A Study on the Student Success in a Blended-Model Engineering Classroom

Dr. Vimal Kumar Viswanathan, San Jose State University

Dr. Vimal Viswanathan is an assistant professor in the Mechanical Engineering Department at San Jose State University. His research interests include design innovation, creativity, design theory and engineering education.

Dr. John T. Solomon, Tuskegee University

John T Solomon is an assistant professor in the mechanical engineering department of Tuskegee University. He received PhD in Mechanical Engineering from Florida State University, USA in 2010. Prior joining Tuskegee University he was a research associate in Florida Center for Advanced Aero- Propulsion. Dr. Solomon's research interests include high speed flow control, actuator development, experimental fluid mechanics and engineering education.

A Study on Student Success in a Blended-Model Engineering Classroom

Abstract

One of the primary issues that many engineering educators face is the lack of engagement of students in their classroom. This becomes a more crucial concern for new engineering educators, many of whom lack any significant teaching experience. While the literature suggests a variety of factors that might negatively influence student engagement, the theory of "Tailored Instructions and Engineered Delivery Using Protocols" (TIED UP) specifically addresses the lack of engagement arising from a weak pre-requisite base and the failure to connect to new concepts in the classroom. This is a blended teaching model where the content delivery follows a set of protocols inspired by the brain-based learning approach. In a typical TIED UP classroom, content delivery is performed using a scripted lecture, supported by short, animated and scripted concept videos that are generated before the class. The class time is carefully planned to include several small active learning pieces associated with each concept. Group work and peer mentoring is also encouraged for all the class activities. Formative feedback is collected from these activities and this feedback guides the activities in the following class. The videos are made available to the students for their further learning. This paper describes the implementation of the TIED UP approach in an engineering classroom in one of the largest public universities in the west coast. A study is conducted to compare the results of the summative assessments from a TIED UP classroom with those from a control semester. The paper highlights the preliminary results from this implementation and some insights for other educators who wish to adopt this technique in their engineering classrooms. Overall, the TIED UP approach is found to be very effective in communicating complicated engineering concepts. The student evaluations of the instructor are also improved in the TIED UP approach.

Introduction

Many new engineering educators start their teaching career with limited to no experience in dealing with students in a formal classroom setting. They find it challenging when it comes to keeping an engaging environment for the students in their classroom. A significant amount of literature suggests that students' academic outcomes are strongly correlated with their engagement in the classroom[1-4]. However, keeping students engaged in a classroom is a complicated issue. There are several factors, as identified by the literature, that influence a student's engagement in the classroom. Some of the examples include perceived ability[5], learning strategies[6], self-efficacy[7], and goal orientation[8, 9]. According to the recent results published by the National Survey for Student Engagement (NSEE), there are four performance indicators for student engagement: academic challenge, learning with peers, experiences with faculty and campus environment[10, 11]. While there are several ongoing efforts to improve engagement in engineering classrooms[12-18], this paper reports the results from the implementation of a blended teaching model at San Jose State University.

"Tailored Instructions and Engineered Delivery Using Protocols" (TIED UP) is a media-rich blended model used for teaching engineering concepts. Developed at Tuskegee University, this model is reported to be effective in improving student grades and their engagement in the classroom[19]. This model relies on the principles of brain-based learning[20-22]. It promotes the delivery of course concepts in the same structure as it is expected to be stored in the human brain. The primary target is to create a virtual neural network of connected concepts and gradually build this concept network in students' long-term memory.

This target is achieved through scripted videos and classroom lectures, supported by active learning techniques. Further details of this method are discussed in the next section of this paper.

As new educators, the authors faced two concerns regarding the implementation of a new teaching method such as TIED UP. The first one was about the student response. TIED UP involved several active learning exercises and required a certain level of commitment from the students to complete. Based on the feedback from several experienced faculty members, students' response to innovative teaching approaches such as a flipped classroom had not been completely positive. The second concern in the implementation was the time commitment for developing the course materials for a complete course. In TIED UP, each course concept required very careful planning and preparation and this demanded a good amount of time commitment from the instructor. This paper reports the experiences of a new faculty in the implementation of the TIED UP class in an applied mechanical engineering course for the first time.

The TIED UP approach

The TIED UP framework is derived based on the network modes of memory[21, 23, 24]. This theory states that information is stored in one's long-term memory by means of a network of interconnected concepts. Based on this theory, if someone needs to master a new concept, they need to place it at the right place within this network and the right place will be determined by the position of the related concepts and pre-requisites. This places the emphasis on the understanding pre-requisite concepts before teaching a new concept to the students. However, previous work[25] shows that a large fraction of students in a core engineering class do not satisfy this requirement. This might lead to the lack of understanding of the concepts and eventually to a disconnect from the course material.

The TIED UP framework aims to address this concern through careful planning in creating the course content. This follows nine protocols while developing course materials. These protocols are: (1) connecting the new concept to the necessary pre-requisite materials, (2) creation of a neural network, (3) integrating an active learning element, (4) repeating the use of neurons, (5) making use of the zone of proximal development (ZPD), (6) Adding an emotional component to the course content, (7) generating patterns of meaning, (8) providing an element of choice, and (9) generation of cognitive maps. A detailed description of these protocols is available elsewhere[25]. This paper focuses on how these protocols are applied in a junior level mechanical engineering design course at San Jose State University (SJSU).

Mechanical Engineering Design at San Jose State University

The Mechanical Engineering Design course is taught as a junior-level required mechanical engineering course at SJSU. Typically, class sizes range from 25 to 40. This paper reports the data from two semesters: a control semester where the course is taught using the traditional lecture method and a treatment semester where the TIED UP course material delivery is performed. The data reported include those from 37 students in the control semester and 25 in the treatment semester. The student population is very diverse in terms of age, work experience and ethnicity. SJSU is a Hispanic Serving Institution (HSI).

The prerequisite concepts of this course originate from courses like basic mathematics (specifically, trigonometry, complex algebra, and geometry), statics, dynamics and mechanics of materials. The course is divided into two modules. The first module deals with the concepts of kinematics and mechanism design. In this module, the students are taught about mechanism synthesis and analysis. In the second module, the students are taught about static and fatigue failure theories along with some case studies of machine component design. The class meets twice a week for 1 hour and 40 minutes each.

Course Material Preparation in TIED UP

In TIED UP, the course material preparation begins with the identification of the concepts involved in the course. Firstly, the course syllabus is revisited to identify the basic concepts involved in the course. The first module (Kinematics) has been divided into 36 discrete concepts, as shown in Figure 1. For the design of the delivery materials, each concept is treated separately. Similarly, the second module is divided into 39 basic concepts.

Once the concept list is ready, the next step is to analyze the resources associated with each concept. The textbook contents and the previous lecture material are analyzed carefully to identify the pre-requisite knowledge necessary to understand that concept. This procedure is according to the first protocol of connecting the course concepts to the required pre-requisite concepts. In class, before the actual concept is delivered, these pre-requisite concepts are reviewed, either in a recorded video format or through a realistic example presented at the beginning of the class.

In a TIED UP classroom, the course material is covered using a mixture of techniques. Each concept is explained using a short video, mostly under 6 minutes. These videos are recorded using a script developed using the nine protocols. The MS PowerPoint slides from the previous semester are divided into additional files according to the concept list. Additional materials are added to these slides according to the pre-requisite information. The target here is to create a virtual neural network with all the connected information, as specified by the second protocol. This additional information includes examples, demonstrations and worked out problems. Each concept video is prepared using multiple examples (with varying levels of difficulty) to promote the repeated use of neurons (protocol 4). Along with the slides, a detailed script is prepared to explain the concept clearly. PowerPoint's animation features are used to support the narration. Once the slides and the script are ready, the video is recorded in the instructor's voice. Then a video editing software is used to remove unwanted content. Majority of the videos for the first module are under 6 minutes long. When a concept mandates more time for explanation, additional time is used for the video.

1. Definition: Kinematics and Kinetics
2. Definition: Linkage and mechanisms
3. Definition: Mechanism and machine
4. Elements of a mechanism – link, joint, ground
5. The ground link
6. Classification of links with # nodes
7. Higher pairs and lower pairs
8. Degrees of freedom – rigid body, linkage (mobility)
9. Full joint & half joint
10. Types of joints in mechanisms and their DOF
11. Form vs force closed joints
12. Open and closed kinematic chains
13. Kutzbach's equation and calculation of DOF/mobility
14. Structure
15. DOF paradoxes
16. Transformation
17. Grashof condition
18. Kinematic inversion
19. Toggle positions
20. Transmission angle
21. Two position synthesis
22. Setting up limits with dyads
23. Three position synthesis
24. Synthesis with fixed ground pivots
25. Quick return mechanism synthesis
26. Dwell
27. Coupler curves & atlas
28. Common useful mechanisms
29. Analytical synthesis of 4 bar mechanisms with 2 known positions
30. Free choices
31. 3 position synthesis
32. Synthesis with fixed pivots
33. Position analysis of mechanisms
34. Velocity analysis of mechanisms
35. Acceleration analysis of mechanisms
36. Dynamic force analysis

Figure 1. The concept list developed for the first module of the mechanical engineering design course

In a typical TIED UP classroom, the same flow as in the script is used to deliver the content. This method differs from a flipped classroom as the content delivery occurs in the class. The video is provided as an additional resource and the script serves the additional purpose of organizing the flow of information during the lecture. The videos are typically made available to students right before the class time. According to the feedback from students, they find these videos very useful for completing their homework outside the class and exam preparation. Many students also report viewing the videos several times, further promoting repeated use of neurons.

While preparing the script, some simple activities are also planned that can be integrated into the class. These active learning elements (protocol 3) are either integrated into the video or performed separately in the class. Some of the techniques utilized include muddy point, group problem solving, simple problem-based concept learning, small concept quizzes, hands-on modeling and in-class discussion. The implementation of these elements mandated very careful planning as they demand extra class time. Some of these, such as hands-on building, are completed as homework to find sufficient time for them.

While selecting the examples for the class material, care is taken to include realistic examples. These examples are targeted to connect the course concepts to realistic situations and provide students an emotional attachment to them (protocol 6). Further, the students are explained how each concept is connected to the previous one and the future concepts they are about to learn through a detailed concept list (as in Figure 1) and through a concept map (protocol 9), as shown in Figure 2. A concept map presents the relation between the concepts they learn in a visual format. The original TIED UP framework proposes metacognitive generation of these concept maps; however, this is not performed due to time limitations. Both the concept list and the concept maps are expected to generate patterns of meaning for the students (protocol 7).

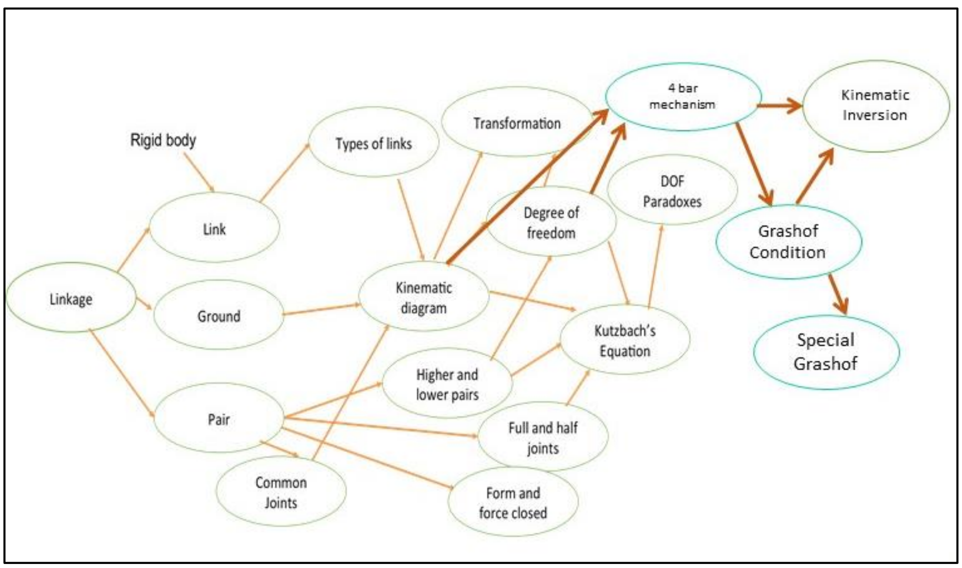


Figure 2. The concept map for the "kinematic inversion" lecture

Another protocol that is used for the mechanical engineering design course is the "element of choice" (protocol 8). In a typical classroom, some students understand the course material quickly, while others struggle to master that information. While repeating the same information, there is expected to be a group of students who feel bored. In order to address the needs of the diverse class population, the same information is presented in multiple formats. They are also directed to further materials, lecture notes or videos for further information. These materials are made optional and are not included in the exams.

Zone of proximal development (protocol 5) is the only protocol that is not formally applied in this course. In this protocol, students solve their problems in a shared collaborative workspace where the instructors can provide live feedback on their work. This protocol is not implemented in this study due to unavailability of the required hardware for the same.

Method

This study was designed as a control vs treatment comparison. The same instructor taught the mechanical engineering design course in two semesters. The first semester was used for control data collection and the development of the course materials for the treatment semester. In order to avoid any bias, the same concept list was used in the control semester and the materials were presented in the same order. The teaching in the control semester was performed using the same techniques as prior semesters. PowerPoint presentations were used along with class problem solving, occasional hands-on activities and a semester-long project.

In the treatment semester, TIED UP materials were used for the delivery of course materials. The lecture became very interactive and supported by the active learning elements. While planning for the class, the activities were carefully planned so the instructor did not talk for more than 15 minutes continuously in any class. The students were always encouraged to work in self-formed groups. Group work was encouraged for discussions, problem-solving, homework and exam review sessions. The classroom activities were supported by the videos posted on a virtual interface and the students had access to these videos throughout the semester. Further, solutions to the problems solved in the class were also posted in the virtual interface. A comparison between the two semesters is shown in Table 1.

Table 1. A comparison of activities across the control and TIED UP semesters

Activity	Control	TIED UP
Lecture	X	X
Script for the lecture		X
Animated short videos		X
Hands-on activities	X	X
Demonstrations		X
Problem solving in class	X	X
Group work		X
Peer mentoring		X
Semester-long project	X	X
Active learning		X
Virtual interface (hosting course materials)	X	X
Formative assessment		X
Summative assessment	X	X

Another integral component of the TIED UP approach was the formative feedback collected from the in-class activities. The materials collected from the in-class activities were immediately reviewed after the class and any missing information was added to the next lecture's script. This helped to clarify any points that were not very clear in the previous class. These additional clarifications were typically included at the beginning of the next class as a review of the previous class' materials. These class activities were graded to ensure participation, but the total grade for these added to only 10% of the actual course grade.

Data collection was performed using the summative assessments in the course - two midterms and the final exam from both the semesters. Across the two semesters, the exams were kept consistent with nearly identical questions. These questions primarily tested the conceptual knowledge of the students rather than their ability to memorize formulae. In fact, required formulae were provided to them during the exam in a formula sheet. The same instructor graded the exams both the semesters and a detailed grading rubric was followed to ensure consistency in grading.

The students were requested to participate in the research study by signing a consent form. The data from only those who signed the written consent were included in the analysis. They were provided some extra credit for allowing the investigators to use the data from their exams. After each exam, the data were anonymized using code numbers and the names of the students were removed from the exams. The code numbers were used for the analysis of the data.

Results & Discussion

Student Performance in a Difficult Concept

The implementation of the TIED UP framework shows some promising results. There is some visible improvement in the enthusiasm of the students in learning the concepts. Several of the students provided unsolicited feedback on the course content and the video material and suggested additional activities for learning the concepts. While these informal interactions are not recorded, the collected data also show an encouraging trend. Here, we report the analysis of the student grades in one of the most difficult concepts in this course - analytical synthesis of mechanisms.

Analytical synthesis involves the identification of a mechanism that satisfies certain specified requirements using complex algebra and trigonometric analysis. Students find this a difficult topic due to the requirements of several pre-requisite mathematical concepts and the ability to visualize a mechanism that does not exist. In TIED UP, this concept is taught using several hands-on activities and CAD models, in addition to the other course materials. In a regular semester, students lose several points on the conceptual questions from analytical synthesis. Typically, these questions are included in their first midterm and the final exam. Figure 3 shows a comparison of the average class grades in these questions across the control and TIED UP semesters.

These data show that the student grades in the TIED UP class are significantly higher compared to the control. Only analytical synthesis problem is used for this analysis, as it is regarded as one of the most difficult concepts by the students and the instructors of this class. In Figure 3, the different questions represent the following: Q1. Identification of a proper vector loop to synthesize a mechanism for completing a given purpose; Q2. Writing the vector loop equation for the selected vector loop; Q3. Identification of the variables to solve for and Q4. Identification of the number of “free choice” variables needed to solve the equations and the selection of the free choices. Typically, students are not asked to solve the equations and find a complete solution due to the time limit during the exam.

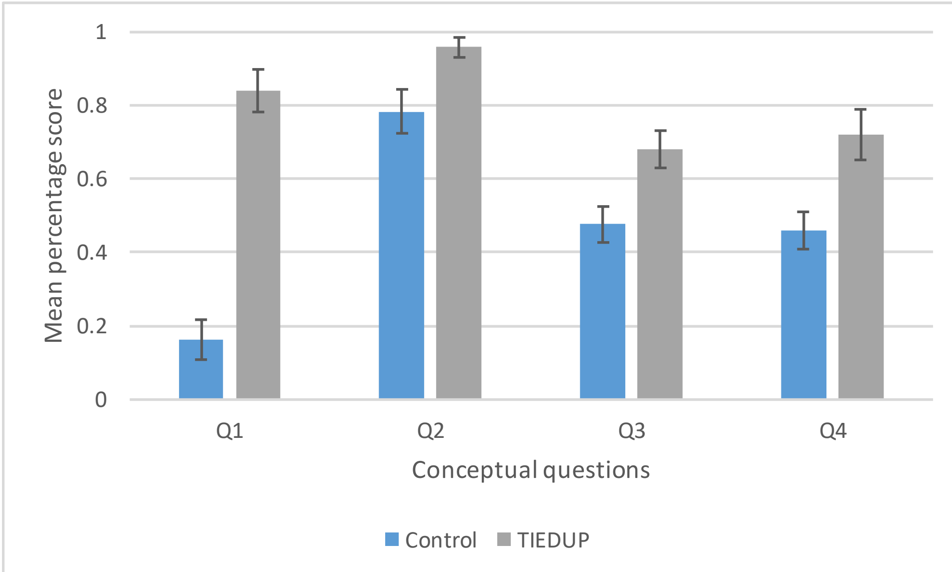


Figure 3. Comparison of the student grades across the control and treatment semesters for the analytical synthesis questions

Table 2 shows the results from the statistical comparison of the grades across the two experimental groups. They show that for all the four questions related to analytical synthesis, the TIED UP group performed significantly better compared to their peers. Informal discussions with some of the participants also revealed that the students who learned this concept using TIED UP possess significant confidence in doing analytical synthesis on their hands-on class project and in their future projects on mechanism design.

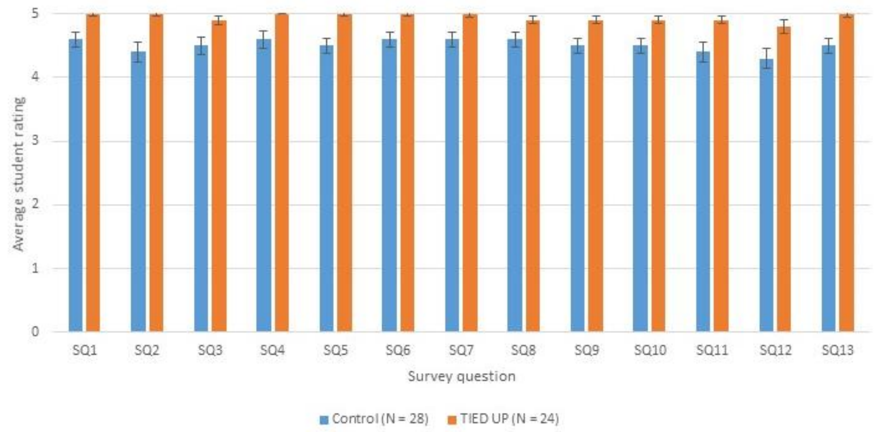
Table 2. Results from the t-test comparisons between the grades of the control and treatment groups for each question

Question	t-statistic (two-taled)	p-value	Remarks
Q1	8.47	<0.01	Significant
Q2	2.30	0.02	Significant
Q3	2.76	<0.01	Significant
Q4	3.07	<0.01	Significant

Significance is calculated using $\alpha = 0.05$

Students' Evaluation of the Instructor

As a new educator, one of the factors that the authors worry about is the student evaluations. In a TIED UP class, students work harder compared to a traditional lecture class where they take notes and solve occasional problems. In the TIED UP class, they do not continuously listen to a lecture for a long period of time. Every 15 minutes of the class time, they have an activity to work on. The feedback from the formal student evaluations conducted by SJSU shows that students generally like the TIED UP approach, as shown in Figure 4. The evaluation contains 13 questions, mostly related to the effectiveness of teaching. In general, the student evaluations are significantly higher in the treatment semester compared to the control for the same instructor. Among the 13 survey questions, SQ1, SQ2, SQ3, SQ5, SQ7, SQ9 and SQ11 are important in the context of the TIED UP framework as this teaching method stress these specific factors.



SQ1	Demonstrated relevance of the course content
SQ2	Used assignments that enhanced learning
SQ3	Summarized and emphasized important points
SQ4	Was responsive to questions and comments from students
SQ5	Established an atmosphere that facilitated learning
SQ6	Was approachable for assistance
SQ7	Was respectful of the diversity of students in the class
SQ8	Showed strong interest in teaching this class
SQ9	Used teachning techniques that helped students learn important concepts
SQ10	Used fair grading methods
SQ11	Helped students analyze complex/abstract ideas
SQ12	Provided meaningful feedback about student work
SQ13	Overall, this instructor's teaching was

Figure 4. Comparison of the student evaluations of the instructor from both the semesters

Overall, the TIED UP approach was found to be very useful in teaching an applied mechanical engineering course like mechanical engineering design. The method is especially effective in conveying complicated concepts to students, which are otherwise difficult to communicate. While the preparation for a TIED UP course takes a significant time investment from the instructor, it saves a lot of time in further semesters of teaching the same course. Once the materials and script are ready, the instructor simply needs to incorporate any student feedback into these materials and periodically improve them. On the other hand, these materials are found to be effective in improving student grades and their satisfaction in the course.

Conclusions

In this paper, we present the preliminary results from the application of the "Tailored Instructions and Engineered Delivery Using Protocols" (TIED UP) approach used for course material preparation and delivery in an applied mechanical engineering course. A control vs treatment study design is used for comparison, where a traditional lecture style class acts as the control. The results show that the TIED UP approach is very effective in teaching a complicated concept, for which students get low grades in the control. Using TIED UP, the student grades are significantly improved and their feedback is mostly positive in this teaching approach. Although the preparation of the course materials takes a significant time commitment from the instructor, the results show that TIED UP is definitely an approach that can help new faculty to improve their teaching and student evaluations.

References

[1] Carini, R.M., Kuh, G.D., and Klein, S.P.," Student engagement and student learning: Testing the linkages", *Research in higher education* Vol. 47, No. 1, 2006, pp. 1-32.

[2] Ewell, P.T.," Outcomes, assessment, and academic improvement: In search of usable knowledge", *Higher education: Handbook of theory and research* Vol. 4, 1988, pp. 53-108.

[3] Astin, A.W.," Student involvement: A developmental theory for higher education", *Journal of college student personnel* Vol. 25, No. 4, 1984, pp. 297-308.

[4] Berger, J.B., and Milem, J.F.," The role of student involvement and perceptions of integration in a causal model of student persistence", *Research in higher Education* Vol. 40, No. 6, 1999, pp. 641-664.

[5] Mac Iver, D.J., Stipek, D.J., and Daniels, D.H.," Explaining within-semester changes in student effort in junior high school and senior high school courses", *Journal of Educational Psychology* Vol. 83, No. 2, 1991, pp. 201.

[6] Pintrich, P.R., and De Groot, E.V.," Motivational and self-regulated learning components of classroom academic performance", *Journal of educational psychology* Vol. 82, No. 1, 1990, pp. 33.

[7] Schunk, D.H.," Introduction to the special section on motivation and efficacy", *Journal of Educational Psychology* Vol. 82, No. 1, 1990, pp. 3.

[8] AMMES, C., and AMES, R., "Research on Motivation in Education. Vol. I, Student Motivation": Londres. Academic Press, 1984.

[9] Nicholls, J.G.," Achievement motivation: Conceptions of ability, subjective experience, task choice, and performance", *Psychological review* Vol. 91, No. 3, 1984, pp. 328.

[10] "Engagement Indicators & High-Impact Practices", 2016.

[11] Kuh, G.D., *National survey of student engagement: The college student report: NSSE technical and norms report*: Indiana University Center for Postsecondary Research and Planning, 2001.

[12] Sandholtz, J.H., *Teaching with technology: Creating student-centered classrooms*: ERIC, 1997.

[13] Zhao, C.-M., and Kuh, G.D.," Adding value: Learning communities and student engagement", *Research in higher education* Vol. 45, No. 2, 2004, pp. 115-138.

[14] Gallini, S.M., and Moely, B.E.," Service-learning and engagement, academic challenge, and retention", *Michigan journal of community service learning* Vol. 10, No. 1, 2003.

[15] Hmelo-Silver, C.E.," Problem-based learning: What and how do students learn?", *Educational psychology review* Vol. 16, No. 3, 2004, pp. 235-266.

[16] Smith, K.A., Sheppard, S.D., Johnson, D.W., and Johnson, R.T.," Pedagogies of engagement: Classroom-based practices", *Journal of engineering education* Vol. 94, No. 1, 2005, pp. 87-101.

[17] Mott, J., and Peuker, S., "Using team-based learning to ensure student accountability and engagement in flipped classrooms", *ASEE Annual Conference & Exposition, Seattle, Washington. doi*, 2015, pp. 25022.

[18] Koretsky, M., Nolen, S., Volet, S., Vauras, M., Gilbuena, D., and Tierney, G., "Productive Disciplinary Engagement in Complex STEM Learning Environ-ments", *ASEE Annual Conference*, 2015.

[19] Solomon, J., Viswanathan, V., Hamilton, E., and Nayak, C., "Improving Student Engagement in Engineering Using Brain-Based Learning Principles as Instructional Delivery Protocols", *ASEE Annual Conference*, Columbus, OH, 2017.

[20] Weiss, R.P.," Brain based learning", *Training & Development* Vol. 54, No. 7, 2000, pp. 21-21.

[21] Jensen, E., *Brain-based learning: The new paradigm of teaching*: Corwin Press, 2008.

[22] Caine, R.N., and Caine, G.," Reinventing schools through brain-based learning", *Educational Leadership* Vol. 52, 1995, pp. 43-43.

[23] Matlin, M.W., "Cognition": NJ: Wiley, 2005.

[24] Ally, M.," Foundations of educational theory for online learning", *Theory and practice of online learning* Vol. 2, 2004, pp. 15-44.

[25] Viswanathan, V., Solomon, J., Unnikrishnan, V., and Hamilton, E., "Improving Student Engagement in Engineering Classrooms: The First Step towards a Course Delivery Framework using Brain-based Learning Techniques", *ASEE Annual Conference*, New Orleans, LA, 2016.