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Improving Student Engagement in Engineering Classrooms: The First Step toward a Course Delivery Framework using Brain-based Learning Techniques

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Abstract

This paper presents the findings from a preliminary study concerning the engagement of students in engineering courses at Tuskegee University, which is a historically black college/university (HBCU). While student retention is a challenge in many STEM programs, it is a very critical concern in HBCUs. Lack of engagement of students in classrooms is identified as one of the contributing factors to the high drop out rates in engineering programs. The study described in this paper is a first step in an effort to introduce the brain-based learning techniques in engineering classrooms. The instructors of mechanical engineering courses are systematically introducing pre-developed tools, referred to as “PROTOCOLS”, to deliver their course materials in the classrooms. This paper presents the findings from the preliminary data collected from a fluid mechanics class to explore the challenges that the engineering students face that negatively influence their engagement in classrooms. The key findings include the factors such as the gaps in their pre-requisite knowledge, their inability to relate theory to practice, and their inability to establish connections between related concepts. The paper presents the quantitative data pertaining to these categories along with their statistical interpretation. Further, the paper will detail how the proposed brain-based learning tools will supplement the existing teaching methods to improve student engagement by addressing many of these concerns.

Introduction & Background

Engineering students, throughout their curriculum, face many challenges that influence their persistence to engineering. Lack of student engagement in classrooms has been one of the serious concerns that cut across most of the engineering schools. This critical concern, often neglected in classrooms, results in serious attention problems among students, leading to their incompetence and poor retention rates¹. This issue is more relevant in HBCUs (Historically Black College or University) where the retention rates were reported less than 50%².

A vast amount of literature shows that students' academic engagement is correlated to their academic outcomes such as their grades, critical thinking and social engagement³⁻⁶. Further, engaged students are highly motivated and develop stronger capacities for learning and personal development⁷. Students get motivated when their basic psychological needs for engaged learning are fulfilled^{8,9}. Over the past three decades, researchers have identified many factors that influence student engagement in classrooms including attributions¹⁰, self-efficacy¹¹, perceived ability¹², motivation^{13,14}, learning strategy¹⁵ and goal orientations^{16,17}. In order to obtain a clearer picture on some of these influencing factors, a project titled *National Survey for Student Engagement (NSSE)*¹⁸ has been conducted and they identified five important benchmarks for student engagement. These benchmarks are: level of academic challenge, enriching educational experiences, student-faculty interaction, active learning and a supportive campus environment¹⁹. In more recent work, these benchmarks are replaced with engagement indicators that are categorized into four themes: academic challenge, learning with peers, experiences with faculty and campus environment⁴⁸. The course material delivery framework outlined in this paper

focuses on some of these benchmarks including higher order learning, reflective and integrative learning and learning strategies (all under the “academic challenge” theme).

There have been several research efforts over the past many years to improve engagement in engineering classrooms. These include the use of a technology-centered classroom²⁰, formation of learning communities²¹, service learning²², problem-based learning^{23,24}, cooperative learning²⁴ and the use of team projects²⁵. More recently, researchers have tried to improve engagement by introducing cultural touch stones for teaching engineering concepts in large classrooms²⁶, collaboration with multiple disciplines²⁷, collaboration between multiple schools²⁸, ethnographic records and virtual learning experiments²⁹.

Recent research efforts have identified the role that faculty plays in the classroom to create an environment that is engaging to the students³⁰. This is especially true in teaching focused schools such as Tuskegee University^{31,32}. The way teacher behaves in classroom and his/her communication ability plays a crucial role in the engagement of students⁸. A study by Umbach reports greater levels of student engagement in schools where faculty are involved in enriching educational classroom experiences, including active and collaborative learning³³. More specifically, as students get more feedback and critical analysis of their work, they become more engaged^{18,19}.

This paper describes the preliminary steps towards formulating a student-focused course delivery framework where the instructor delivers course materials using a set of well-established brain-based learning techniques⁴⁹⁻⁵¹. The brain-based learning theory suggest that information should be delivered to the students in such a way that it will be easier for their brains to grasp and store in their long-term memory. The new framework is titled “Tailored Instruction and Engineering Delivery Using PROTOCOLS” (TIED UP). In ‘tailored instruction’, 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 space. 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) 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 principles to be followed while delivering a new concept via different learning tools. The ‘engineered concept delivery’ proposed here utilizing such learning tools is expected to enhance the brain capacity to elicit patterns of meaning during learning^{34,35}. More details about these PROTOCOLs are available in the “TIED UP Framework” section.

While there are many aspects for student engagement, this study focuses on how their learning in the classroom affects the engagement. Based on our interaction with the students, we believe that one of the many reasons for students to feel disconnected in their classrooms is the lack of understanding of the new concepts being taught. Most of the times, students struggle to establish a connection between the concepts they learn. While it is easy to blame this on the students, we believe that all students have the ability to perform well in engineering classes. We need to modify the methods used for course material delivery so that we can create a very effective learning environment in the classroom. Throughout this paper, we assume that the lack of understanding of students in classrooms is mainly due to a non-engaging environment in their

classrooms. The traditional way of delivering course concepts using lectures, homework and an occasional hands-on project may not be sufficient for all students to consider the classroom as an engaging environment.

Please note that this study is conducted at an HBCU. In addition to the challenges that most schools face in terms of student engagement, HBCUs often face additional socio-economic challenges. While these factors are not explicitly considered for the study, we believe that the results might be generalizable for all HBCUs. In order to generalize the results outside HBCUs, additional investigations are necessary.

As a preliminary step in the development of TIED UP framework, this paper analyzes how the pre-requisite information affects student success in class quizzes and exams. From the authors' experience in classrooms, we believe that when a student's pre-requisite knowledge is strong and when the faculty present new concepts linked to said pre-requisites, they learn faster. However, if pre-requisite knowledge base is weak, they struggle to relate to new concepts taught in the classrooms. This is a progressive process as the new concepts they learn one day might be the pre-requisite for a later concept in the same course or later in a higher-level course. In order to understand this, the following research questions are investigated.

- (1) *Do pre-requisite concepts (from a pre-requisite course) play any role in a student's understanding of a new concept?*
- (2) *Within the same course, how well do our students make connections between the related concepts?*
- (3) *To what extent can students learn a higher-level engineering concept without a proper understanding of mathematical concepts (both basic and advanced)?*
- (4) *How well can our students apply the theoretical concepts learned in a realistic challenge?*

In order to investigate these questions, we collected data from a junior level mechanical engineering course offered at Tuskegee University. The purpose was mainly to understand how well students perform in class quizzes and exams that require pre-requisite knowledge from a variety of lower-level courses. Specially designed questions were employed in class quizzes and exams for facilitate data collection. The following sections describe the details of the study. Further sections of the paper will also introduce the concept of TIED UP and how it envisions solutions to some of the crucial issue that result in lack of engagement in classrooms.

Method:

In this study, the data collection was performed in a junior level Fluid Mechanics course that was offered by the Mechanical Engineering Department at Tuskegee University. This is a required core course in the mechanical engineering curriculum and has pre-requisites like elementary mathematics (both algebra and calculus), physics and mechanics. Fluid Mechanics describes properties of fluids and its static and dynamic characteristics. This specific course was chosen because it was a course many students found hard to learn. This is an essential course for the follow up courses in the senior year. It also consists of many concepts that require pre-requisite concepts from a variety of other courses, especially from physics and calculus. Further, the course was structured with a bottom-up approach where the fundamental concepts such as

density, viscosity, fluid stress, fluid pressure etc. are taught first and then the more advanced concepts in fluid dynamics were built on those preliminary concepts. For a student to be successful in this course, he/she should be able to relate the new concepts to the pre-requisite concepts from the previous courses as well as the same course.

Data Collection

Similar to most of the other engineering courses, the level of understanding of a student in the fluid mechanics course was judged using his/her performance in class tests, quizzes and a final exam. As a part of the study, we designed new questions for the class quizzes and tests that specifically test students' knowledge about each concept they learn in the class and their connections to the related concepts. The related concepts were either from their pre-requisite courses or from the same course. In addition to the regular grading for assigning a grade to the students, we performed a more detailed analysis of each question. This more detailed analysis was the source of our data. An instructor, who is an expert in that field, specifically formulated all the questions.

In order to understand the level of pre-requisite knowledge of the students attending the fluid mechanics class, we conducted a pre-requisite test at the beginning of the semester. This test had two purposes: to examine the understanding of each student of the pre-requisite concepts and to include the pre-requisite material in the course lectures depending on the need identified from the test. In other words, this pre-test was designed to help the students with their understanding of the course concepts rather than judging them in anyway based on their performance. There were 10 questions in the pre-requisite test to understand their knowledge on fundamental concepts that are required and related to the fluid mechanics course.

Student's participation in the research study was completely voluntary. They were presented with the opportunity to participate in the research study in the first class of the semester. An investigator, who was not their instructor for the course, presented the opportunity. They were explained about the data collection and what the data were used for. They were also offered some extra credit in the class as a compensation for their participation. However, this extra credit was not high enough to force their participation. A student's data were used for analysis only if he/she agreed to participate. There were 22 students in the class and all of them agreed to participate.

Analysis of the Data

The instructor of the course performed the detailed analysis of the data after the semester was concluded. This was done to avoid any biases in the analysis. For the analysis purpose, the answers given by the students for four tests and one quiz were considered. Each question was classified into one of the following categories.

- (1) Questions where the students need to know some pre-requisite information from a previous course and they should be able to link it to the concept being tested
- (2) Questions where the students need to know some pre-requisite information from the same course and they should be able to link it to the concept being tested

- (3) Questions where the students need to have reasonable skills in elementary mathematics (such as algebra and basic calculus) to solve the problem
- (4) Questions where the students need to have reasonable skills in more advanced mathematics (such as advanced calculus) to solve the problem
- (5) Questions where the students should display a skill to apply the theoretical knowledge to a more realistic or practical situation.

Categories 1-4 were analyzed using the grading scale shown in Table 1. Each question was graded with a maximum score of 5. The maximum score means the student displays an excellent understanding of the new concept tested and he/she could make excellent connections with the related pre-requisite concepts. The instructor carefully analyzed students' solutions to sort them into one or more of the categories. There were some overlaps between categories 1 and 3 as well as categories 1 and 4. The mathematics concepts (either elementary or advanced) were also considered as pre-requisite knowledge. Hence these overlaps were not expected to cause any bias in the results. Categories 3 and 4 were formed to understand how the information learned in an entry-level gatekeeper course such as mathematics was carried forward to an advanced level course.

Table 1. Grading scale used for questions in the categories 1-4

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

Questions in category 5 were slightly different from those in other categories. While categories 1-4 tested students' ability to connect to old information, category 5 tested their ability to relate the concepts they learned to a realistic situation they were familiar with. This ability is crucial for any engineer to be successful in his/her profession. Similar exercises were performed in the class along with the introduction of new concepts. Hence the students were expected to be familiar with this type of problems. In order to grade this category, another grading scale, similar to those for categories 1-4 was developed. Said grading scale is shown in Table 2.

Table 2. Grading scale used for questions in category 5

Grade	Explanation
5	Identified the concept, made the required connections and provided a solution that works well for the situation
4	Identified the concept, made the required connections, but the solution was incomplete/not perfect
3	Identified the concept, made a few connections, but connections were unsatisfactory
2	Identified the concept, but failed to make any connections
1	Could not identify the related concept or make any connections

Results & Insights:

The Pre-requisite Test

The purpose of the pre-requisite test was to identify the percentage of students in the class who needed additional training in the pre-requisite concepts required for the course. If the pre-requisite concepts were not clear, the students would struggle to make proper connections to the new concepts they learned in this course. This test was graded out of 100 points. Figure 1 summarizes the grade distribution on this test.

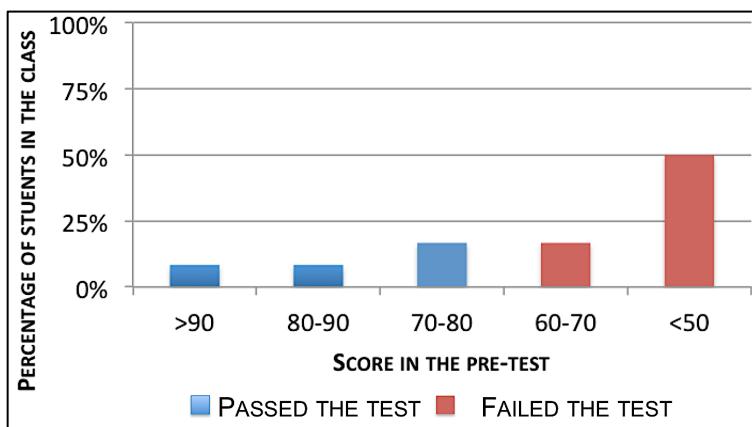


Figure 1. The grade distribution in the pre-requisite test at the beginning of the semester

Considering a score of 70 as the passing grade in this test (this is decided based on the existing passing grade policy at the school), it was observed that more than 70% of the students failed the pre-requisite test. This showed that most of the students entering the fluid mechanics class did not have the sufficient pre-requisite knowledge required for the course. This could be due to many reasons, but the lack of understanding of a pre-requisite concept causes a serious problem for learning the higher-level connected concepts in the fluid mechanics course. When students cannot connect properly to the concepts taught in the class, it might lead to disengagement in the classroom. To explore how this lack of pre-requisite knowledge affects the learning of the new concepts learned in the fluid mechanics class, the following analyses were performed on the data.

Analyses of Class Tests and Quizzes

Category 1:

Category 1 contained questions that require the knowledge of one or more pre-requisite concepts from a previous course to solve. Mainly, the students were required to identify the pre-requisite information, make connections between the pre-requisite and the concept that was being tested and then solve the problem. The solutions provided by students for each question in this category was carefully analyzed for each step during the grading process and the grading scale in Table 1 was used for its further evaluation. Figure 2 summarizes the results from this analysis. This graph shows the mean percentage of students that scored each grade level.

In Figure 2, grade levels 1 and 2 (bars shown in red) represent the percentage of students who showed unsatisfactory knowledge of pre-requisites and failed to solve the problem due to that reason (14 questions were analyzed in this category). Hence these are considered to be failing grades. In an ideal classroom, the percentage of students with failing scores on these questions (grades 1 and 2) should be close to zero. As evident from Figure 2, nearly 50% of the students received a failing grade in category 1 questions. A one sample t-test shows that the percentage of students obtaining a failing grade is significantly greater than zero ($t = 11.47$; $p < 0.01$).

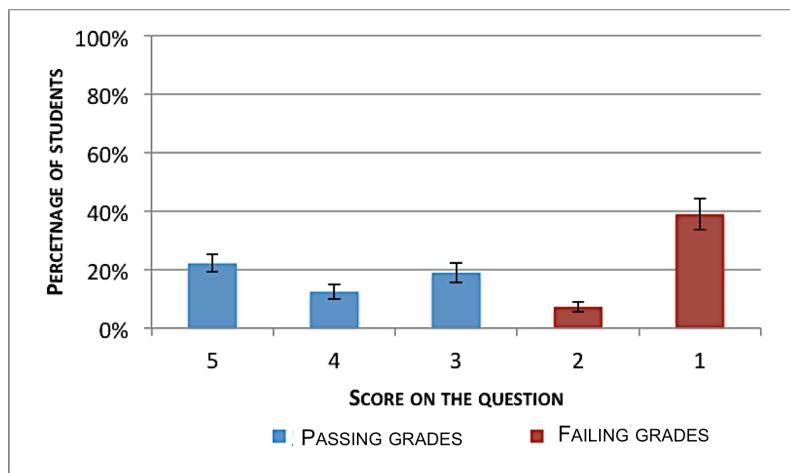


Figure 2. The percentage of students who belonged to each grade level for category 1 questions. All error bars show $(\pm) 1 \text{ SE}$.

While the instructor provided an overview of these pre-requisites in the class, the details were not covered to the full extent due to insufficient time. This is a common problem in engineering courses, especially the core courses. When the time available during the semester is barely sufficient to teach the new concepts in the course, instructors find it very difficult to cover the details of the pre-requisites too. While the students are expected to revise their pre-requisites and catch up on their new concepts, many students find it extremely difficult in their busy schedule. Especially at an HBCU like Tuskegee University, this is especially true. Hence we believe that, for students, to make sound connections to their new concepts, the instructors need to integrate their pre-requisites to their regular course instruction within the limited available time.

Category 2:

Category 2 contained questions that were linked to the previous concepts from the same course. Essentially, the students were expected to know the previous concepts taught in the fluid mechanics course and establish proper connections between those and the current concept being

tested. These questions were also analyzed using the grading scale shown in Table 1. The results are shown in Figure 3 (4 questions were analyzed).

Similar to category 1, grades 1 and 2 were considered to be the failing grades in category 2 questions as well. When a student is completely engaged in the class and learns the concepts properly, he/she is expected to make the connections between the concepts without much trouble. In the classrooms, typically instructors try to establish these connections. So, in an ideal classroom, the percentage of students with a failing grade should be close to zero. However, as observed in Figure 2, nearly 50% of the class received failing grades. Statistically, this percentage was significantly different from zero ($t = 3.28$; $p < 0.05$).

These results highlight another critical aspect of student engagement and learning in the classroom – many students struggle to establish proper connections between the concepts that are being taught. While there might be many reasons for the same, one key aspect to consider is the way the concepts are being delivered. We believe that by modifying the course delivery methods to highlight these connections, students can learn more efficiently.

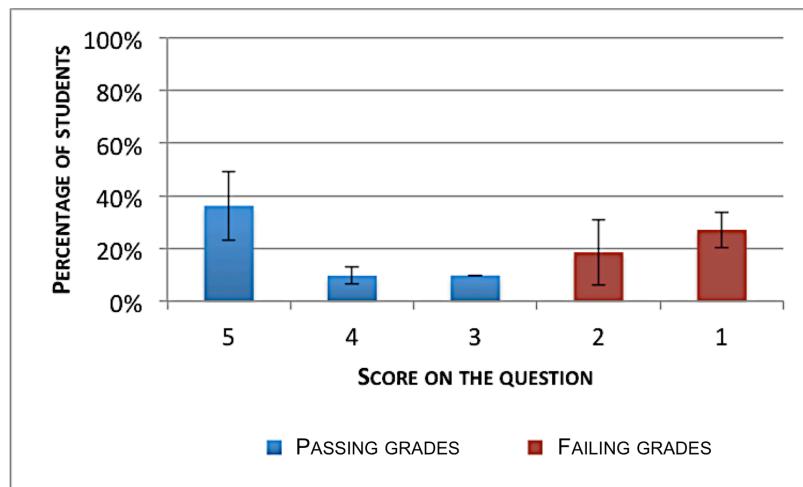


Figure 3. The percentage of students who belonged to each grade level for category 2 questions. All error bars show $(\pm) 1$ SE.

Category 3:

This category contained questions that required the knowledge of elementary mathematics concepts to solve. While this was a sub-category of category 1, it could provide some potential insights regarding the memory connections that students could make to concepts learned a few semesters ago. For engineers, a strong base in elementary and advanced mathematics is necessary to be successful in many follow-up courses. The questions in this category were also graded using the same grading levels and the results are shown in Figure 4 (six questions were analyzed).

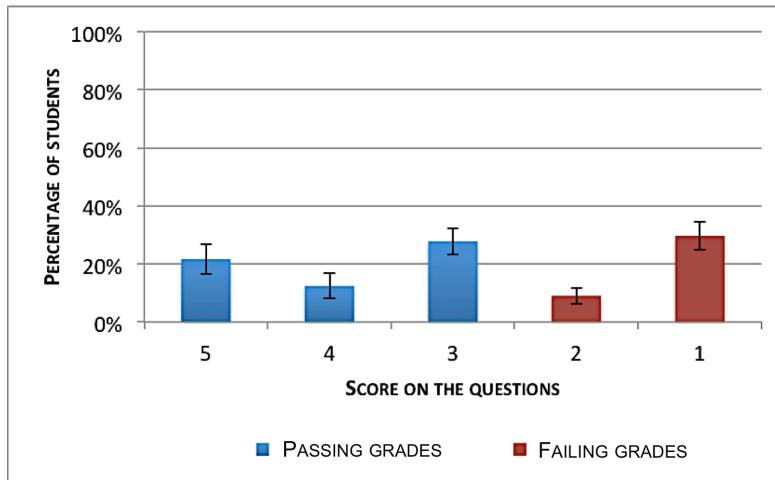


Figure 4. The percentage of students who belonged to each grade level for category 3 questions. All error bars show (\pm) 1 SE.

Once again, considering grades 1 and 2 as failing grades, it was observed that nearly 50% of the students failed to recognize the elementary mathematic concepts required to solve the problems or failed to make connection between those and the concepts being tested. These elementary concepts included solving for an unknown variable from a simple equation, deriving the parameters using the equation of a straight line and simple calculus operations like differentiation and integration. Statistically, a significant percentage of students received failing grades for questions in this category ($t = 10.26$; $p < 0.01$). This is a serious concern as majority of the mechanical engineering courses are built on elementary mathematics.

Category 4:

This category contained questions that tested students' knowledge of a concept while relating that to a more advanced mathematical concept. In this case, the concepts included matric algebra and solving a differential equation. Once again, these concepts are necessary for a student to succeed in core mechanical engineering courses such as fluid mechanics. The results for this category of questions are shown in Figure 5 (four questions were analyzed).

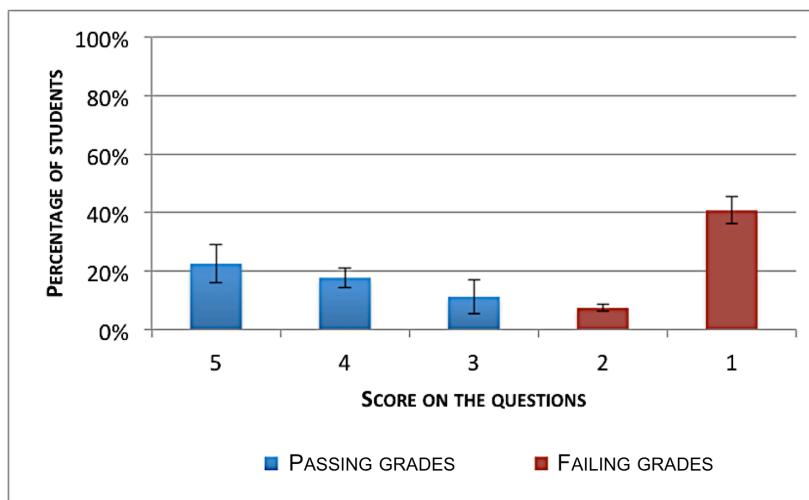


Figure 5. The percentage of students who belonged to each grade level for category 4 questions. All error bars show (\pm) 1 SE.

It was observed that around 50% of the students in the class received failing grades in this category as well. Once again, this percentage was statistically significant ($t = 9.29$; $p < 0.01$). These grades meant that at least 50% of the students failed to recognize the mathematics concept to be used for solving the problem or failed to make connections between the concept and the problem. Once again, considering the importance of these mathematics concepts in engineering courses, these results pose a serious concern.

Category 5:

The last category contained questions that tested the practical aspects of the concepts that were taught in the class. These questions asked the students to solve a real-life problem (something very familiar to all the students) and instructed them to apply one of the concepts they learned to solve it. This category was especially important as this represented an essential skill that students were expected to earn during their coursework. These questions were graded using the scale shown in Table 2. The results are shown in Figure 6 (five questions were analyzed).

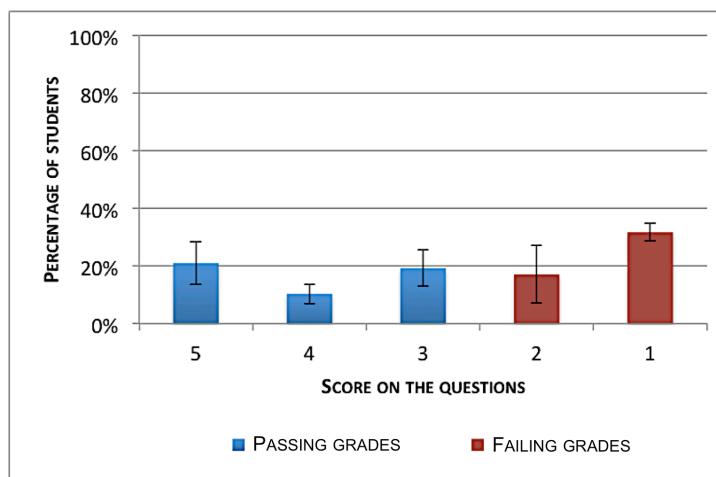


Figure 6. The percentage of students who belonged to each grade level for category 5 questions. All error bars show (\pm) 1 SE.

In this category of questions, again, an average of around 50% of the students failed to respond to the questions accurately. Statistics showed that this percentage was significantly greater than zero ($t = 5.34$; $p < 0.01$). This meant that a significant percentage of students could not identify the basic concept that could explain the phenomenon given to them or make proper connections between the two. While most of the students could make connections for the specific examples explained in the class, many faced a hard time when a new situation was given to them.

Conclusions from the Study:

The main concerns identified from this preliminary study are the following:

- Many students have trouble in identifying and connecting to the pre-requisites required to solve problems related to a new concept. These pre-requisites include those from elementary mathematics.

- (b) Many students have trouble in connecting the related information learned within the same course.
- (c) Many students have trouble in connecting to the practical applications of the concepts they learn in classrooms

We believe that in an HBCU environment these lack of connections often lead students to frustration and lack of engagement. While there might be many reasons behind these problems, we identify the course delivery methods as one of the key issues. By restructuring the course delivery methods to suit the needs of each individual student in the classroom, we envision to solve these problems to a great extent. The next section summarizes the TIED UP framework, which is under development and implementation currently.

The TIED UP Framework:

The idea of TIED UP originates from the network models of memory³⁶. While the “network model of memory” is a well-established framework, the TIED UP is a new model that is developed at Tuskegee University based on said theory. This model, in simple words, describes human memory as a net-like structure where each concept is stored in a web connected to the related concepts. During learning, students are adding new concepts to this web. When they can relate the new concept to something that already exists in their memory, the learning becomes faster. When students can relate each concept to something they already learned in the same course or a pre-requisite course, they create faster connection. This leads to a better engagement in the classroom. When connected to old information, the new information changes itself to fit into existing knowledge structures in the brain³⁷. For example, in a fluid mechanics course, when the concept Bernoulli’s principle is presented (via delivery tools), the old information that can be easily connected to this concept are concepts of force, Newton’s second law, work-energy principle and mechanical energy conservation principle which they have already studied in the first year in particle mechanics. It is very important to review these basic concepts before introducing the concept of Bernoulli’s principle to students who have limited knowledge on the pre-information.

In the ‘tailored instruction’ approach of this project, the course syllabus will be re-organized into an integrated concept format using a model titled “Re-structuring Engineering Courses for E-Learning and Integrated Virtual Education” (RECEIVE) where complex engineering concepts will be presented as networked sub concepts in a web interface, creating a virtual neural space. 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) and mandated student activities that are designed leveraging latest insights from established theories of cognitive science with the help of a number of PROTOCOLS. PROTOCOLS are systematic brain based learning principles to be followed while delivering a new concept via different learning tools. Figure 7 summarizes these two key features of TIED UP project, the RECEIVE model for course re-structure and the PROTOCOLS for brain based learning.

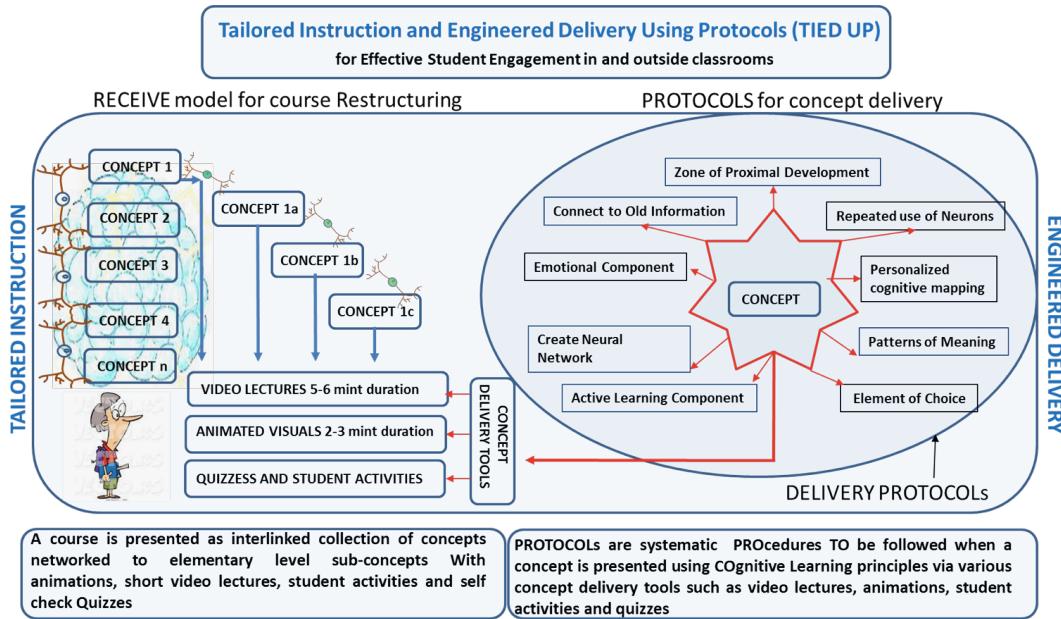


Figure 7. TIED UP project uses RECEIVE model and PROTOCOLs for brain based learning

The first element of the TIED UP project, RECEIVE, systematically tells students what to learn in a course using integrated modular concepts made available through a web interface.

Importantly, each concept in a course is not only linked to several other concepts of the same course but also to a number of elementary sub-concepts that are needed as pre-requisites. This is useful when teaching higher-level courses in junior and senior level. The main purpose of this web interface is to provide the students a single place to go to when they need to study the pre-requisite needed for a new concept. This is in addition to the pre-requisite concept being delivered in the class using PROTOCOLs. One aspect of RECEIVE is it allows to retrieve the old information very quickly in a way they have studied earlier and allowing repeated use of their neural network connections. Neuroscience research points out that practice and repeated use of stored information improve memory and performance³⁴.

The second element of TIED UP is development of PROTOCOLs. They are systematic PROcedures TO be followed when a concept is delivered via COgnitive Learning principles. In this project we propose 9 brain-based learning PROTOCOLs (P1-P9) for a concept's delivery. To demonstrate how PROTOCOLs are used for instructional delivery, an example concept 'gravity' is chosen and discussed further. Each concept is delivered using as many PROTOCOLs as possible.

The First PROTOCOL (P1) 'connect to old information' will make sure that before teaching a new concept, the basic pre-requisites connected to said concept will be reviewed. In this case, a brief review of basic concepts such as force, acceleration and Newton's second law may be appropriate. After refreshing the connected pre-requisites, the central idea of the concept will be presented via another PROTOCOL (P2), 'create neural network'. In this process, the new concept is linked to the previous concepts learned in the course and the students are exclusively told about those connections.

When possible, an active learning component will be integrated as the third PROTOCOL (P3). In this example, an experimental demonstration calculating the value of acceleration due to gravity using a classroom demonstration will be ideal. Research has proved the effectiveness of active learning with demonstrations and tangible physical models³⁸⁻⁴¹.

With the sequential steps P1-P3, students may have some understanding on the concept. The next mandatory PROTOCOL (P4), ‘repeated use of neurons’, will help them to re-enforce the idea via repeated practicing. Solving similar problems in class and through homework, this can be implemented. Studies on neuro science confirm that repeated use of neurons improves learning capability³⁴. ‘Repeated use of neurons’ will allow pathways more permanent and the concept will be integrated to the students’ long-term memory.

Some of the problems to be solved during class time could be slightly harder and might require assistance from the instructor. TIED model has a mandatory PROTOCOL (P5) ‘zone of proximal development’ (ZPD) where such problems will be solved using tablets using a collaborative workspace and screen sharing technology. Instructor will see how students are approaching a problem in real time and will provide necessary support as and when necessary. The faculty will identify the independent problem solving skills of the students before using this approach. The ‘zone’ actually refers to the gap between student’s actual ability to solve a problem and the potential level he/she could reach with knowledgeable support from a faculty member or peer. Step by step solution of a problem, guiding students to think about what would be the next step will help establish neural connections faster.

To implement this PROTOCOL effectively, TIED UP utilizes the concept of ‘shared collaborative workspaces’ developed and successfully evaluated by Pepperdine University⁴². In this activity essentially two students sharing a tablet – such as a Microsoft Surface™ pro 3 with full power and high-resolution stylus, where the teacher can see everything the student teams are doing. This approach, developed by Pepperdine University⁴² can realize the vision of the teacher having a direct line of sight into student cognition as they carry out mathematical activities with digital ink. This approach had powerful effects on engagement. The PROTOCOL of Zone of Proximal Development (ZPD) will be implemented via special tutorials combining several concepts once every two weeks. Students will share a tablet computer and solve problems inside class. The screen sharing technology will allow the instructor to watch what student groups are doing and provide help and suggestions interactively.

‘An emotional component’ and ‘generate patterns of meaning’ are two other PROTOCOLS (P6 and P7) to be used. The former will describe the same concept in an emotional perspective. A well-known incident or story already known to the student and that has ties to this concept will be integrated here. Such integration will further infuse the concept and help better learning. In the example concept of gravity, the famous experiment by Galileo in 1589 on the leaning tower to demonstrate gravity is same for objects having different mass may work well. The PROTOCOL binding ‘emotional component’ to a concept delivery is important since an emotionally charged memory will last longer. Emotions strongly influence learning as it helps storage and retrieval of information easier⁴³.

Another PROTOCOL (P7) for concept delivery is the inclusion of patterns of meaning. ‘Patterns of meaning’ explore the more general visions of the concept. The brain’s capacity to stimulate patterns of meaning is a key concept of brain-based learning³⁴. To create patterns of meaning, pre-exposure to the new information is essential. The RECEIVE course structure envisions this goal. Each concept is linked to other concepts that are directly associated with the elementary concepts that it constitutes, in a web space resembling a neural network. Most of the sub/elementary concepts that have already been learned in the lower semesters will generate easier pathways and create a pattern of meaning for the new concept. Brain capability to search for patterns is linked to previous experience/exposure of student. Previous information readily available with a new concept will provide the experience required for making patterns of meaning.

‘An element of choice’ is another PROTOCOL (P8) to be used while delivering the same concept. Here a higher level description of the concept will be presented in this protocol. For the example concept ‘gravity’, a brief information on general theory of relativity and how gravity is perceived differently from Newtonian point of view could be considered as an element of choice. The goal is to provide some challenging aspects of the concept using this protocol. This PROTOCOL will provide autonomy to students with different intelligence levels to choose the extent to which they learn a concept⁴⁴. The element of choice is mandated in short video lectures, animations, quizzes and other activities in the TIED UP model.

The final PROTOCOL (P9) is the meta-cognitive generation of ‘concept maps’. This is a tool developed by J. D. Novak while he was investigating the changes in a children’s understanding of science⁴⁵. According to Ausubel’s learning psychology, learning takes place by the assimilation of new concepts and proposition into existing concepts frame work held by the learner^{46,47} and Novak’s work was based on this idea. Using this tool, each new concept is connected to the relative concepts using a simple visualization as shown in Figure 8. The students will be trained to draw these representations themselves and they will be instructed to generate these after each concept. This will allow students to revisit the concepts and organize them properly in their memory.

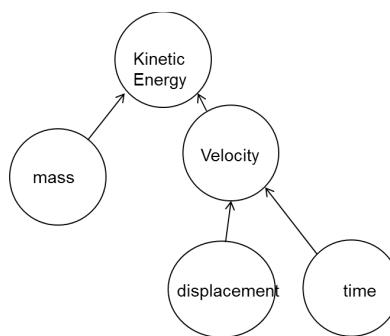


Figure 8. An example concept map developed for the concept “kinetic energy”

The Path Forward:

The TIED UP framework aims to develop a more effective script for the delivery of course concepts following a set of PROTOCOLs based on the brain-based learning techniques. Currently, the fluid mechanics course is being redesigned (no change to the course contents) to include the TIED UP framework. The new course delivery method will be implemented in Fall 2016. Data for the commonly used engagement measures such as critical thinking ability, meta-cognitive skills, academic motivation etc. will be measures in that semester. In addition, the same analysis as described in this study will be repeated to identify the effectiveness of the TIED UP framework. If found effective, the script will be shared with the instructors of the same course in other universities. The instructors from other schools can enrich this script with their expertise. We plan the implementation of the framework in multiple universities as well.

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