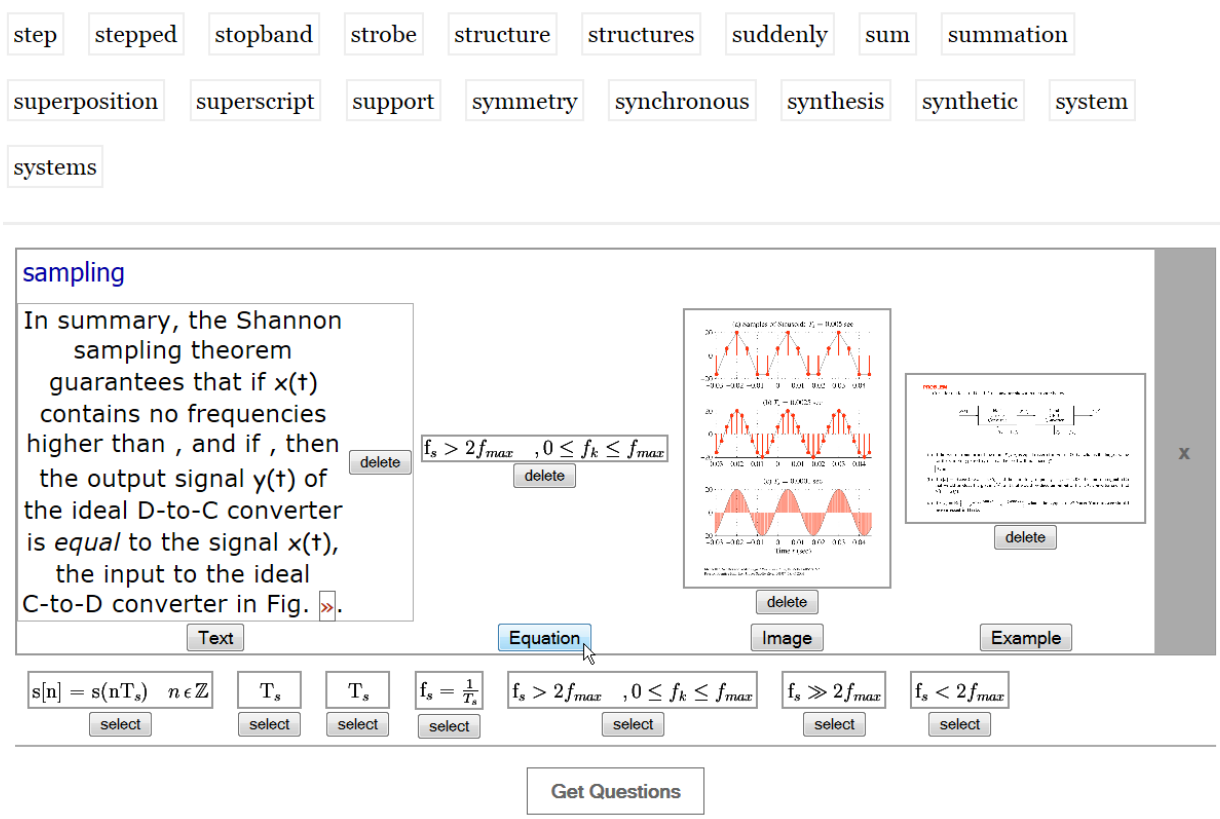

Fig. 2. ITS Resource Selector with conceptual resources shown for the "sampling" query.

Figure 2 shows a concept browser along with a "crib-sheet" for the "sampling" concept. In the figure, a user searches for equations associated with the "sampling" concept, in addition to other corresponding resources, before proceeding to practice solving "sampling" based questions. The idea behind concept exploration and discovery is for the learner to initially associate resources with each concept. Subsequently, through practice and in the context of each new question, users update their conceptual understanding through a revised resource association.

ITS – Retrieval Practice

In the “Practice” mode, students solve problems where concepts associated with the question and the resources are known to the student. ITS initially presents concept-specific resources that have been previously referenced by the user during the "crib-sheet" assignment activity. During practice problem session, ITS prompts students to search for more applicable resources and revise their prior assumptions via a new resource selection in the context of the stated problem. In Figure 3, a "sampling" problem is shown along with user specified "sampling" and "nulling" concept-based resources, which have been revised in the context of the problem.

ITS – Retrieval Testing

In the “Assignment” mode, ITS also enables students to reference their conceptual "crib-sheet" as an aide during the problem solving activity for problems corresponding to concept-centered questions. However, in the testing phase, these concepts associated with the questions are not stated explicitly and neither are the resources. Again, students have the option of further revising their resource assignments in the context of the problem.

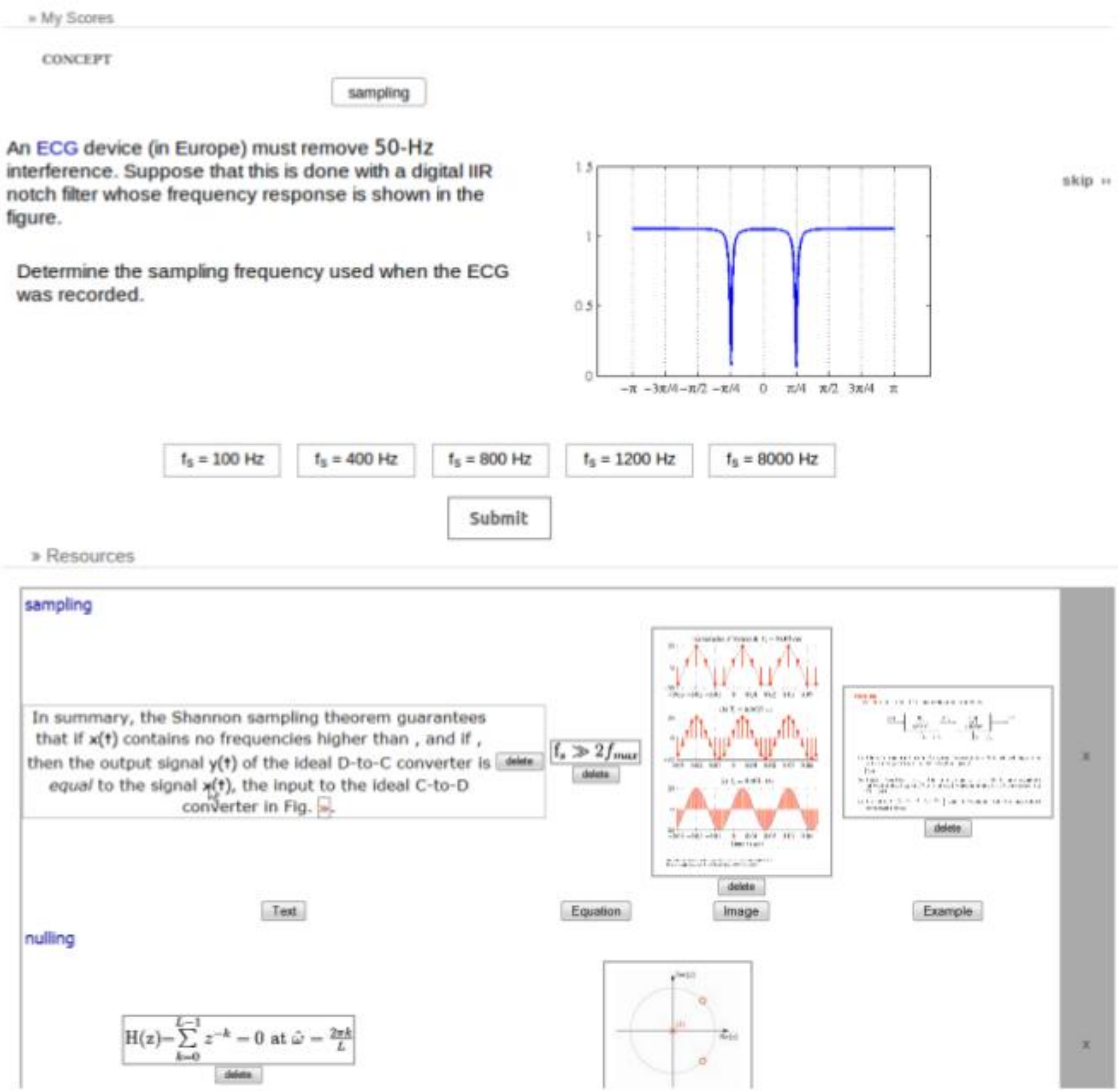

Fig. 3. ITS Retrieval Practice via the "sampling" problem.

Preliminary Data

Over the last six semesters, we have been collecting on-line problem solving activity of 1023 students. During each semester, students were required to work through 8 scheduled assignments consisting of 40+ questions, where 65% of the questions had to be answered correctly. For each assignment, conceptual questions were drawn at random from a database consisting of 482 DSP related questions and presented as either a multiple-choice, matching, or computed question. On average, students attempted 89% of the available questions, and 78% of the students managed to earn a full-credit.

In addition, ITS allows students to skip questions and provides the option to rate perceived question difficulty. On average, students answered 78% of the available questions with an average score of 68.5% correct per question. Students spent on average 2.87 minutes answering questions, and skipped 8% of the available questions, taking on average 11 seconds per question. In total, 16% of the students rated questions for difficulty, with an average rating of 2.92 out of 5, on a Likert scale.

Conclusion

Presently, ITS is a testing platform with an extensive data collection capabilities. However, we are working on extending its functionalities to infer from student-activities a student's conceptual state in order to introduce more effective learning opportunities by developing machine learning techniques. Furthermore, we are interested in developing a framework for studying how learners evaluate different sources of information, how they make resource-based decisions, and evaluate potential individualized learning sequences in the hope of developing a tailored educational experience.

References

1. J. D. Karpicke and H. L. Roediger III, “The critical importance of retrieval for learning,” Science, 319(5865):966-968, Feb. 2008.

2. 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 , Feb. 2011

3. D.R. Woods, “An evidence-based strategy for problem solving,” Journal of Engineering Education, Washington, vol. 89, no. 4, pp. 443–460, 2000.

4. 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

5. T. P. Novikoff, J. M. Kleinberg and S. H. Strogatz, “Education of a Model Student,” Proc. Natl. Acad. Science, 23 Jan. 2012.

6. F. N. Dempster, "Spacing Effects and Their Implications for Theory and Practice", Educational Psychology Review, 1989 Vol 1, Issue 4, pg. 309

7. Bloom, B. S. (1984), 'The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring.', *Educational Researcher* **13** (6) , 4--16 .

8. Todd M. Gureckis and Douglas B. Markant, *Perspectives on Psychological Science, September 2012; vol. 7, 5: pp. 464-481.*

9. Philip N. Johnson-Laird, "Mental Models and Human Reasoning", *Proc. Natl. Acad. Sci. USA* 2011 108 (50) 19862-19864

10. Richard A. Carlson, "The Higher Mental Processes in The American Journal of Psychology", 2012, Vol. 125, zno. 2 pp. 25-38

11. Committee on Developments in the Science of Learning with additional material from the Committee on Learning Research and National Research Council Educational Practice, How People Learn: Brain, Mind, Experience, and School: Expanded Edition, The National Academies Press, 2000.

12. J. Hattie and H. Timperley, "The Power of Feedback", Review of educational research, March 2007, Vol. 77, No. 1, pp. 81-112

13. S.A. Ambrose, M.W. Bridges, M. DiPietro, M.C. Lovett, M.K. Norman, and R.E. Mayer, How Learning Works: Seven Research-Based Principles for Smart Teaching, Wiley Desktop Editions. Wiley, 2010.

14. J. Hattie, H. Timperley, "The Power of Feedback", Review of Educational Research, Vol. 77, No. 1. (01 March 2007), pp. 81-112

15. G.A. Krudysz and J.H. McClellan, "Collaborative System for Signal Processing Education," in Proc. ICASSP-2011, Prague, CZ, May 2011.

16. G.A. Krudysz and J.H. McClellan, "Concept-based tutoring system for on-line problem centered learning," in International Conference on Engineering Education, Turku, Finland, July 2012.