# Repairing Misconceptions and Inadequate Preparation in Upper Level Undergraduate Engineering: the TIED-Up Model and Pen-Based Computing

***Short Title:*** Engineering Education, Misconceptions, and Tablet-Computing


***Author Names***: John Solomon, Eric Hamilton, and Chitra Nayak

***Short Author List:*** Solomon, Hamilton, and Nayak

***Author Affiliations:***

John Solomon, Tuskegee University, Tuskegee, AL, USA, jsolomon@mytu.tuskegee.edu
Eric Hamilton, Pepperdine University, Malibu CA 90263, USA, eric.hamilton@pepperdine.edu
Chitra Nayak, Tuskegee University, Tuskegee, AL, USA, cnayak@mytu.tuskegee.edu

***Contact Author: Eric Hamilton***.



**Abstract**

Engineering educators frequently discover that students coming into upper level courses lack the foundational knowledge necessary for course success, and frequently entertain common misconceptions common to entry-level engineering students. This paper reports on an NSF-funded initiative that approaches this difficulty with a comprehensive portfolio of research-based strategies for students to acquire, manipulate, express, and revise conceptual systems around engineering. These strategies, referred to as protocols, entail a labor-intensive, methodical, and stepwise approach to working with upper level students with less course preparation than they should have. The overall approach is referred to as "Tailored Instruction and Engineered Delivery Using PROTOCOLs (TIED-UP)". One aspect of the strategy portfolio involves the use of pen-based computing. The paper reviews statistically significant results from this approach as prelude to ongoing research to assess the efficacy of the digital ink component of the project.


## 1. Introduction

A sizable research literature indicates that student engagement in classrooms correlates strongly to academic and professional success [e.g., 1, 2, 3]. Student engagement in engineering classrooms is a challenge for several reasons, including inadequate course preparation, low self-efficacy, socio-economic factors and ineffective course delivery methods [e.g., 4, 5, 6]. The main goal of this project is to test a research-based approach designed to improve engagement and success of third- and fourth-year engineering students in classroom settings.

This short paper describes the overall project approach and the role of the digital ink and pen-based computing component of it, as the project enters its third year of activity.

Engineering courses require continuous development of strong mathematical skills throughout the curriculum. Moreover, learning complex engineering concepts in higher-level classes requires minimum prerequisite knowledge. Prerequisite knowledge deficits can lead to attention problems, aversion to the course and to overall poor course performance. While these issues are partly addressed by the curriculum rules on mandatory prerequisite courses, a major fraction of students can enroll in higher-level courses with a minimum grade in these prerequisite courses. Since their understanding of this prerequisite information is weak, they may face significant difficulties understanding the advanced courses and may eventually drop out or change their engineering major.

### Major Goals

While this issue is prominent in all engineering programs, it is more critical and pervasive in Historically Black Colleges and Universities (HBCUs) [7]. In this project, we look specifically at this problem in an HBCU context and aim to understand the challenges and then to provide a pair. The goal is of this project is to develop an effective teaching-learning model to titled to address these issues. We approached model development by seeking with a microgenetic approach, seeking to identify and repair conceptual shortcomings immediately and at the level of small increments, customized to each learner, using approaches

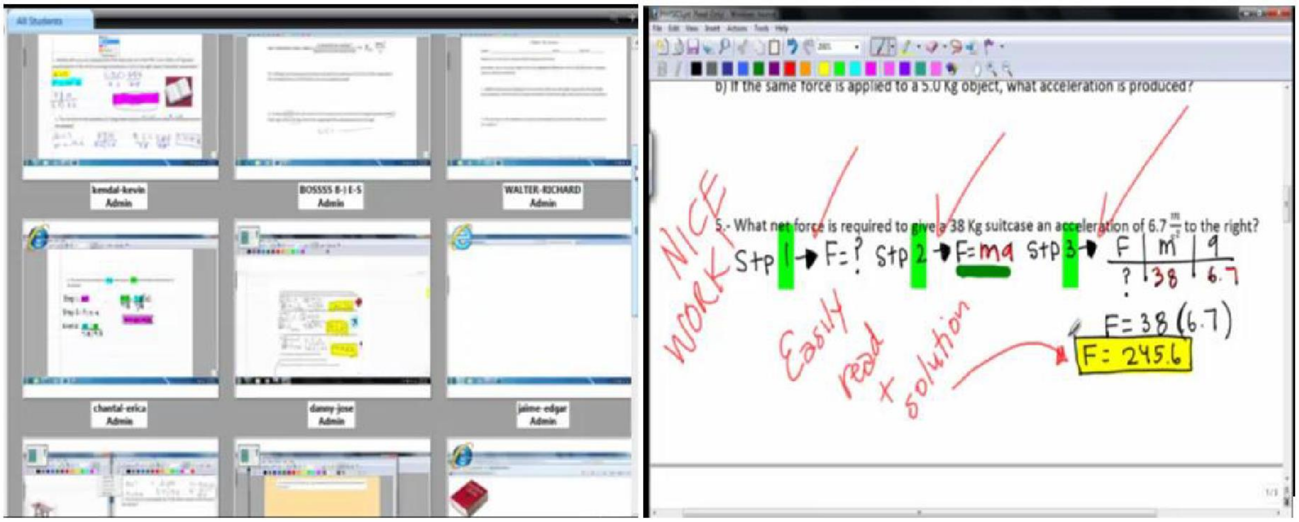


Figure 2: Sample Teacher View When Applying Zone of Proximal Development (ZPD) Protocol

Figure 1: Schematic Representing Tailored Instruction and Engineered Delivery Using PROTOCOLs (TIED-UP)

established in learning sciences literature and taking advantage of findings in cognitive neuroscience. In this model, referred to as "Tailored Instruction and Engineered Delivery Using PROTOCOLs (TIED-UP)" [8], course concepts are presented as connected concept modules. The modular concept representation is intended to 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 a student's learning ability. The model provides opportunity for students to review and reconnect to these basics and prerequisite knowledge before they attempt to learn and understand the higher-level engineering concepts. Each of these concepts is linked to short, animated video lectures, student activities and quizzes that are developed based on a number of mandatory learning principles established in the learnings sciences and cognitive neuroscience literature. We call the steps based on these mandatory learning principles steps as PROTOCOLs. These 'engineered' delivery materials is expected help students to learn such prerequisites independently. The "PROTOCOLs" in TIED UP stands for "procedures to be followed for a concept delivery using cognitive learning principles". As an example, review of the prerequisites of a concept is a mandatory PROTOCOL to be used in the course material delivery. The PROTOCOL 1 or P1 connect to old information reminds faculty to deliver prerequisites before introducing higher-level concepts. This is one of the several learning protocols we introduce in the TIED UP model. Elements of TIED-UP model and protocols used appear in Fig. 1.

**Tablet computing and digital ink component.** In addition to the tailored content media, each class employs 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]. The intention behind this ensemble of PROTOCOLS, or 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. The combination of pen input and shared screens facilitates embodied cognition via active manipulation of mathematical symbolism and sketching while the instructor can view and provide rapid feedback to this manipulation. The system allows the instructor more immediate or ready access to the student work because of the combination of the digital ink affordance and remote view of the work provided to the instructor. An instructor view of student screens appears in Fig. 2. The strategy is carried out with tablet computers, as noted below, with students working in pairs. This component of the ensemble is called the Zone of Proximal Development (ZPD) protocol, referring to the social learning theory of Lev Vygotsky [9, 10]. This theory emphasizes the importance of scaffolding learning at the outer edges of an individual's learning "zone", between trivial tasks (boredom) and tasks that are not manageable (learning to frustration).

Csikszentmihalyi [11, 12] relied heavily on the ZPD framework in his work on studies of flow consciousness, or states of profound immersion and engagement. The ZPD protocol finds application in this project through pen-based computing in the following way. Because digital ink in this type of collaborative workspace permits the instructor to "see" the student cognition,

| Mode | Mean | Question |
|---|---|---|
| 4 | 4.071 | During these sessions, my partner or I actively used the pens for the problems we were asked to solve. |
| 4 | 3.667 | The pens felt pretty natural, so that writing with them on the computer screen was reasonably similar to writing with a pen on paper. |
| 3 | 2.429 | The use of the pen significantly improved the effectiveness of in-class communication of ideas to the instructor. |
| 3 | 3.071 | The use of the pen made it easier for my partner and I to communicate engineering ideas to each other. |
| 4 | 3.643 | The use of the pen made it easier for us to solve problems on the computer in class. |
| 4 | 3.929 | It was usually easier for us to solve problems on paper and then write down a solution for the teacher. |
| 4 | 2.929 | Sometimes the instructor could use software that enabled them to see your display as you were typing or writing on it. The ability of the instructor to see our work significantly changed how the class could function. |
| 4 | 4.071 | I think it would be valuable to have this type of pen-based tool in other science, engineering, or mathematics classes. |
| 4 | 4.143 | I would use a computer that had pen capabilities for other courses. |
| 4 | 4.143 | Having a partner in class made it a better experience than if I was using the computer alone. |
| 4 | 3.714 | The touch capability of the screen was just as important to my experience as the pen as the pen capability. |
| 4 | 3.572 | I used the touch capability on the computer more than I used the mouse for navigating the device. |

Table 1: Student Attitudes Toward Using Pen-based Computers in ZPD Component of Program (n=14)

and because it permits the instructor to give immediate feedback, the instructor is able to help maintain the delicate equilibrium of task difficulty at the outer edges of a student's ability, thus sustaining student engagement in the classroom and even promoting flow-like learning experiences in upper level engineering. The ensemble of PROTOCOLs, with its focus on methodically introducing, reinforcing, and furnishing tailored feedback to a student's conceptual development, includes the ZPD protocol as the primary avenue for real-time, highly informed feedback to the student.

**TIED UP Material Development and Intervention in Fluid mechanics (2016 Fall semester)**

As noted on the first page, this effort, funded by the National Science Foundation IUSE Program, is entering its third year [8]. The major activity of Year 2 was instructional material development for TIED-UP course fluid mechanics. For each of 55 concepts in this course, a scripted, animated short video lecture was developed using various PROTOCOLs along with a TIED UP sheet for formative assessment. These movies, designed to leverage the maximum attention span, are 2-6 minutes in duration and are available to students through a YouTube channel http://bit.ly/tuskegee-tiedup.

**PROTOCOL examples.** The ZPD protocol discussed above is one of several in the project. Various other delivery PROTOCOLs used are explained with respect to concept 1 "density." The first PROTOCOL involves the principle of connecting new concepts to prior knowledge [13] and thus reviews prerequisites that can be connected to the density concept. The video starts by reviewing the basics of physical units and unit conversion, as the concept requires them as its prerequisites. After introducing and reviewing prerequisites, the actual concept is methodically repeated with examples and slight variations to strengthen neural connections [14]. In this example, the definition of density as mass per unit volume is introduced with a few examples. An active learning component [15, 16] is introduced via creating an imaginary situation where students are asked to solve practical examples where they can calculate the density of a fluid. The PROTOCOL associated with attention to affect or emotion also comes into play. The famous "eureka" story of Archimedes is related to the concept of density and a revisit of this story then reinforces this concept. Several other protocols involving conceptual variation, abstracting a higher level perspective or generalization of the concepts of interest [17], and development of a concept map round out a suite of eight strategies or protocols that each student experiences strategies in this and each of the other 54 topics in the course.

**Preliminary Results**

This is admittedly a highly intensive and methodical approach to repairing inadequate preparation for upper level courses. Pre- and post-testing with a comparison group suggests strong and usually statistically significant learning achievement gains by participants, reported in a publication in submission at the time of this paper's submission [18].

**Student attitudes towards pen-based computing**

Using a 5-point Likert scale (5 = strongly agree, 1 = strongly disagree), students were asked whether their use of the digital ink affordances in the ZPD protocol boosted their learning. This scale was only administered to the treatment students, but will be used for forthcoming research and comparisons in the project. Likert scale analysis should treat means based on interval data as limited in value, reporting primarily on mode. These results suggest a strong but not intense affinity for the use of digital ink in helping to maintain student learning in the proximal development zone. Each protocol is an important part of the stepwise effort to bring student success in the upper level courses. One current task involves unpacking not only the theoretical role but the perceived value for each protocol. This survey is an opening part of that process. At the time of the CPTTE conference, we will also report on interviews with students as we build a broader understanding of how to integrate the strategies in this project, and to understand the potential for using pen-based input as a means to assure rapid feedback to students in live classroom settings.

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