On the Use of Brain-Based Learning Protocols in Fluid Mechanics Instruction

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Abstract

A personalized and media-rich learning framework called "Knowledge and Curriculum Integration Ecosystem" (KACIE) has been developed and implemented in a junior-level fluid mechanics course in Fall 2016, Spring 2017, Fall 2017, and Spring 2018, in a prominent HBCU. This model shares characteristics of blended instruction as well as a flipped classroom, with an overall structure that includes the application of established principles emerging from the learning sciences and cognitive neuroscience. These principles have taken form in the KACIE model as classroom protocols or written instructions to scaffold and guide teaching and learning. In KACIE, the course has been presented as a sequence of 55 concepts that each connect to its pre-requisites. Scripted and animated short self-contained video lectures of 2-6 minutes duration and mandatory in-class activity sheets were developed and used for teaching each of the 55 concepts. This paper presents details of the KACIE model and its impact on fluid mechanics instruction by comparing relevant data from a control semester (Fall 2015) when the same course was offered in a traditional teaching environment. The results show that this media-rich KACIE intervention in an HBCU has significantly improved students' academic engagement and success, substantially reduced failure rate, and enhanced their critical thinking ability.

I. Introduction and background

Despite progress and fresh thinking in recent years, 21st century STEM education in the US still faces significant challenges [1-3]. A positive notion that relying solely on the traditional lecture is ineffective to engage students so fully connected to a digital world has led to numerous efforts to integrate technology into the teaching-learning process [4, 5]. The issue of classroom disengagement is critical as sizable literature indicates that engagement has a strong correlation to student's academic and professional success [6-9]. Student disengagement in the engineering classroom has proven challenging for several reasons. Lack of preparation, self-efficacy, perceived ability, socio-economic factors, and less-effective course delivery methods are contributing to the core issue of classroom disengagement [10-17]. Continuous development of mathematical skills and an in-depth understanding of pre-requisite concepts are considered preconditions for academic success in engineering. The lack of these essential ingredients can lead to attention problems, aversion to the course, and finally to overall poor performance. While such issues are partly addressed by curriculum rules which enforce mandatory pre-requisite courses, a major fraction of students still enroll to higher-level with the minimum grade allowed to move on in these pre-requisites. With deficient or subpar foundations, they may face more difficulties and eventually drop out or change their engineering major for academic survival. While this issue is prominent in all engineering programs across universities, it becomes more critical in Historically Black Colleges/Universities (HBCUs).

Teaching-learning models that blend technology with a traditional lecture to ensure the quality of instruction have been reported promising for engaged and effective learning of higher-level skills [18, 19]. Exploiting more fully the potential of online web-assisted tools along with face-to-face meaningful and engaging interactions inside classrooms, the blended learning methods have often successfully merged traditional teaching with computer-assisted instructional models of the modern era [20]. In one variation of this approach, online video lectures and other instructional materials were used for skill preparation and learning before the normal hours designated for classroom engagement. A viable instructional model emerged from this, involving subsequent face-to-face interaction of faculty with students through problem-solving, active learning, and skill application, within the classroom environment [21]. This model is intended to help shift the role of the teacher from that of a traditional lecturer to that more prominently of a mentor, trainer, or consultant, who actively participates with students in their learning activities. The model is reported to be promising for providing an engaging learning experience for engineering students [22- 24]. Numerous studies indicate that these technology-integrated instructional methods, including those that formally feature classroom flipping, provide an opportunity for active and interactive learning, particularly in engineering education. Many have significantly improved academic success in terms of problem-solving skills, quick learning, and deeper-structure understanding and use of concepts [25, 26]. Many studies report that such methods have reduced the failure rate in comparison to instruction methods that merely rely on traditional lectures for content delivery and classroom management [27].

Although technology integrated instructional models were reported promising for providing an improved teaching-learning experience for the millennials, not many efforts to understand how this increased effectiveness scientifically connects to the neurobiological phenomena, which forms the basis for the fundamental process of learning. Essentially, from a neuroscientific point of view, learning is considered as a gain in the ability to perform a certain task or transformation/expansion of knowledge level of an individual made possible through circuit firing within the brain that are manifested by electrochemical processes called synapses [28]. In this sense, it is trivial that the development of effective instructional models must have a connection to the neuro-biological science of learning and conceptualization. Although there have been several attempts to develop structures for formal neuro-science guided instruction, they were limited to the K-12 educational system and have met with significant criticisms that they were inconclusive, premature, and distorted [29-31]. A recent attempt [32] has explored possible connections of efficient classroom activities to the neurobiological basis of learning.

Although the metacognitive aspect of learning remains elusive in neuro-biology research, it is logical that teaching and learning have a strong connection to the phenomena of neural plasticity. As experienced teachers, we believe that conceptual understanding is very important in engineering education, as it leads to knowledge organization within the brain. Combining the best practices of teaching and learning with the current understanding of the neurobiology of learning [33-43], it is possible to develop instructional models that are effective for the next generation.

Based at an HBCU-designated school with extensive support from the National Science Foundation (NSF), we initially investigated the gap between our expectations and student performance in the mathematical competencies and preparation for advanced coursework [44-47]. As observed, such weaknesses connect to the level of student academic engagement – both inside and outside of the classroom [44]. This study, attempting to address student weaknesses by addressing low academic engagement levels, led to the design and exploration of the

Knowledge and Curriculum Integration Ecosystem" (KACIE), in which a framework that organizes research-based principles from the learning sciences and cognitive neuroscience into practical protocols or patterns for classroom learning and teaching. The overall aim has been to foster a research-based and media-rich classroom ecosystem for an engaged and improved learning experience that effectively prepares students to succeed in upper-level courses. The model we present not only blends critical and established research findings in learning with multimedia, but it also uses shared screen feedback and other digital tools to significantly alter what can be called the attentional intensity of the course [48-51]. Students are more engaged both in and out of class time with course material, and instructors can direct attention to each student's unique concept-building journey. The KACIE model we present in this paper shares, at the college level, important aspects of cognitively-guided instruction approach (CGI) 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 stepwise and large structure level by drawing the instructor into a more finely grained involvement in the process [52,53]. The detailed descriptions of the KACIE model and methods used in the control and the intervention semesters are discussed next.

II. Methods

Table 1 summarizes the details of students participated in the control and intervention semesters from the Mechanical Engineering department of Tuskegee University, which is classified as an HBCU. Fall 2015 was used for collecting control data. KACIE intervention has been carried out in four semesters from 2016-18 as indicated in Table I. Twenty students (n=20) were participated in the control group and 88 students have participated in the intervention that span over four semesters.

Semester	Instructor	No. of students
Fall 2015 Control Group	Solomon	20
Fall 2016 Using KACIE Model	Solomon	21
Spring 2017 Using KACIE Model	Solomon	33
Fall 2017 Using KACIE Model	Solomon	20
Spring 2018 Using KACIE Model	Solomon	14

Table 1. Summary of student participation in this study

Table 2 summarizes distinctions between the methods used in the comparison and intervention periods. In the comparison/control semester (Fall 2015), the course content is categorized as eight chapters, like the representation in a standard textbook that is adopted for the course. This junior level, three credits, fluid mechanics course has three contact hours every week during the semester. The content of each chapter is delivered traditionally, with extensive use of the whiteboard, homework assignments for each chapter, and with a summative test every two chapters. Twenty percentage weightage of the course grade has been given to the homework assignments and 80% weightage to the four summative tests that span the semester at equal intervals. At the end of the semester, letter grades were assigned based on their performance in homework assignments and the four summative tests.

In the KACIE model intervention, the Fluid Mechanics course comes to students explicitly as a sequence of interconnected concepts and sub-concepts in which course content is presented as short, scripted animated video lectures in a YouTube channel (http://bit.ly/tuskegee-tiedup) in the same format as they experience inside the classroom. The key feature of this tailored instructional content is that it uses presentation and interaction tools that are developed based on several protocols that appear in Fig. 1. The protocols used for concept delivery are identified by the key principles they represent: 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,

Activity/Method	Traditional	KACIE
Course Content	Categorized as 8 Chapters Power point slides that that cover each chapter provided as instructional material <u>after each</u> lecture Extensive use of lecture notes and demonstrations in whiteboard	Categorized as 55 concepts and 22 sub-concepts Short-scripted, animated video lectures on each concept posted and available to students 24x7 Students have to prepare before coming to the lecture Demonstration in class using these pre-made videos KACIE based material development and delivery
Pre-class	None.	Inform student the concepts to be discussed. Ask them to watch KACIE video lectures (2-6 mint duration maximum)
In-class	Lecture, students takes notes, solve problems based on white board demos	Lecture using KACIE video (5-15 min.) Each student work on his/her KACIE sheet developed for EACH of the concepts Mandatory submission of sheets Peer discussions allowed Teacher work with individuals on demand Repeated view of video lectures Zone of proximal development Quizzes using Microsoft surface pros, digital ink and screen sharing
Assessment	Assessment of homework on each chapter (20% credit) and feed-back Summative assessment by Four tests for two chapters (80% credit)	Assessment on KACIE sheets for each concept (20% credit) and feed-back Summative assessment by Four tests for 10-15 concepts together (80% credit) Critical thinking assessment (CAT) Test before and after

Table2. Summary of methods used in traditional and KACIE approach

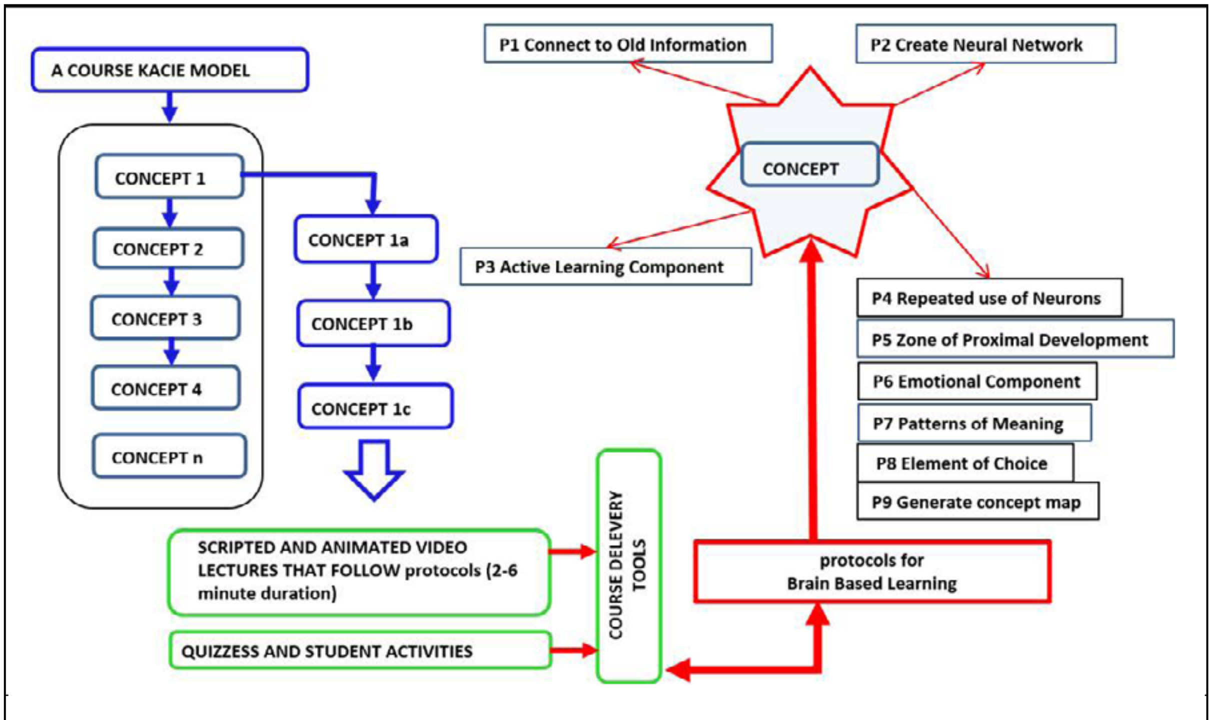

Fig. 1. Elements of KACIE framework and several protocols used for content preparation

P7 – Patterns of meaning, P8 – An element of choice and P9 – Create a cognitive map. These designated protocols were identified from research reported on neuroscience that explored neuro-physiology of learning. Each of these constructs was studied extensively for its respective significance in education at different levels [38-49].

The neuro-biological significance of each protocol and how these protocols are used for content preparation and delivery are discussed next. The protocol 'P1-Connect to old information' is essentially a guideline to the instructor to discuss or to refresh the most important concepts that are immediately related to the concept under consideration. Neuro-biologically this pre-conceptual understanding is extremely important to move forward in the learning process. Mandatory inclusion of informative content that revises or refreshes prior connected memories will excite neurons and synapses that are formed during the learning process. The intention is to revive those connections so that the new ideas can be integrated logically to the pre-requisite information. The instructor's ability to connect the present topic to something they already knew is the key to this protocol. At this initial stage, the instructor also tries to erase any misconceptions that students may have regarding a pre-requisite concept. Apart from this, from a student's point of view, it is important to realize that the pre-information revised using protocol 1 is essential to understand the concept under consideration.

The second protocol 'P2-Create neural connections' is a segment in the instructional sequence where a new concept is presented after the pre-requisite review. The third protocol 'P3-Active learning component' presents a problem or a deliberate practice of the skills mastered in the previous section P2. Neurologically, the practice of a problem is the best method for the development and re-enforcement of synapses [55]. The content of this segment demonstrates a real-life problem related to the concept under consideration. It is an accepted fact that problem-solving improves the learning skills of all classes of students [56-59].

The fourth protocol 'P4-Repeated use of neurons' demonstrates a second practical problem, very similar to one discussed in segment P3. The memories are believed to be encoded as synaptic networks and this electro-chemical manifestation of memory can be retrieved or re-activated when students repeat an exercise they have just understood. The essential goal of P4 is a repetitive demonstration of a practical problem so that the process will reactivate the entire network of synapses that have been formed during the segment P3. Now, we have the content described in segment P2, connected to a real-world situation twice through the demonstrative solutions in segments P3 and P4. We expect that these mandatory processes described from P1 to P4 will help them to understand a concept more effectively.

The fifth protocol, 'P5-An emotional component', looks for an emotional event that can be connected to the knowledge segment described in segment P2 of the video content. Neuroscience research confirms that emotions can convey memory benefits for positive aspects of experiences. Emotions can also lead to enhanced recruitment of conceptual processes [60]. It may not be possible to connect every concept with this protocol. However, if there is a story or event that can be linked to the concept under consideration, it could be used as segment P5 in the video.

We adopted screen sharing as well as the incorporation of pen-based input for solving engineering problems in class, enables what has been termed "micro genetic analysis in giving feedback", whereby the college instructor can see conceptualizations more clearly and form more exact inferences in real-time about student conceptualization [61]. This enables rich, real-time feedback in ways that correspond closely to the sixth protocol that KACIE emphasizes, 'P6- ZPD exercise' most directly to Vygotsky's zone of proximal development [62, 63]. Surface tablets and scree screen software have enabled instructors to see student work and to give feedback in real-time [64]. The shared screen arrangement follows a logic model, in which students are aware that their work is always visible to the instructor and the instructor is always available to see and respond to questions.

Since KACIE envisions course content as a sequence of interconnected concepts, it is important to discuss the collective meaning of concepts. If there is an overall picture to evolve, then this integrated meaning is presented in the segment P7 –'Patterns of meaning' of the video content. This description will emphasize a bigger picture of several concepts. This segment may promote creativity and development of a sense of ownership on what they are learned if they identify a pattern of meaning by themselves [65]. By the protocol P8-'An element of choice', the KACIE model envisions inclusion of a segment that deals with higher-level understanding or a prevailing generalized view of the concept under consideration in the video content. For a beginner, this segment may not be useful or hard to understand. But this would be a valuable addition for another student who has previous exposure to this concept. Finally, the last protocol P9- 'Generate concept map' will summarize the entire video content into a concept map. Many studies report that concept maps enhance comprehension and a good tool to revise the concept more effectively [66].

The protocols used for developing the video content of concept 32 (C32), Bernoulli's principle, is discussed below as an example. Please watch this concept video C32 available on YouTube channel http://bit.ly/kacie-videos. The protocol P1 connects to old information and seeks review of the concepts steady flow, streamline, and inviscid flow (they are concepts C-29, C-30, and C-31 respectively) since concept 32 requires these as pre-requisites. A review of these pre-requisites will refresh memory, allowing re-

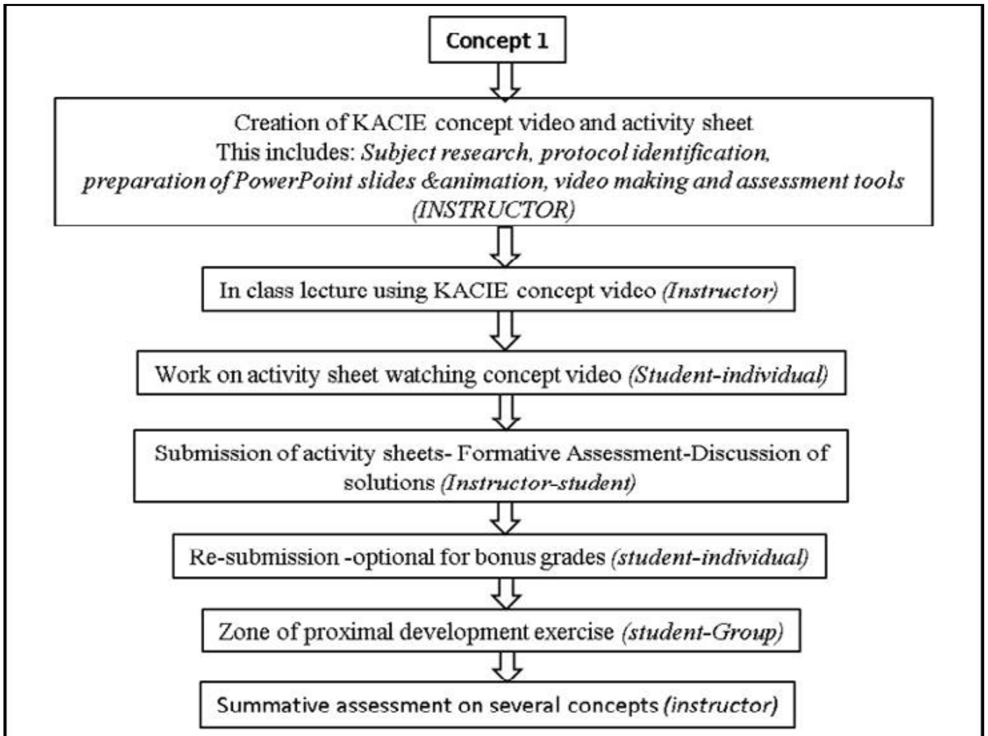

Fig. 2. Flow chart of a concept delivery in KACIE model

freshed neural associations or connections. P1 also reviews the basic concept of Newton's second law of motion applied to a particle in motion and relations 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 a mathematical formulation of Bernoulli's principle followed by a simple equation, describing the 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 the velocity of a given flow configuration. P4 mandates a description of another problem for re-enforcement of the same idea. P5 brings a real-life problem, for example, calculation of airspeed using a pitot tube fixed to an aircraft, which is slightly harder than problems discussed in section P3 and P4. In this ZPD exercise, students were asked to solve this problem in a collaborative manner using a shared digital workspace with the "invisible" supervision of faculty who could help through helping within the workspace. P6 brings a summary of this principle as a cognitive map. In the 'Bernoulli's concept' example, only 6 protocols were used. On average, 4-6 protocols used in each video of the 55 interconnected concepts the curriculum entitles.

A flow chart that shows the activities of the KACIE 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 student, the engineering skills they are acquiring, and the classroom instructor. In the KACIE model, students see the course differently, as 55 interrelated concepts rather than as book chapters. The course organization centers on learning, not on divisions in a book. While this may seem a subtle difference, making the concepts rather than chapters of paramount salience, fosters a concept-focused mindset.

In the KACIE model, learning begins with the instructor who creates a concept video. This involves subject research, protocol identification, scriptwriting, animation, audio and video making, editing, and final upload to a webpage. These concept videos are very short and are accessible to all the students before the same concept is formally introduced in the class. Along this process, activities associated with this concept are also prepared in advance as "KACIE sheets", which include short quizzes that test conceptual knowledge and problems of varying levels of complexity. The in-class lecture is the next step, using the KACIE concept video prepared which normally takes 2-6 minutes. Depending on the interconnection between the concepts, 2 to 3 concept videos along with a short instructor-led discussion take place in class followed by students attempting the KACIE sheets. Each KACIE sheet surveys the frequency of individual views, as well as students' understanding level in a 0 to 5 scale after completing all prescribed activities.

In the activity sheets, harder problems were broken down to basic intermediate levels so that students who encounter difficulty with intermediate steps will be given a quick review of pre-requisites. Such a strategy will help both faculty and student to rectify the teaching/learning disabilities experienced during the instructional process. The KACIE sheets also create a form of embedded assessment, evaluated every week as part of the homework grade assessment, and as a means for formal and timely performance feedback. In a typical 50-minute lecture, 20-30 minutes are allotted for working on the KACIE activity sheets. Several students complete this sheet within the class period and the rest submit it during the next class if additional time is required. The activity sheets comprise 20% of the overall course grade. These regular activities help the instructor to 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. The 80% of the course grade is decided over four summative tests, conducted every quarter, which altogether evaluates 12-15 concepts. Before each quarterly summative evaluation test, an in-class, a cumulative ZPD exercise based on principles of Vygotsky's zone of proximal development (ZPD) is performed using a digital collaborative workspace. Tablet computers allowing digital ink (Microsoft Surface™ Pro tablets to date) are used in the ZPD protocol activities; two students work together to solve difficult problems collaboratively on a single device. Screen-sharing software (Lanschool™ or Mythware™) is used for online interaction of student activities by the faculty for instantaneous feedback on the real-time problem-solving exercises.

III. KACIE Intervention-Data and analysis

The students enrolled and participated in the intervention semesters Fall 2016, Spring 2017, Fall 2017, and Spring 2018 are n=21, n=33, n=20, and n=14 respectively. During the control period (Fall 2015 semester) n=20 students were enrolled and participated. Student surveys indicate that, on 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. To date, these videos have been watched nearly 60000 times with a total view time of more than 1500 hours over 125 countries, based on YouTube statistics.

Fig. 3 shows a comparison of the test scores of the KACIE group in the four intervention semesters with the control group (Fall 2015). In all four tests and all intervention semesters, the average test scores of the students trained through the KACIE pedagogy was better than those who were in the control group. To keep the data comparable, these tests were administered with a similar level of difficulty. To compare statistically, t-tests were performed on the data on the two groups. Statistical comparison between control and KACIE semesters shown in Table 3 indicate that except for spring 2018, the difference in perfor-

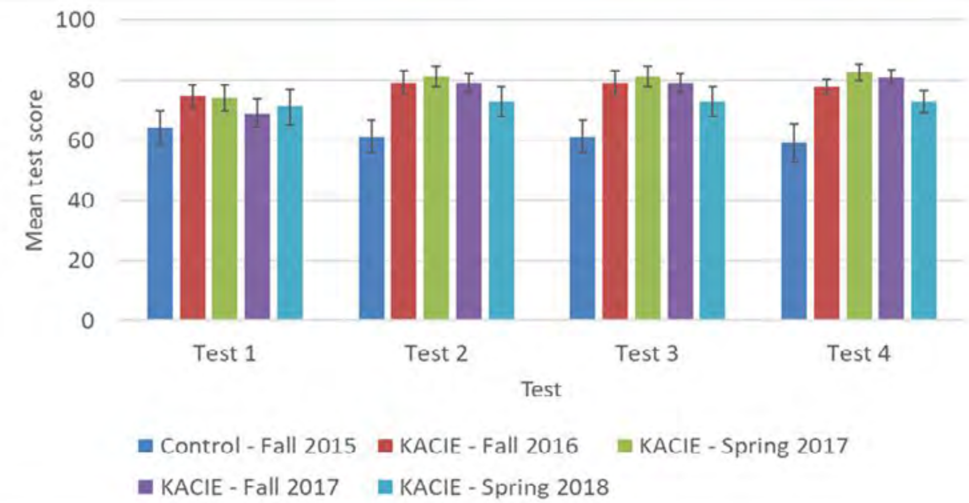

Fig. 3. Comparison of average test scores across the control and KACIE classes

	KACIE implementation semester			
	Fall 2016	Spring 2017	Fall 2017	Spring 2018
Test 1	0.138	0.165	0.513	0.397
Test 2	0.011*	0.004*	0.007*	0.120
Test 3	0.011*	0.004*	0.007*	0.120
Test 4	0.012*	0.002*	0.004*	0.073

*statistically significant

Table 3. Test comparison between control and kacie semesters

mances in test 2, 3, and 4 was statistically significant. In all semesters, Test 1 was not statistically significant although the average score improved from the control semester.

To understand possible reasons for the statistically insignificant observation in spring 2018, we have analyzed the media engagement in each intervention semesters. The view count and watch time data for the videos used for fluid mechanics intervention is tabulated in Table 4. A statistical average of these two parameters, which is video watch time per person and view count per person, is also calculated. These indices for spring 2018 are the least among all the intervention semesters. The highest indices of 311 minutes/person and 132 views/persons were noted in the fall 2016 semester followed by 263, and 119 in Fall 2017. In both spring semesters, the indices were observed 50% less than the fall semesters. This data points to a peculiar characteristic of students enrolled in fall and spring semesters. Normally, students enrolled in Fall are observed to be better as many of them complete the pre-requisite math courses on time and register for the Fluid Mechanics course progressively as suggested by the curriculum. This data also point to the fact that academic engagement through media plays an important role for statistically significant changes seen in test scores in the intervention semesters.

Another observation is that the students following KACIE pedagogy did not show statistically significant improvement (note that all tests averages improved from control) for Test 1 consistently in all four intervention semesters. We believe that after test 1 assessment, students realize that engagement with the course content is important for them to do better in subsequent tests. Also, we believe that lack of pre-requisite knowledge adversely affects early course performance, and as the course proceeds the self-contained KACIE video lectures strengthen the foundation and improve their learning outcome, as observed in the statistically significant data of test 2, 3 and 4.

Comparison of Critical Thinking Ability of Students before and after the intervention

Since KACIE focuses on research developments in the learning sciences and cognitive neuroscience the course was expected to instill deep learning and develop critical thinking in the students. To identify the degree to which their critical thinking ability was improved after attending a KACIE model course, critical thinking assessment test (CAT) developed by Tennessee Tech University [67] was administered as pre- and post-test for the treatment group in two semesters. The CAT instrument consists of questions derived from real-world situations that require a short answer and essay responses. This measures the students' ability to evaluate and interpret given information, problem-solving skills, creative thinking, and effective communication skill. The detailed scoring guide and the scoring mechanism ensure scoring reliability and test-retest reliability. The validity of this measure has been established in the literature [67].

The CAT test was administered to a class of 21 students in Fall 2016 and 26 students in Spring 2017. However, only 17 tests were used for the *final scoring* in the Fall 2016 tests, as one student missed the pre-CAT test or due to multiple unanswered questions. 88.2 % of the population was African American among the Fall 2016 batch and 96.2% population was African Americans among the Spring 2017 batch. 11.8% were of Spanish, Hispanic, or Latino ethnicity in the Fall 2016 group whereas it was 3.8% among the Spring 2017 group. 94% of the students considered themselves as primarily English speaking among the Fall 2016 group while 96.2% in Spring 2017.

YouTube statistics

Period	Watch time (minutes)	Views
Jan 15, 2018 – May 15, 2018, Alabama	1,589	840
Aug 15, 2017 – Dec 15, 2017, Alabama	5,253	2,366
Jan 15, 2017 – May 15, 2017, Alabama	5,491	2,368
Aug 15, 2016 – Dec 15, 2016, Alabama	6,540	2,768

Semester	No. Students	Video watch time/per person during semester	Views/per person during semester
Spring 2018	14	113 minutes	60
Fall 2017	20	263 minutes	119
Spring 2017	33	167 minutes	72
Fall 2016	21	311 minutes	132

Table 4. Youtube watch time statistics

Fall 2016

		N	Min.	Max.	Mean	Std. Dev
CAT Total Score	PRE	17	1.00	30.00	12.59	6.76
	POST	17	4.00	28.00	17.00	6.33

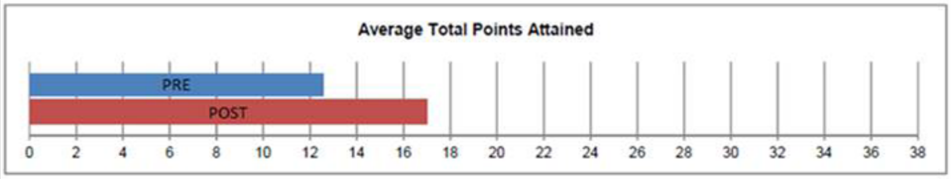

Fig. 4. CAT test results of pre and post-intervention for Fall 2016

29.4% seniors, 64.7% juniors, and 5.9% sophomore were present in the distribution in Fall 2016. 11.5% were seniors, 69.2% were juniors, and 19.2% were sophomores among the Spring 2017 group.

For identifying changes in the critical thinking ability of the students attending the KACIE course, a pre- vs post-test analysis has conducted, using a two-tailed t-test for the comparison. In general, the Fall 2016 data shows a significant improvement in the scores for each question except on two occasions (and the decrease in score was not significant, statistically). For two questions, the t-test showed statistical significance (measured at p-value) less than 0.1. Overall, the total score on the CAT test improved from 12.59 to 17 as shown in Fig. 4, resulting in a 35% change after the KACIE intervention in Fall 2016, and this difference was statistically significant ($p<0.001$). The data from Spring 2017 an improvement of 4% in the overall score. We believe that the use of carefully prepared formative assessment tools, such as KACIE worksheets, and that promotes critical thinking ability skills concerning a concept they have mastered, may have influenced these changes.

IV. KACIE Intervention-student survey and analysis

Table 5 summarizes the details of the student survey at the end of the intervention semester. Data shows that the KACIE sheets did assist in increasing their knowledge of the course materials. The survey also shows that the students very positively accepted the idea of delivery of course materials as concepts. 32% of the students responded that they have a deficiency with the pre-requisites, and it is limiting their learning achievement. 29% of students responded that they watched the concept videos 1-3 times. A majority (57%) watched them 3-6 times. 14% responded that they watched movies 10-14 times. Nearly half of the student population responded that they are more satisfied with KACIE in comparison to other courses. The other half indicated satisfaction at the same level as other courses. A majority (more than 80%) indicated that their confidence increased along the course and videos helped them reach a higher test performance level. Finally, nearly all responded that KACIE sheets were useful for better understanding and learning course concepts.

Students were also allowed to provide feedback and comments for the KACIE course structure. In their opinion, the KACIE videos were short, accessible, to the point, and with sufficient examples and clear diagrams. They also like the background discussion included on each concept. The videos are accessible and helped them to learn at their own pace. They preferred human voice over computer-generated audio. The average video length of 4-6 minutes duration was considered long by some students. Students also suggested more examples and inclusion of more content breakdown videos in the future. The student also liked the ZPD group sessions and KACIE sheets.

V. Conclusions:

This paper reports development, implementation, and impact of a brain-based course delivery framework, titled KACIE, in fluid mechanics course. The primary aim of this framework is to address the lack of engagement and academic deficiencies in engineering classrooms in an HBCU. These include the phenomenon of the gap between our expectations and the performance of students reaching upper-level engineering. Based on the theories on neurocognitive learning, we suggested and implemented several protocols integrated with multi-media for instruction. The entire course material preparation process is guided by these protocols. The content is presented in a media-rich format, and the students have access to these media within and outside the classroom. The intervention data indicate that students who are instructed through the KACIE framework outperform peers in the comparison group. Further, this intervention shifted grade patterns within the class. More students in the KACIE group scored higher grades compared to those in the control group. The critical

		Completely agree (%)				Somewhat agree (%)				Disagree (%)			
		F16	S17	F17	S18	F16	S17	F17	S18	F16	S17	F17	S18
Q.1	The supplementary videos provided helped to understand the course material in better manner	50	65	65	83	50	30	29	17	0	5	6	0
Q.2	These videos equipped me to self-learn the materials in my own pace	80	85	65	100	20	10	23	0	0	5	12	0
Q.3	These videos helped me to prepare for tests with more confidence	80	81	53	75	20	14	41	25	0	5	6	0
Q.4	My confidence level increased as the course proceeded	73	38	65	58	26	52	29	34	0	10	6	8
Q.5	Lack of pre-requisite has played a role limiting my achievement.	19	10	23	18	13	14	18	36	68%	76	59	46
Q.6	I would like to have additional video materials for other courses	74	62	59	67	20	33	41	33	6	5	0	0
Q.7	Course description in terms of 'concepts' is very positive	79	71	82	73	21	29	12	27	0	0	6	0
Q.8	On average, how many times you watched the concept videos	1-3 times (%)				3-6 times (%)				6-10times (%)			
		29	55	20	82	57	40	47	18	14	5	33	0
Q.9	Overall satisfaction in this course delivery in comparison to other courses	Better satisfied (%)				Satisfied just like any other course (%)				Not satisfied (%)			
		47	33	47	58	47	62	47	42	6	5	6	0
Q.10	In class KACIE sheets were useful for better understanding of concept and learning	Agree (%)				Somewhat agree (%)				Disagree (%)			
		67	81	77	83	34	19	23	17	0	0	0	0

Table 5. Student survey response

thinking assessment test (CAT) score before and after intervention shows a substantial change. In summary, these results indicate that the newly-implemented framework is effective in improving student grades and their learning outcomes in an upper-level engineering course. Currently, the scalability of this approach and the transferability of the materials are being tested across disciplines at other universities.

Limitations and Future Directions

The data reported in this paper is based on the implementation of the KACIE framework in a single upper-level engineering course at Tuskegee University. To generalize the results, data need to be collected from other mechanical engineering courses as well as preparatory courses. Further, the scalability of this approach will also be studied in other engineering schools in the future. Although this study focuses on the tools, course content, elements of structure, and process of learning, it does not specifically address the role and influence of faculty on the learning environment.

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