Improving Student Engagement in Engineering Using Brain-Based Learning Principles as Instructional Delivery Protocols

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Abstract

This paper presents a plausible solution using brain based learning principles as instructional delivery protocols to address the issue of lack of academic engagement among the upper level engineering students. The study was conducted at Tuskegee University, an HBCU and can be implemented universally in other institutes due to its foundation on brain based learning principles. 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. A previous pilot study confirmed that a large fraction of students who reach junior and senior level classes require repeated review of pre-requisite concepts and need assistance in reviewing their basic and essential mathematical skills before they can successfully engage in their classes. To address these issues, an instructional delivery framework titled "Tailored Instructions and Engineered Delivery Using PROTOCOLs" (TIED-UP) has been designed and explored, where mandatory brain-based learning procedures were used along with a media rich online delivery strategy. This paper summarizes the efforts currently undertaken to develop this framework based on brain-based learning theories to address some of these issues. In this framework, each course concept is broken down to interconnected sub-concepts. Short conceptual videos that use a number of mandatory instructional protocols were developed for the instruction of each of these concept and sub-concept. The study shows that such an intervention has significantly increased students' academic success as measured by grades and caused a substantial decline in their failure rate, when compared against a control group.

Introduction & Background

Twenty-first century engineering education in the United States has benefited greatly from attention and fresh thinking in the recent years, although we still face significant challenges that prevent broader national success[1-3]. In this paper, we report the weakness we identified in retaining the pre-requisite information necessary for upper level courses among engineering students who make up a sizable fraction of the undergraduate population entering the engineering workforce. Based at an HBCU-designated school with extensive NSF support, this study has analyzed foundational weaknesses in student mathematical competencies and preparation for advanced coursework. It connected these weaknesses to the level of student academic engagement – both inside and outside of the classroom – and concluded that novel and effective brain-based learning interventions that promoted student academic engagement in our digital era could translate to students experiencing more successful acquisition of engineering competencies that successful career entry requires.

This analysis, attempting to address student weaknesses by addressing low academic engagement levels, led to the design and exploration of a brain-based learning framework titled "Tailored Instructions and Engineered Delivery using PROTOCOLs" (TIED-UP), in which mandatory teaching protocols were used along with a media-rich instructional delivery strategy for an engaged and improved learning experience. The TIED-UP pilot data appearing in this paper confirm that a large fraction of students who reach junior classes require repeated review of pre-requisite concepts before introducing a higher-level concept, and consistent assistance in reviewing their basic and essential mathematical skills in order to engage them actively at the higher level. The TIED-UP intervention is an intensive – and, so far, successful - approach to repairing underperformance in junior and senior engineering classes. It employs novel and media-rich tools and protocols with firm research support to provide assistance and repeated review.

This study can be seen as an effort to handle one of the knottiest issues in undergraduate STEM education nationally, namely the large fraction of students who simply will not succeed without significantly upgrading competencies they should already possess. We do not believe that the answer is to re-teach in ways that have already failed for these students. Indeed, each student with STEM deficiencies has their own unique set of misunderstandings, misconceptions, and uneven skills. It is not a situation that lends itself to blanket re-teaching. This is a "hard work" project that entails a diligent reconnecting, concept by concept, of foundational STEM ideas as they are used and embedded in the engineering curriculum. The reconnection is scaffolded by the multimedia and sound pedagogy, but it is carried out by the students themselves. The model we present blends critical and established findings in brain and learning science with multimedia, shared screen feedback, and other digital tools to significantly alter what can be called the attention intensity of the course. Students are more engaged both in and out of class time with course material, and instructors can direct attention to the particulars of each student's unique concept-building journey. The TIED UP model shares, at the college level, important aspects of cognitively-guided instruction approach (CGI)[4,5] as well as related theories of learning progressions at the elementary school level, in that it focuses on building coherence of student thinking at both a stepwise and large structure level by drawing the instructor into a more finely grained involvement in process. It represents an advance over CGI in its reliance on diverse technologies, and of course the target population differs.

Vast amount of literature indicates that student engagement in classrooms has strong correlation to their academic and professional success[1-6]. 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[6-16]. Engineering courses require continuous development of strong mathematical skills throughout the curriculum. Moreover, learning of complex engineering concepts at higher level classes requires minimum pre-requisite knowledge, and the lack of which can lead to attention problems, aversion to the course and finally to an overall poor performance. These issues are partly addressed by curriculum rules on mandatory pre-requisite courses. However, a major fraction of students still enrolls in higher-level courses with a minimum grade and performance in these pre-requisite courses. With deficient or subpar foundations, they may face more difficulties and eventually drop out or change their engineering major for an 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 strategy to overcome this.

TIED UP Course Delivery Framework:

In TIED UP model a course is presented explicitly as a model of interconnected concepts and sub-concepts. The key feature of this approach is the use of presentation and interaction tools that are developed based on several brain-based learning protocols, as shown in Fig. 1. 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 knowledge space. Each of these networked concepts and sub-concepts will be further linked to several learning tools such as animated short concept lecture videos (2-6 minute duration), the shared screen approach 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 *pro*cedures *to* be followed while delivering a new concept via *co*gnitive *l*earning tool*s*. The 'engineered concept delivery' proposed here utilizing such learning tools is expected to enhance the effectiveness of teaching and learning. The details of mandatory protocols listed in Fig. 1 appear below.

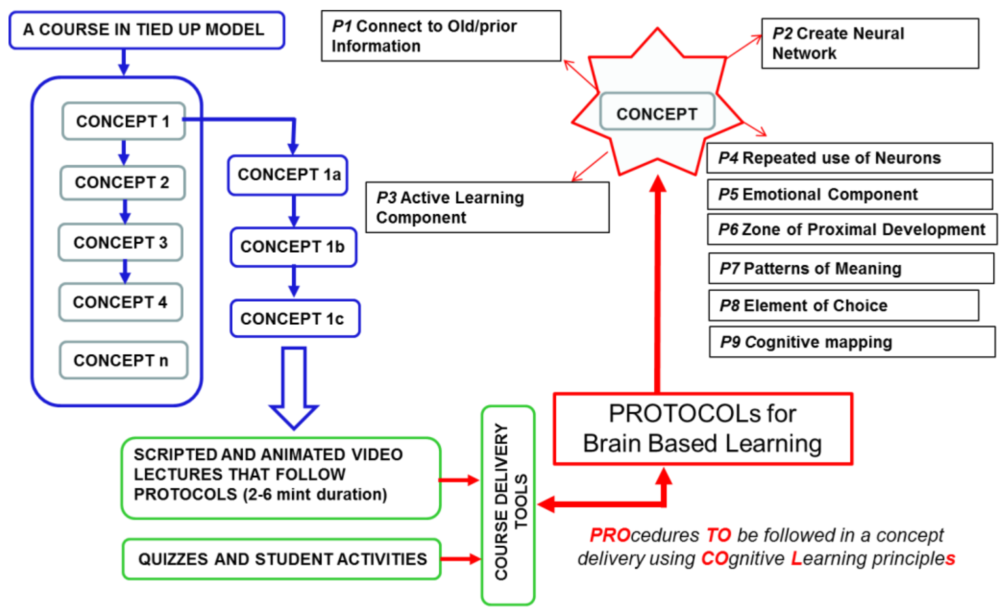


Fig. 1 Elements of TIED UP framework

The protocols used for concept delivery are: *P1 Connect to old/prior information, P2 Create neural connections, 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 Create a cognitive map*[23].

Various delivery PROTOCOLs used are explained with respect to concept 1 which is "density" and described in video 1 of the fluid mechanics course where TIED UP model has been implemented. More details of concepts used in Fluid Mechanics and the protocol-based short videos are available in (http://bit.ly/tuskegee-tiedup). PROTOCOL 1 or P1 will search for necessary pre-requisites that can be connected to the concept density. The video starts with a review of the basics of physical units and unit conversion, as the concept to be delivered requires them as its 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 a 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 of density and a revisit of this story then reinforces this concept. P6 will search for patterns of meaning of this concept. Introducing various types of 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. A 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.

As another example, six PROTOCOLs used for the delivery of the 32nd concept 'Bernoulli's equation' are as follows: P1 connect to old information seeks review of the concepts steady flow, streamline, and inviscid flow (they are concepts 29, 30 and 31 respectively) since the concept requires these as pre-requisites. A review of these pre-requisites will refresh memory, allowing development of fresh neural connections in the brain. P1 also review the basic concept of Newton's second law of motion applied to a particle in motion and relation between force, displacement and work since these sub-concepts are also connected to this concept. The conservation of mechanical energy as applied to a particle in motion is also reviewed using P1, since Bernoulli's equation describes the same principle to a flowing fluid. P2 presents mathematical formulation of Bernoulli's principle followed by a simple equation that describe principle of conservation of mechanical energy of an inviscid, incompressible, steady, irrotational flow. The meaning of each term in the equation is explained in this section. P3 applies this principle to a practical problem to find velocity of a given flow in a given configuration. P4 mandates description of another problem for re-enforcement of the same idea. P5 brings a practical problem which is slightly harder than discussed in section P3 and P4. This problem uses the ZPD protocol where students were asked to solve this in a collaborative manner using a shared digital work space with indirect supervision of faculty. P6 brings a summary of this principle as a cognitive map. In the 'Bernoulli's concept' example, only 6 PROTOCOLs were used. On an average, 5 PROTOCOLs were used for the delivery of 55 short videos lectures developed for this purpose.

More details of protocols are available in other papers[24,25]. Scripted short video lectures and other mandatory activities, such as concept tests, are used for student engagement inside and outside the classroom. In the TIED-UP model, the instructional delivery begins with the process of creating the concept movie that involves subject research, protocol identification, script writing, animation, audio, as well as video making, editing, and uploading to a web interface accessible to all the students before the same concept is introduced in the class. Along this process, activities that are mandated for this concept are also prepared in advance as a set of what we call TIED-UP sheets. TIED-UP sheets include short quizzes that test conceptual knowledge, along with problems of varying level of complexity that enable the instructor to assess the student's knowledge. This follows in-class delivery of the concept, using the TIED-UP movie (2-6 minutes maximum duration) created. Depending on the interconnection between the concepts, 2 to 3 concept videos along with a short lecture are given in the class followed by students attempting the TIED-UP sheets.

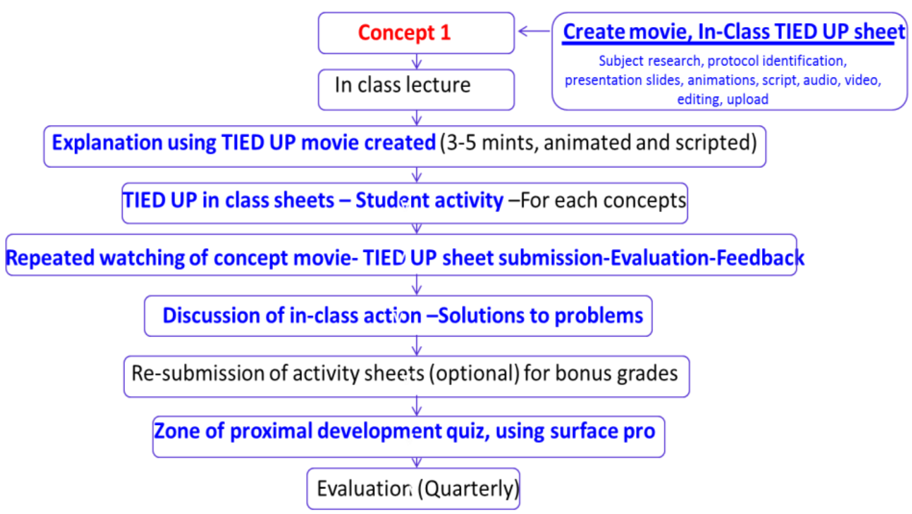


Fig. 2 Flow chart of a concept delivery in TIED-UP model

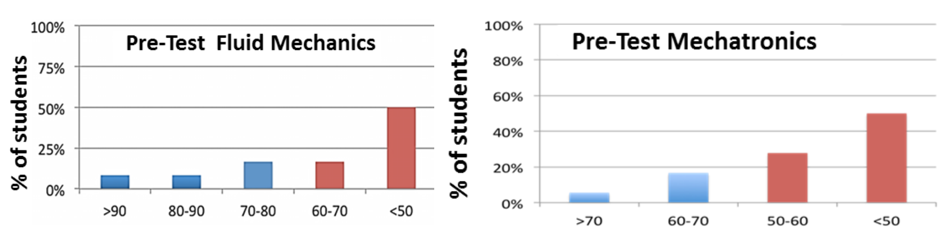
Student can access these short videos inside the class through their personal devices and they are continuously displayed on a larger screen in the class. Out of 50 minutes of a typical lecture, nearly 20-30 minutes are given to the students to work on the TIED-UP activity sheets. Several students complete this sheet within the class period and many submit it during the next class if additional time is required. 20% of total grade points are evaluated based on these activity sheets and hence part of summative assessment. These regular activities help the instructor give timely feedback to the students and direct them to the available videos to learn identified missing concepts. Once all students submit these sheets, solutions are discussed in the class, followed by one final review of the concept. Students who still struggle to complete the activity sheet are given an opportunity to re-submit these sheets for minimal bonus points. 80% of the course grade is decided by 4 tests conducted on a quarterly basis that evaluate 12-15 concepts altogether. Before each quarterly evaluation test, an in-class ZPD (zone of proximal development, one among several protocols used in instructional delivery) exercise that combines all concepts delivered until then, is performed using a digital collaborative work space. Tablet computers allowing digital ink (Microsoft Surface™ Pro tablets to date) are used in this exercise and two students are engaged together in solving difficult problems in a collaborative manner on a single device. Screen-sharing software (Lanschool™ to date) is used for online monitoring of student activities by the faculty for instantaneous feedback to their ongoing problem solving exercise. A flow chart that shows activities of concept delivery in TIED-UP model appears in Fig.2.

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.

Testing the Pre-requisite Knowledge of the Participants:

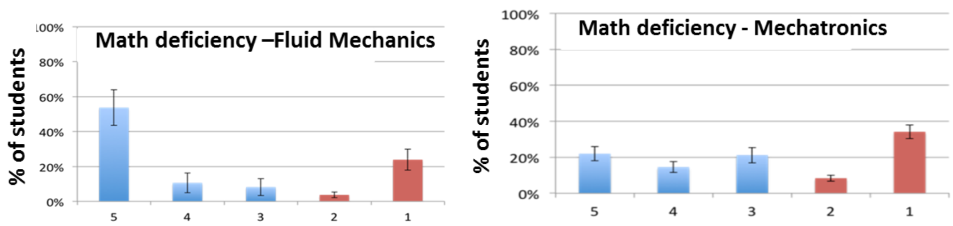
Before the TIED-UP intervention, engagement issues in junior and senior engineering courses were studied. The control data appearing in this section is from an HBCU where the TIED-UP intervention is currently implemented. The goal of this study was to identify key issues that lead to lack of engagement in junior and senior engineering classes, which in turn leads to low student retention in STEM majors. Although enrollment in higher engineering courses requires mandatory pre-requisite courses, students often lack a solid foundation for these courses. To quantify the difference or discrepancy between the expected and actual pre-knowledge and the real standing on mathematical skills, a pre-knowledge test has been conducted for two courses: Fluid mechanics (junior level) and Mechatronics (senior level).

Fig. 3*a&b* indicates data of pre-tests showing that a larger percentage, over 50% of the students in junior and senior classes require review of pre-requisites for successful engagement at this level. We identified this as a critical issue that needs to be addressed. Apart from this, we examined and correlated the students' failure in their higher-level courses to their basic skills in math. Fig. 4*a&b* indicates that a lack of math skills contributed to students failing (25%) at the junior and senior level in fluid mechanics and mechatronics courses. Access to, and reinforcement of, essential engineering math skill throughout the curriculum is important to resolve this problem. More details of this study are available in previous papers[24, 25].



a) b)

Fig. 3 Mean percentage of students who scored various grades for pre-requisite knowledge in a) Fluid Mechanics course b) Mechatronics course



a) b)

Fig. 4 Mean percentage of students who scored various grades for pre-requisite knowledge in a) Fluid Mechanics course b) Mechatronics course

The analysis of pre-test data and the data on math skills inform us that a major fraction of students need a comprehensive review of basic math and pre-requisite concepts, even at junior and senior levels, in order to facilitate higher class room engagement. Several factors contribute to this need, including socio-economic factors, inherent issues with the education system, and the teaching abilities (methods and effectiveness) of faculty. In order to help students and to address these issues, we developed the brain-based teaching-learning framework TIED UP. In this model higher-level concepts were presented using animated short concept videos along with required the pre-knowledge and necessary math associated. Such a media rich delivery tools were developed using a number of mandatory teaching-learning protocols as indicated earlier in Fig.1.

<u>TIED UP Model Implementation and Intervention:</u>

During the exploration phase, 78 scripted concept and sub-concept videos were developed for Fluid Mechanics. The first intervention was conducted in Fall 2016 semester and the resources were updated on a weekly basis. On an average, 4-7 protocols were used in each concept movie making. These concept video lectures are made available to students at all times and are well ahead of concept delivery.

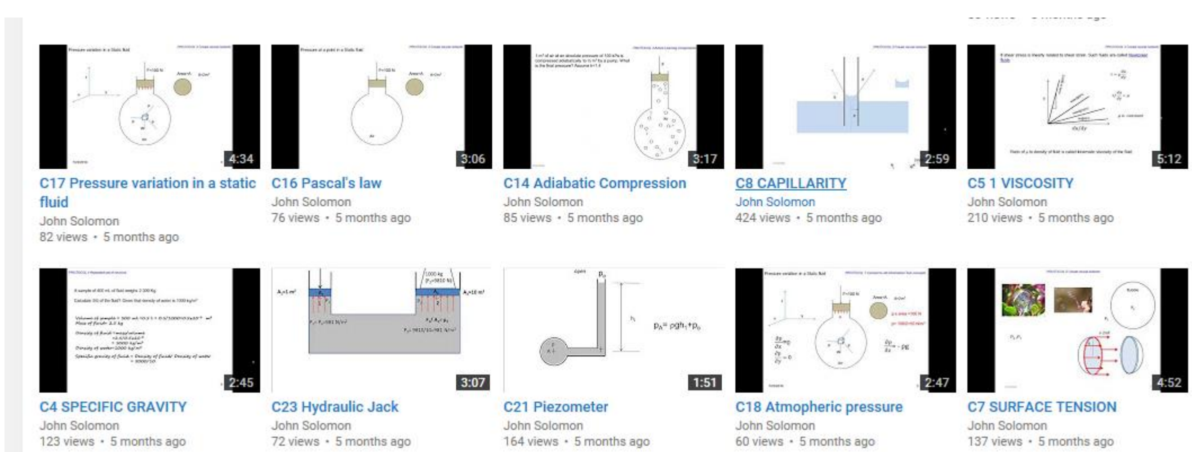


Fig. 5 Screen shot of the modular presentation of concepts in the YouTube channel (http://bit.ly/tuskegee-tiedup) created and used for this study

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. Figure 5 shows modular presentation of the fluid mechanics course in the YouTube channel.

There were 22 students who participated in the TIED-UP Fluid Mechanics intervention in the Fall 2016 semester. During control period (Fall 2015 semester) 20 students participated in the study. This is a 3-credit course with 3 hours of classroom course delivery per week. During the first quarter, 15 concepts were delivered before the first test. Usage statistics and the survey show that these videos were viewed nearly 1200 times by students with a total engagement of nearly 50 hours outside the classroom in this quarter. A student survey indicates that, on an average, a student watched concept movies 4-6 times with an average view time of nearly 10-15 minutes. This repeated watching is self-regulated. It provides a context for the students to make conceptual connections and repairs at a pace they determine. Each concept delivery followed the process flow as indicated in Fig. 2.

This intervention also used a shared screen software that enables instructors to see student work in real-time[17]. The shared screen arrangement follows a logic model by which students are aware that their work is always visible to the instructor and that the instructor is always available to see and respond to questions. The intent is to promote student engagement in class time by providing "sightlines" between the instructor and the student, making student thinking more visible to the instructor, enabling a higher feedback level to students as the concepts connect together into a coherent whole. Using the experience-sampling method (ESM), this approach has been documented to significantly increase student engagement in undergraduate mathematics courses[18]. Incorporation of pen-based input for solving engineering problems in class and screen-sharing enables what has been termed microgenetic analysis in giving feedback[19], whereby the college instructor can see conceptualizations more clearly and form more exact inferences in real time about student conceptualization. This enables rich, real-time feedback in ways that correspond closely to the protocols that TIED-UP emphasizes, most directly to Vygotsky's zone of proximal development [20, 21].

Fig. 6 shows a comparison of the test scores of the TIED-UP group with the control. As indicated by the figure, the TIED-UP students outperformed their counterparts in all the four tests conducted in this class. The tests administered were identical and with a similar level of difficulty, to keep the data comparable. A statistical analysis using one-way Analysis of Variance (ANOVA)[22] with the type of course delivery as an independent variable shows a significant effect ($F = 17.27$, $p < 0.01$). The data are not homogeneous in the variance, but followed a normal distribution. Hence ANOVA is robust to the violation of homogeneity and it is used for the analysis. Further, comparisons are performed within the scores of each test. Independent sample t-tests without assuming homogeneity of variance is used for these comparisons and the results are shown in Table 1.

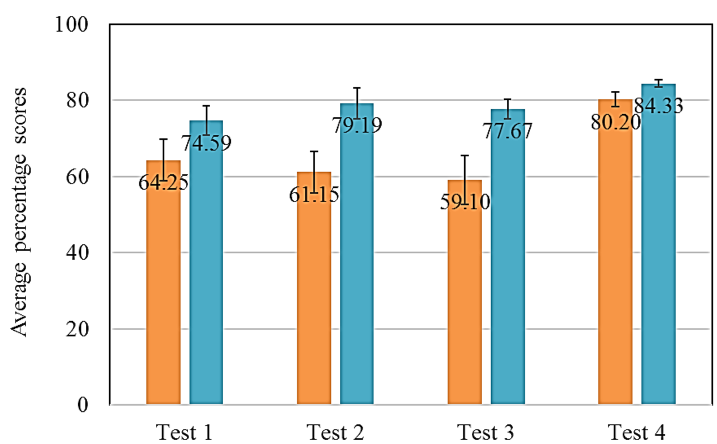


Fig. 6 Comparison of average test scores across the control and TIED UP classes. All error bars show (±) 1 S.E.

The evidence presented in Fig. 6 and Table 1 suggest that the students who grasped their course material through the TIED-UP framework were able to score better in the class tests compared to those who did not. The comparisons were statistically significant for the first three tests. In the fourth test, no statistical significance was observed, but even in this test, students in the TIED UP group outperformed the control group. The fourth test was given, both in control and TIED-UP intervention period, as an open book exam that resulted in a higher grade that maybe the reason for the slightly higher p-value.

Table 1 Results from the statistical comparison of control and TIED UP groups across the class tests

Test	**t-statistic**	**p-value**	**Effect Size (Cohen's d)**
Test 1	2.03	<0.05*	0.48
Test 2	2.03	<0.05*	0.83
Test 3	2.06	<0.05*	0.85
Test 4	2.05	0.06	0.60
* statistically significant comparisons with α = 0.05			

Fig. 7 shows the distribution of various grades in the two groups, consolidated across all the exam scores. Typically scores less than 60 are considered to be failure in the test. As evident from the Fig. 7, the failure rate in tests, with TIED-UP intervention, fell from 38% to 3% in comparison with the control period. Another interesting feature noted was a visible shift in the grade range. A large percentage failed during control period has been re-distributed to C and B grades. The number of students having an A grade (>90%) also increased in the intervention period. To date, these videos were watched approximately 13000 times worldwide, with total view duration of nearly 25000 minutes (statistics from the YouTube channel, for a period September 2016-April 2017).

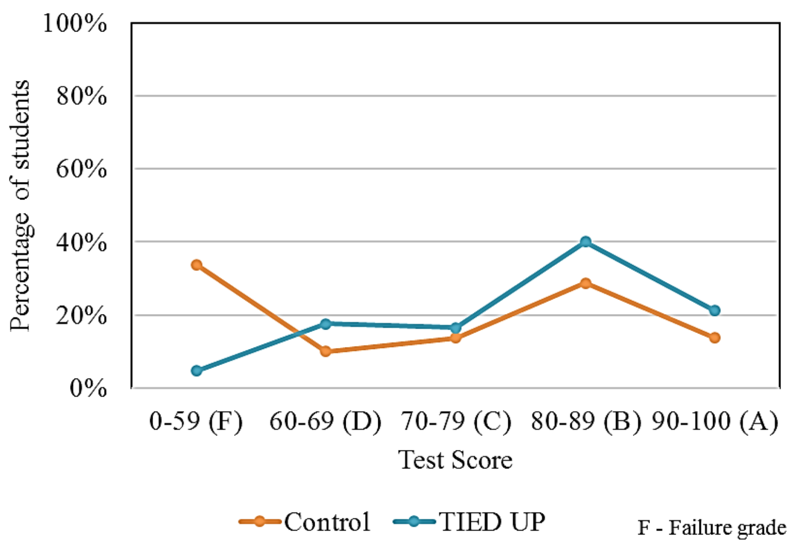


Fig. 7 Comparison of the percentage of students in each grade levels across the control and TIED-UP classes.

Conclusions:

This paper reports implementation of a brain-based course delivery framework, titled "Tailored Instructions and Engineered Delivery Using Protocols" (TIED-UP). The primary aim of this framework is to address some of the concerns identified in our previous study on what leads to lack of engagement in engineering classrooms in an HBCU. These include foundation deficiency and insufficient mathematical skills of students reaching upper level engineering. Based on the theory of brain-based learning, we suggested and implemented several mandatory protocols integrated with multi-media for instructional delivery in an upper level mechanical engineering class. The entire course material preparation process is guided by these mandatory brain-based delivery protocols. The content is presented in a media-rich format and the students are allowed to access these media within and outside the classroom. The intervention data indicate that students who are instructed through the TIED-UP course delivery framework performed better in their class tests when compared with their peers in a control group. Further, this intervention causes a shift in the grade patterns within the class. More students in the TIED-UP group score higher grades (C and above) compared to those in the control group (where a good proportion of the class scores an F). In summary, these results indicate that the new course delivery framework that we implemented is effective in improving student grades and their learning in an upper level engineering course. Currently, the scalability of this approach and the transferability of the materials are being tested at other universities.

Limitations and Future Directions

The data reported in this paper is based on the implementation of the TIED-UP framework in a single upper-level engineering course at Tuskegee University. In order to generalize the results, data need to be collected from a larger set of courses including preparatory courses such as mathematics and physics. The flow of information through a series of courses taken by undergraduate students also needs to be studied. These issues will be addressed in future studies and will be reported in the upcoming conferences. Further, the scalability of this approach will be studied using the implementation in a variety of engineering schools.

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