Course Material Delivery in Engineering using Brain-based Learning Techniques

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Abstract—**Although student engagement issues inside engineering classrooms have several components, we focus our attention in this paper mainly on two issues: the dis-engagement arising due to the lack of understanding of pre-requisites and insufficient mathematical skills of students reaching junior and senior engineering classes. As a first step, a pilot study was conducted at two engineering schools, including an Historically Black College/University (HBCU). The primary aim was to identify the issues that lead to attention problems and underperformance of students. The preliminary results indicate that at both institutions, many students reaching junior classes need repeated review of the pre-requisite concepts before introducing a higher-level concept within the course. We also notice that several students still need assistance in reviewing the basic and essential mathematical skills to be fully engaged in junior and senior classes. This paper summarizes the efforts currently undertaken to develop a course delivery framework that is developed based on brain-based learning theories to address some of these issues. We introduce brain-based learning tools as mandatory teaching protocols in the proposed framework. With the implementation of this framework, we envision an engaged classroom, with effective learning in junior and senior engineering classes thus leading to persistence to engineering.**

Keywords—Engagement; brain learning; learning models

I. Introduction

Vast amount of literature indicates that student engagement in classrooms has strong correlation to their academic and professional success [e.g., 1-4]. Student engagement in engineering classrooms is a challenge because of several reasons, including lack of preparation, self-efficacy, perceived ability, socio-economic factors and less-effective course delivery methods [e.g., 5-12]. Engineering courses require continuous development of strong mathematical skills throughout the curriculum. Learning of complex engineering concepts at higher level classes requires a minimum pre-requisite knowledge on these concepts and the lack of which leads to attention problems, aversion to the course and finally to an overall poor performance. These issues are partly taken care of by the curriculum rules on mandatory pre-requisite courses. However, a major fraction of students still enroll in higher-level courses with a minimum grade in these pre-requisite courses. Since their pre-requisite foundation is weak, they may face more difficulties and eventually drop out or change their engineering major for academic survival. While this issue is prominent in all engineering programs, it becomes more critical in an HBCU. In this paper, we look specifically at this problem and suggest a work-in-progress strategy to overcome this.

A teaching learning model titled, Tailored Instruction and Engineered Delivery approach Using PROTOCOLs (TIED UP), developed based on brain-based learning techniques [19], will be introduced in 3 junior/senior engineering courses to study this problem. In this model, course concepts will be presented in an integrated modular format using a web interface. Each of these concepts will be linked to its pre-requisite concepts along with a brief review of related essential mathematics concepts. This representation will inform the students that a complex engineering concept is connected to several sub-concepts and their lack of understanding of pre-and connected concepts including math, will hinder their learning ability. This will also provide an opportunity for students to review these basics and pre-requisite knowledge before they attempt to learn and understand the higher-level engineering concept. Additionally, each class will employ a system of shared screen interaction over pen-based tablet computing devices [13]. The use of shared screens, by which the instructor can see both group thumbnails of student problem-solving and full screen views of an individual student's work in real-time classroom activity has been shown to promote significantly higher engagement in subject matter content [13, 14]. Next, each of the concepts will be linked to short, animated video lectures, student activities and quizzes that are developed based on a number of mandatory brain-based learning techniques. We call these mandatory steps as PROTOCOLs. These 'engineered' delivery materials will finally help students to learn such pre-requisites independently.

The intention behind these content-rich, media-rich and feedback-rich strategies is straightforward. This effort seeks to facilitate more immediate, precise and successful interaction between each individual student, the engineering knowledge and skills they are acquiring, and the classroom instructor who is facilitating that knowledge and skill acquisition.

PROTOCOLs stands for procedures to be followed for a concept delivery using cognitive learning principles. As an example, review of pre-requisites of a concept is a mandatory PROTOCOL to be used in the course material delivery. The PROTOCOL 1 or P1 *connect to old information* will remind faculty to deliver pre-requisites before introducing higher-level concepts. This is one of the several brain-based learning protocols we introduce in the TIED UP model. More details of PROTOCOLs are discussed in section V. In this paper we discuss the preliminary data on how lack of pre-requisites and limited math skill eventually lead to unsatisfactory performance in junior/senior level engineering courses. The present study is conducted in three engineering courses (two courses at an HBCU and the other in a public university).

II. Testing for Pre-requisite Concepts in Engineering Courses

From the authors' class room experience, we believe that when a students' pre-requisite knowledge is strong and when the faculty present new concepts linked to these pre-requisites, they learn more effectively. This reflection, of course, is consistent with widely established principles for learning [15, 16]. However, if the pre-requisite knowledge is weak, they struggle to learn new concepts taught in the classrooms. This is a progressive process as any new concepts they learn one day might be a pre-requisite for a later concept in the same course or later, in a higher-level course [17]. In order to understand this, at the beginning of the semester, a well-designed pre-test is conducted to understand the level of pre-requisite knowledge of students in each course. The specific research question investigated is:

What percentage of students needs review of pre-requisite knowledge before teaching a new concept in this course?

Instructors of engineering courses, very often, assume that student know these basics and try to build the knowledge-tree upon this assumption. If this assumption is wrong, students find it hard to understand the new concept being delivered. If they cannot follow the new materials, they get disengaged and lose attention. Often, this leads to failure in the course as well. Figure 1*a-c* show the pre-test data from three junior/senior level courses (Fluid Mechanics and Mechatronics at Tuskegee University/TU and Algorithm Development and Implementation course at The University of Alabama/UA).

Based on the instructors' experience, a score of 60% is determined as a passing score for these tests. These figures show that between 30-50% of the incoming students in these courses require a refresher of the pre-requisites (represented by red color bars in Figure 1*a-c*). If this pre-requisite refresher is not provided, students tend to be ill-prepared for the new course's concepts. In other words, the assumption that the instructor makes about sufficient pre-requisite knowledge at the beginning of the course is not valid for majority of the students in the class.

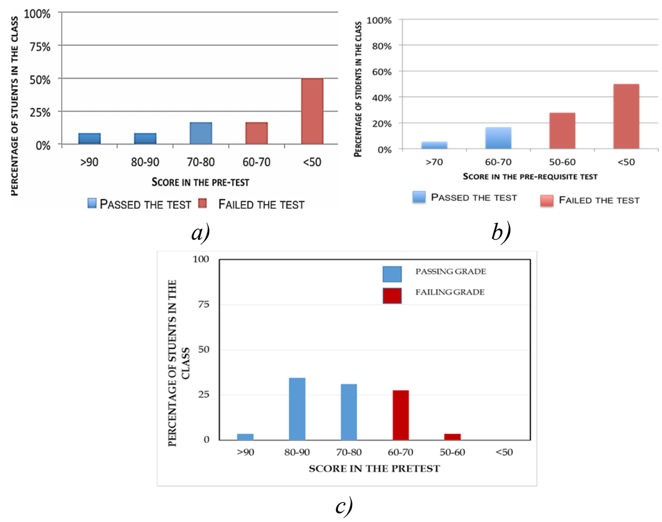


Fig. 1 pre-requisite test at the beginning of a) Fluid Mechanics course TU b) Mechatronics course at TU c)Algorithm course (UA)

III. Testing for Expected Math Skills at Junior/Senior Level Students

Another reason we notice for under performance in junior and senior engineering classes is related to the mathematical skills of the students. It is mandatory to qualify a number of math courses before enrolling for the courses under this study. However, from our experience and research elsewhere [e.g., 18], many students repeat or get lower grades because of their insufficient math skills at junior level. Although these are pre-requisites, they are analyzed separately as these come from courses offered by non-engineering departments in most schools. Many times, math instructors do not offer the connections between the concepts and their engineering applications, which might lead to a gap in the students' learning. To understand this, we re-evaluated various tests and quizzes in these courses giving emphasis on the following research question:

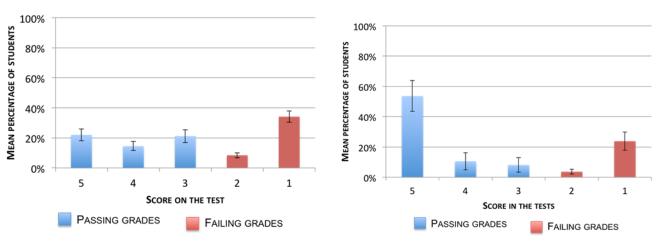
Did a failure grade attribute to the in sufficient mathematical skill of the student?

The math skills required include basic algebra to solve an unknown variable from a correctly formulated physical problem, solutions of systems of equations, basic geometry and elementary skills on calculus. The following data summarizes the data on expected math skills at junior level. These data are presented for two courses at TU: the Fluid mechanics (junior level) and Mechatronics (senior level). These data are very important as these courses need very strong math skills to learn and understand most of the concepts. For these data, the instructors analyzed each question from their class exams carefully to identify the ones that require elementary or advanced mathematical skills to solve. While these problems do not specify the math skill explicitly, the students are expected to identify these skills themselves. Each of these questions is graded using the scale shown in Table I.

In this analysis, grades of 1 and 2 are considered as "failing grades" primarily because these levels of knowledge are not sufficient to learn new concepts in that course. Figures 2 shows the mean percentage of students who received various grade levels on exam questions that required pre-requisite math knowledge to solve.

TABLE I. GRADING SCALE USED FOR DATA COLLECTION ON MATH PRE-REQUISITE SKILLS

Grade	Explanation
5	Displays excellent understanding of the new concept and the math pre-requisite(s)
4	Knowledge of the math pre-requisite concept(s) is satisfactory and correctly applies it to the current concept, but the solution is incomplete
3	Knowledge of the math pre-requisite concept(s) is satisfactory, but its application to the current concept is only partially correct
2	Displays limited knowledge of the math pre-requisite concept(s), but not enough to apply it correctly on the current question
1	Displays no knowledge of the math pre-requisite concept(s) and this leads to failure on the question

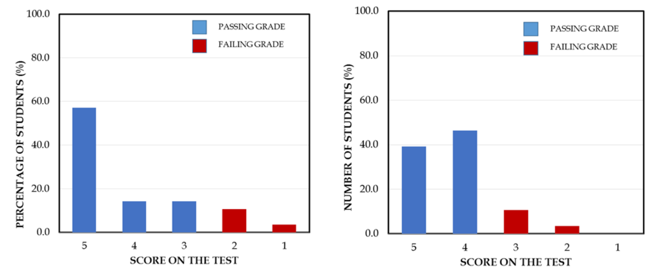


a) *b)*

Fig. 2 Mean percentage of students who scored various grades for pre-requisite math knowledge in a) Fluid Mechanics course b) Mechatronics course (TU)

For another course, Algorithm Development and Implementation, this research question is formulated differently as this course requires not only basic mathematical skills, but also critical reasoning skills to translate a mathematical concept to computer language. Most of the students in this course are exposed to computer programming for the first time and hence is a fertile ground to test their programming reasoning skills is required. To test pre-requisite knowledge, the students are asked questions in basic mathematics, such as the continuity of a mathematical function, calculation of area of simple shapes and also basic technology awareness questions.

The results indicate that to perform well in the numerical methods part of the course students require a strong foundation in basic calculus. To perform well on the translation of the mathematical concepts to computer programming the students' needs to have strong reasoning skills.



a) *b)*

Fig. 3 *(a)* Mathematical and *(b)* critical reasoning skills in algorithm development course (UA)

This reasoning skill test was performed using two questions: to complete the programming statements for the solution of a quadratic equation, and to identify the errors in a set of computer statements that performs basic mathematical additions. The students at this point in the course were not expected to be experts in programming. These results shown in Fig. *3a&b* indicate that almost thirty percent of the students do not get the mathematical reasoning concept correct while ninety five percent of the class has proficient critical reasoning skills.

The analysis of pre-test data and the data on math skills inform us that a major fraction of students need comprehensive review of basic math and pre-requisite concepts even at junior and senior levels in order to facilitate higher class room engagement.

In order to help students and to address these issues, we developed a brain-based teaching-learning framework known as TIED UP. The main idea is to present higher-level concepts along with the pre-knowledge required and with the necessary math associated. Such additional tools are made possible through a number of mandatory teaching-learning protocols in this model. More details of this framework are discussed next.

IV. The TIED-UP model

Development of TIED UP learning model

The TIED UP model has two components. In the 'tailored instruction' component the course syllabus will be re-organized into an integrated modular concept format where complex engineering concepts will be presented as networked sub concepts in a web interface, creating a virtual neural network (similar to the one suggested by network models of memory [20]). Each of these networked concepts and sub-concepts will be further linked to several learning tools such as animations, short concept lecture videos (4-6 minute duration), the shared screen approach discussed earlier that promotes rapid feedback exchanges between the teacher and student, and mandated student activities that are designed leveraging latest insights from established theories of neuro and cognitive science with the help of a number of PROTOCOLs. PROTOCOLs are systematic brain-based learning procedures to be followed while delivering a new concept via cognitive learning tools. The 'engineered concept delivery' proposed here utilizing such learning tools is expected to enhance the effectiveness of teaching and learning. These mandatory protocols are designed to address the issues discussed earlier in the section III.

For example, protocols P1 *connect to old information*, P2 *repeated use of neuron,* P3 *active learning component,* P4 repeated use of neurons, P5 an emotional component, P6 *zone of proximal development,* P7 patterns of meaning, P8 an element of choice and P9 a cognitive map are various brain-based mandatory learning steps to be used while delivering a concept in TIED UP framework. As an example, for each concept, the protocol *Connect to old information* (P1) necessitates availability and access of pre-requisite knowledge, connected to it in a webpage allowing quick and easy review of these materials. Figure 4 summarizes the key features of TIED UP project. To better understand the modular representation of a course and course material delivery using protocols, we present an example TIED UP course currently under development.

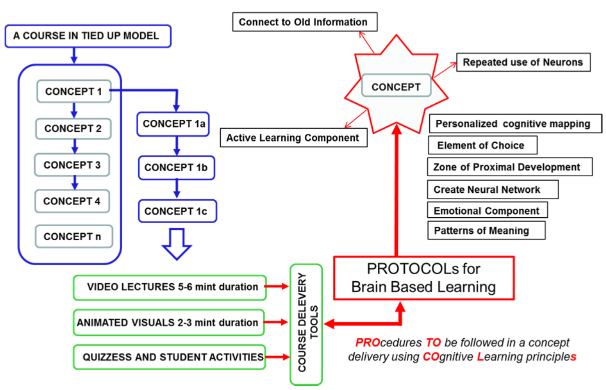


Fig. 4Elements of TIED UP framework

V. TIED UP FRAME UNDER DEVELOPEMNT FOR THE FLUID MECHANICS COURSE

As shown in the previous sections, more than 50% of student population requires additional support for proper review of the pre-requisite material. Data on anticipated mathematical skills show that a more than 40% of student population requires addition support for mathematical skills even at junior/senior classes. The TIED UP structure of the course considers this aspect.

Figure 5 shows modular presentation of the fluid mechanics course. This is a screen shot of a video we developed to teach the concept of viscosity in the fluid mechanics course. All the topics of this course are represented as nearly 90 concepts and sub-concepts. Each of these concepts and sub-concepts will be linked to short animated videos that are developed based on various PROTOCOLs in a webpage.

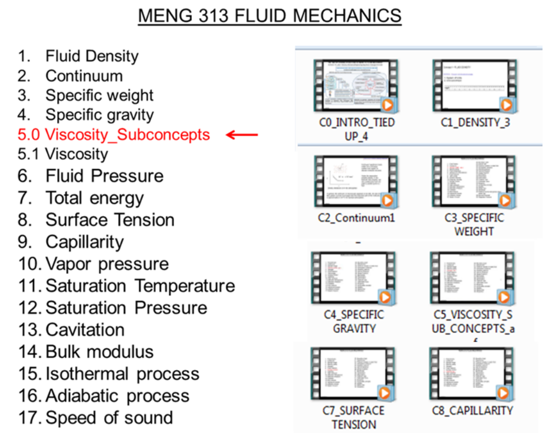


Fig. 5 screen shots showing modular representation of TIED UP course and videos describing each of the concepts with PROTOCOLs

Each of these concepts will also have quizzes and other learning tools integrated to it. The duration of animated lecture is maximum 4-6 minutes. These lectures are carefully developed by preparing storyboards on each concept, based on several PROTOCOLs to be used for its delivery. Animated presentations are separately prepared based on the storyboard. A text to speech conversion tool is used for narration of animated sequences of the material. These two files were combined to generate the TIED UP video of the concept. All these materials will be available in a web page dedicated for TIED UP courses.

Various delivery PROTOCOLs used are explained with respect to a concept "density", described in video 1 of TIED UP fluid mechanics course. PROTOCOL 1 or P1 will search for necessary pre-requisites that can be connected to the concept density. In this video, it will review basics of physical units and unit conversion, as the concept to be delivered requires them as pre-requisites. After introducing and reviewing pre-requisites, P2 will introduce the actual concept with examples to generate brain connections. In this example, the definition of density as mass per unit volume will be introduced with few examples. In P3, an active learning component is introduced via creating an imaginary situation where students are asked to solve practical examples where they can calculate the density of a fluid. P4 will create an opportunity to repeat this exercise and P5 will search for an emotional component that can be related. The famous "eureka" story of Archimedes is related to the concept density and a revisit of this story then reinforces this concept. P6 will search for patterns of meaning of this concept. Introducing various matter having different density and its correlation to its mass and volume will help them to generate patterns of meaning. P7 will present a higher-level perspective of the same concept. More accurate definition of density used in continuum approximation is explained here. Finally P9 will generate a cognitive map for this concept. The cognitive map will summarize the core idea of the concept, which can be retrieved later when this concept is required as pre-requisite for another higher-level related concept. We are in the process development of TIED UP frame work structure of 3 courses under this study. These courses will be delivered in the fall semester of 2016.

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