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Interventions for Promoting Student Engagement and Predicting Performance in an Introductory Engineering Class

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ABSTRACT

Studies show that a significant fraction of students graduating from high schools in the U.S. is ill prepared for college and careers. Some problems include weak grounding in math and writing, lack of motivation, and insufficient conscientiousness. Academic institutions are under pressure to improve student retention and graduate rates, whereas students are under pressure to graduate and find employment. Consequently, there is room for substantial innovation in better motivating students, improving their performance, and helping them succeed.

This paper describes two interventions consisting of cinematic meditation and online books. We utilized them to improve student engagement while developing important skills including conscientiousness and communication. In cinematic meditation, we engaged students in goal-directed and guided viewing of films concerning important technological developments. We administered this exercise during the first week of class, which helped to motivate students and stimulate classroom discussion. We asked students to write an essay describing their responses to questions related to the films. Online books help to log student activity and provide supplementary learning material for the students to master. Both these interventions produce quantitative data about student behavior, such as timeliness, which we used to predict subsequent student performance. A timeliness measure, obtainable as early as within 5 weeks of the semester, is correlated ($r = 0.4$, $p < 0.001$) with a cumulative score computed at the midpoint of the semester. This facilitates the early identification of at-risk students, and could avert further performance problems in the semester.

The interventions and data-driven techniques described in this paper are easy to administer and scalable to large class sizes.

Key words: assessment, educational innovations, instructional design.

INTRODUCTION AND MOTIVATION

The U.S. has identified Science, Technology, Engineering, and Mathematics (STEM) as critical areas for the creation of an educated workforce that maintains competitiveness (https://www.ed.gov/stem). According to the Department of Education, STEM-2026 Innovation Report (https://innovation.ed.gov/files/2016/09/AIR-STEM2026_Report_2016.pdf), "those graduates who have practical and relevant STEM precepts embedded into their educational experiences will be in high demand in all job sectors. It is estimated that in the next five years, major American companies will need to add nearly 1.6 million STEM-skilled employees." However, there is a large gap between vision and reality. Consider the sobering statistic that "fewer than 40% of the students who enter college with the intention of majoring in a STEM field complete a STEM degree" (https://innovation.ed.gov/files/2016/09/AIR-STEM2026_Report_2016.pdf).

This gap between the stated vision of creating more STEM graduates and the reality of low graduation rates and poor penetration rates in underserved populations (Perna and Jones, 2013) creates significant opportunities for innovative educational techniques. According to many educators, the current education system is not delivering expected outcomes, as many high school graduates are ill-prepared for college and careers, even those identified as top-performers under current grading schemes (Spencer, 2017). Hence it is important for instructors to be able to identify students who are struggling in first-year classes, especially engineering courses which tend to be challenging (Reich, 2011). There are multiple motives behind this identification, including the need for universities to take early remedial action, and the necessity for students to gauge their own performance. Timely interventions should lead to better student motivation, engagement, and retention. Ultimately, this translates to joint success for both the student and university.

Georgia State University has benefited from the timely identification of struggling students (Kirp, 2016). Students who receive a midterm C grade are required to meet with an academic advisor. This meeting prevents the possible decline of the student's grade from a C into an F for that semester.

There are deeper issues regarding the decline in many countries of students pursuing science and engineering careers. For instance, Becker (Becker, 2010) suggests that university professors may perpetuate the belief that "the study of engineering is and must be something particularly difficult." Consequently, students may be unwilling to "suffer" or endure "unattractive teaching" (Becker, 2010). Other researchers such as Vedder-Weiss (Vedder-Weiss and Fortus, 2012) have investigated factors related to high-school environments to understand why there is a declining motivation to learn science. We aim the research in the current paper squarely at the improvement of teaching quality in introductory engineering courses, and the development of motivation in first-year students.

The labor market imposes significant expectations on the quality of education that students receive. Hence, it is imperative for teachers to prepare their students for professional skills demanded by employers, in addition to technical skills such as problem solving and competency in STEM courses. Typically, professional skills such as communication and writing are taught in courses offered by humanities departments at universities. These professional skills are usually not integrated into STEM courses. The top professional skills in demand are communication, teamwork, and punctuality (Davidson, 2016). Fisher (Fisher, 2016) reports that 80% of hiring managers are not able to find enough potential hires with strong professional skills like speaking and writing clearly, listening well, collaborating, and even just showing up on time. Similarly, White (White, 2013) found that more than 60% of employers complain that candidates are lacking in motivation, communication skills, punctuality, and flexibility. Hence, it is important to investigate techniques that will improve factors such as quality and timeliness, thereby providing a more holistic academic experience to STEM students. Furthermore, there is an acute need to develop professional skills such as writing, communication, punctuality, and curiosity.

It is important to consider every opportunity to develop professional skills by introducing appropriate interventions in every course. This will reinforce the development of these skills throughout the undergraduate years (Rao et al., 2019).

Three major forces are shaping higher education in the U.S. These consist of the rising cost of university education in the U.S., low graduation rates — especially in STEM fields — and an increasingly competitive job market due to globalization (Brown, 2016). Hence, it is imperative for universities to prepare their students to graduate on time, be employable, and be successful in the workforce.

The central research question we investigate in this paper is: How can we efficiently develop professional skills in an integrated fashion along with technical skills in STEM courses? This involves extra effort on the instructor's part, and requires interventions that go beyond standard textbook-based "chalk and talk" teaching. We focus specifically on two skills noted earlier, namely motivation and punctuality. We explore the use of two interventions, termed cinematic meditation (Rao, 2017), and interactive online books (Liberatore, 2017). Cinematic meditation involves a goal-directed exploration of cinematic content where the viewer is primed with specific inquiry questions during viewing, and subsequently answers them in writing. Interactive online books are increasingly being utilized to supplement traditional print-textbooks (Liberatore, 2017).

We can characterize student populations at a university in terms of their SAT scores, retention rates, graduation rates, and total percentage of minorities. We offer the following figures for the author's institution, Fairleigh Dickinson University, Metropolitan Campus (referred to as FDU), and compare them against nationwide figures. In 2015, the SAT scores were relative to a maximum of 2400. At FDU, the average combined SAT score in 2015 was 1515 (http://view2.fdu.edu/site-downloads/16213, last accessed 5/31/20). The nationwide average SAT score in 2015 was 1484 (https://nces.ed.gov/programs/digest/d16/tables/dt16_226.40.asp, last accessed 5/31/20).

Using the same sources above, the first year to second year retention rate for FDU students in 2015 was 74%, whereas the nationwide average was 72%. The four-year and six-year graduation rates at FDU for first-time students attending class full-time were 29%, and 52% respectively. The corresponding nationwide figures were 33.4% and 47.6%. For student demographics, the mean value for the total minority percentage across 4,605 US colleges was 37.33% (data obtained from https://www.chronicle.com/interactives/student-diversity-2016, last accessed 5/31/20). For the author's institution, FDU, the total minority percentage was 37.5%, which was very close to the nationwide average.

Based on the metrics presented above, we can consider FDU to be an average university, where the caliber of students is close to the national average. Therefore, techniques developed at FDU are likely to scale to similar institutions across the U.S. This observation is similar to the use of the city of Columbus, Ohio by restaurant marketers when they try out new recipes, as the demographics in this city mirrors national numbers (Groth and Weinmann, 2011; Scott and Yalch, 1980).

The author is well aware of the realities faced by average students, minorities, and those struggling through their STEM education program on a daily basis. Some students are likely to be the first in their families to attend college, and their challenges have been well studied (Thayer, 2000). As observed by other researchers (Richardson Jr and Skinner, 1992), "they are likely to lack knowledge of time management, college finances and budget management, and the bureaucratic operations of higher education." The student body at FDU predominantly consists of commuters, with many holding part-time jobs. The author has taught several students who worked night shifts, came from inner city neighborhoods such as Newark, NJ, where crime is quite prevalent, and were caregivers for disabled family members. The standard guidance given to students is to spend two to three hours of study time per contact hour with the instructor (Laitinen, 2012). However, less than 10% of the author's students reported putting in this recommended number of study hours. Hence, we shaped the following interventions in the context of these student constraints.

Based on our experience of offering computer science and information technology courses to an underserved population, we realized that the development of fundamentally new approaches are vital to students' success. Oftentimes, the basic foundation of students from underserved populations is weak, and they lack the proper orientation and interest in STEM courses. Addressing this requires a significant change in the way we impart instruction and evaluate student progress. We present a case study involving an introductory undergraduate STEM course entitled "Digital System Design," offered to incoming first-year students. In this course, the cinematic meditation technique has become a successful early intervention in improving student motivation and engagement (Rao, 2017). An online interactive textbook called ZYBooks (Edgcomb et al., 2015) improves student engagement and also provides a wealth of detailed data about student participation and punctuality.

Given the demographic background of the students at our institution, it becomes important to identify "at-risk" students — those who are likely to receive poor grades in a course — as early as possible. It is preferable to use in-class performance measures and related problem-solving skills. At the same time, it is crucial in today's challenging job environment to develop professional skills such as punctuality, frequently demanded by employers. Consequently, we formulated our specific research questions as follows.

1. Can novel interventions such as cinematic mediation and interactive online books improve student motivation?
2. How can we develop techniques for the early identification of at-risk students in a course?
3. How can we develop objective methods that will scale automatically to large class sizes?
4. How can we promote classroom discussion and develop professional skills including writing, communication, and punctuality in STEM courses?

The main contribution of this paper is to develop a data-driven approach to measuring and evaluating student motivation and punctuality. We develop quantitative measures that have predictive value, and are positively correlated with student grades in the class. Hence, the measures will allow students, instructors, and educational institutions to clearly visualize student performance trajectories during every week of a course.

BACKGROUND

The research of Hidi and Harackiewicz (Hidi and Harackiewicz, 2000) showed that variables related to motivation can predict success in college. Hence, the nurture and development of motivation should play an important role in current educational practices (Harackiewicz et al., 2002).

At FDU, a successful program called SOS (Bronson and Kaufman, 1993) has been in use for several years. This program provides additional contact hours with instructors, covers the material at a slower pace, and gives the students extra practice with applied problems. Students can enroll in special course sections designated as SOS. The SOS (Bronson and Kaufman, 1993) approach at FDU is useful for foundational courses. However, it may not be appropriate for more advanced courses where it is not possible to offer slower-paced sections due to insufficient student enrollment or instructor availability or both. Hence, there is a need for alternate types of interventions to improve student engagement.

The cultural pedagogy for STEM fields indicates that interventions such as the flipped classroom (Bishop and Verleger, 2013) are useful in improving student engagement and retention. The author has already applied these techniques successfully. The National Center for Women in Technology, NCWIT (Barker and Cohoon, 2009), recommends that instructors "provide early feedback on assignments and the meaning of grades so that students can self-judge whether they are on par with their peers." The purpose of this current paper is to design novel interventions and feedback techniques to help students succeed.

Peter (Peter, 2007) developed the concept of cinematic meditation, which consists of a goal-directed exploration of cinematic content. Prior to watching the content, the viewer is given specific starter questions. This helps the viewer maintain focus while watching the content. The current generation of students attending college is referred to as Generation Z (Geck, 2007). Recent studies have shown that this generation is more visually oriented than previous generations, and also has a liking for video content (Mims, 2019). The cinematic medium is useful as it appeals to Generation Z students, who are naturally attracted to such content. Furthermore, cinema can readily depict the emotional content of human interactions, which facilitates attention. For instance, one of the films viewed by the students is 'Imitation Game', which describes the invention of an early computer by Alan Turing. By understanding the factors that motivated the protagonists in such films, students may be inspired to undertake similar challenges.

Rao (Rao, 2017) applied the cinematic meditation technique to the first-year Digital System Design course. Rao found that student engagement increased, and the students were able to understand the broader importance of their course material. In the current paper, we expand our analysis to utilize data from N = 86 students over two semesters. In addition, we utilize information provided by student behavioral patterns captured by ZYBooks, an online learning portal (Edgcomb et al., 2017) which is becoming popular in U.S. universities.

Falkner and Falkner (Falkner and Falkner, 2012) recognized the need for creating early indicators of potential student problems. They found that students exhibit habitual patterns, whereby students who submitted the first assignment late were more likely to submit subsequent assignments late. Koprinska et al. (Koprinska et al., 2015) described the importance of detecting at-risk students early in courses in order to take appropriate remedial action.

METHODS

We first describe our use of traditional teaching and assessment methods, and discuss their limitations.

The Traditional Situation

For our study, we used the course "Digital Systems Design" taught to first-year engineering students at FDU. The assigned textbook is authored by Mano and Kime (Mano et al., 2008). Initially, we used traditional assessment techniques whereby students submitted hand-written homework material, containing equations, logic symbols, and circuit diagrams. The first challenge we faced was that it was difficult to grade this material automatically. Hence, we utilized manual grading. Though we were able to give detailed and customized feedback to the learner, it required more time, and the cost of paying a grader. Such a method cannot scale to a large number of students. Furthermore, we could give challenging assignments only after four weeks into the course, as it took time to develop a substantive technical foundation. We observed the need for an "early warning" scheme that helps identify at-risk students as early in the course as possible. It would be especially advantageous to automate such a scheme, and scale it to large class sizes. Figure 1(A) describes the original timeline before we began our interventions.

In addition to performing these assessments manually, a second challenge is that a substantial number of students are unmotivated and lack the proper work ethic to succeed in college. A suggested strategy is to increase student participation (McFarlane, 2010). We designed a first intervention, cinematic meditation (Rao, 2017), that increases student participation while imparting technical knowledge in an engaging manner. We introduced a second intervention, the use of online ZYBooks for Digital System Design. Figure 1(B) and Figure 1(C) describe the timelines for these interventions.

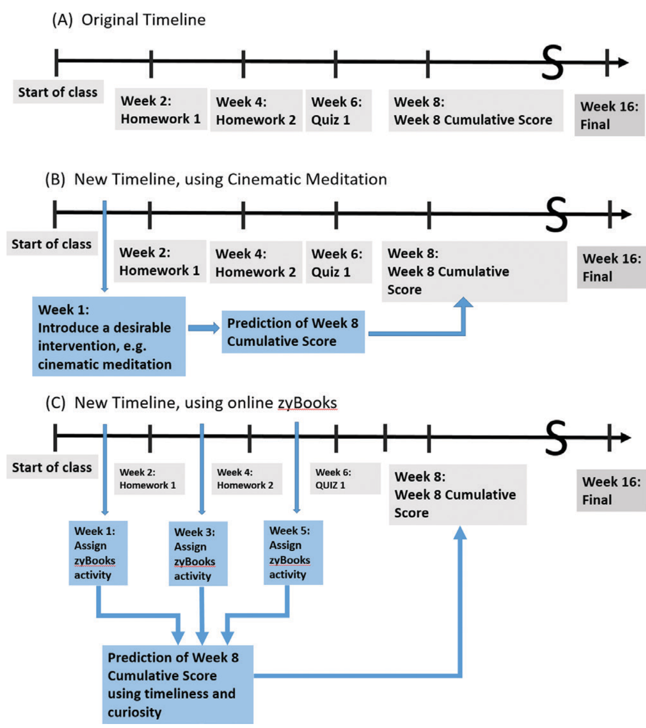

Figure 1. This figure describes the timeline for student assessment before and after we introduced the interventions.

Design of New Interventions

We address the research questions outlined earlier by utilizing two interventions, consisting of cinematic meditation, and an online book, ZYBooks for Digital Systems Design. We describe these interventions in detail as follows.

Participants

Data were gathered during the Fall 2016 and Spring 2017 semesters in the first-year "Digital Systems Design" course required for engineering majors. The class size was 43 students in each semester for a total of N=86 students. Table 1 describes the student demographics. The total minority population was 39.5% in Fall 2016, and 30.2% in Spring 2017. These figures could help other educators determine if the techniques described in this paper could translate to their individual classes.

All students were required to submit the assignment described below.

Assignment Material

For the intervention consisting of cinematic meditation, we showed students the first twenty minutes of the movie "Imitation Game" about the work of Alan Turing during World War II. This film was highly relevant to the course as it described the invention of one of the earliest computers by Alan Turing. For the intervention consisting of the online ZYBooks for Digital Systems Design, we asked students to complete online sections. The ZYBooks portal automatically logged responses, completion rates, and times of completion.

Procedure for Intervention #1: Cinematic meditation

This technique was developed by Peter (Peter, 2007) at the Film School at the University of Southern California and involves watching a film with a specific set of questions in mind, followed by a focused discussion. Figure 2 illustrates this procedure.

Table 1. Comparing the student demographics across the two semesters.

	Fall 2016 (Counts)	Fall 2016 (Percentages)		Spring 2017 (Counts)	Spring 2017 (Percentages)
Asian	7	16.28%	Asian	14	32.56%
Black	7	16.28%	Black	7	16.28%
Hispanic	10	23.26%	Hispanic	6	13.95%
White	19	44.19%	White	16	37.21%
Total	43	100%	Total	43	100%
Male	34	79.07%	Male	31	72.09%
Female	9	20.93%	Female	12	27.91%
Total	43	100%	Total	43	100%

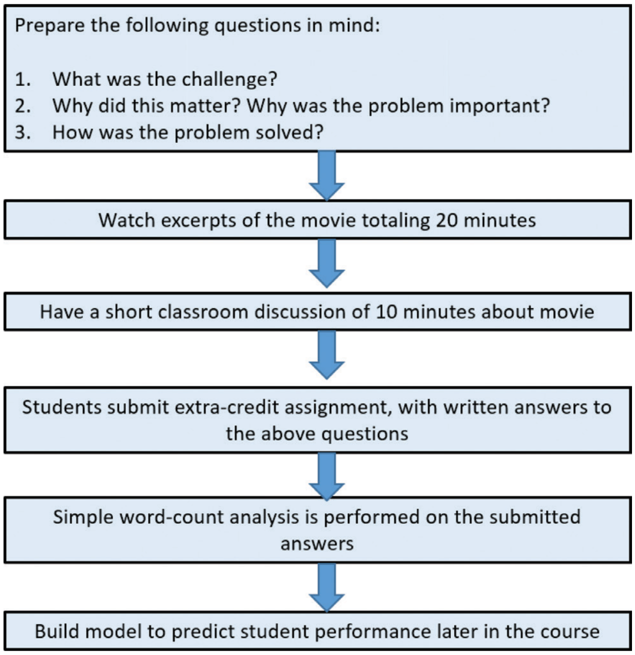

Figure 2. A flowchart describing the steps used in the cinematic meditation intervention. We first introduced students to the set of questions described in Figure 2. Subsequently, we screened the first twenty minutes of the movie "Imitation Game."

We asked students to write a short essay describing the background of the invention, the challenge faced by Turing, and the approach he used to solve it. Students then submitted this essay for extra credit.

Students submitted online Microsoft Word documents. We first measured whether the students actually submitted this assignment. This is a valuable piece of information as it can represent student motivation and conscientiousness. We performed automatic text analysis on submitted essays. We used a simple measure based on the word count of each essay. Figure 3 shows a sample submission, with an associated word count of 184. The intuition behind using word count is that students who write longer essays are more motivated and enthusiastic.

A semester runs for 16 weeks at FDU. Instructors are required to submit a tentative grade for each student at the midpoint, which is the end of week 8. For this purpose, we use a cumulative score that takes into account all the activities of each student, including graded homework submissions, online ZYBooks activity, and a quiz. We refer to this cumulative score as the "Week 8 cumulative score", measured on a scale of 0 to 100%. We also measured the correlation between the word count of the extra credit assignment problem and the Week 8 cumulative score. We identified "at-risk

Cinematic Meditation

1. What was the challenge? The challenge is to break the ENIGMA code which is what the German's were using to encrypt their information.
2. Why did this matter? Why was the problem important? This mattered because the ENIGMA changed itself every day, and something needed to be done. So the person in charge of recruiting people to crack ENIGMA chose all the top mathematicians he could think of. The problem was important because it could save plenty of lives on their side and make Germany surrender quicker.
3. How can this problem be solved? One can solve this problem analytically by cracking each code every time. You could have 10 humans working on this, but there is a finite amount of codes to try and it could take 10,000 years like they said. Or, you can do what Alan Turing did and create a machine that did the same work as ENIGMA did. Turing's approach was called "The bombe," and that allowed him to decrypt German messages. That allowed them to know when the U-boats were coming due to them having German communications.

Figure 3. A sample student submission for the assignment. The word-count for this document is 184.

students", defined as those receiving a Week 8 cumulative score of 66% or less (which translates to a letter grade of C or less).

After the initial viewing of film clips from the "Imitation Game", students viewed additional clips from the film "The Pirates of Silicon Valley" in week 8, and the film "Robot and Frank" in week 12. These films represent the advance of computer technology over the past three decades, culminating in a world where robots are ubiquitous. We followed the viewing of the latter two films by a discussion. However, no written assignments were required in order to lessen the homework burden on the students.

Intervention #2: ZYBooks for Digital Design

The two main types of circuits covered in this course are combinational circuits and sequential circuits. Students struggle with sequential circuits, as their output is a time-varying function of both the current state of the circuit elements and the input. Animations can explain

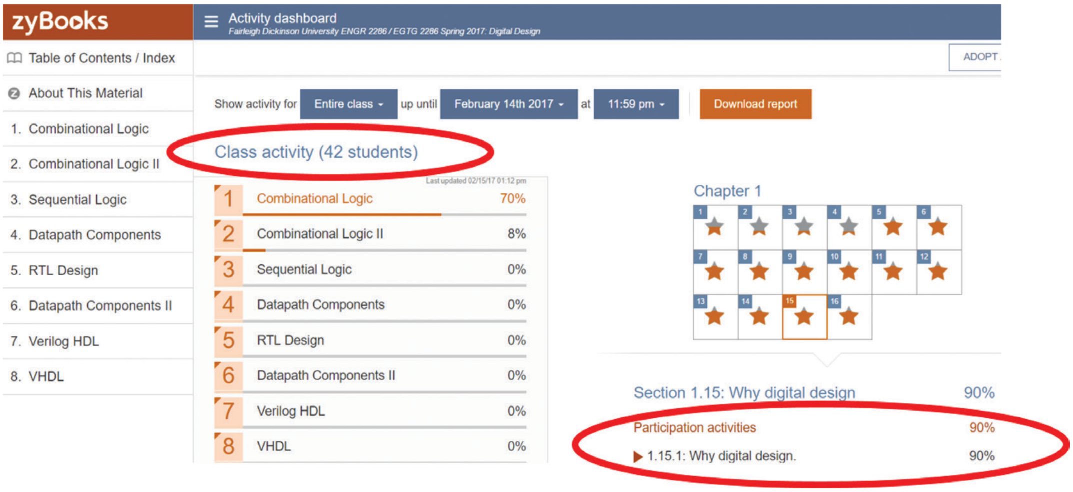

Figure 4. The instructor dashboard for the online portal, ZYBooks for the Digital Systems Design course. This dashboard shows that 90% of the students completed the assignment to read and answer questions in the module "Section 1.15: Why digital design."

such time-variations well, as compared to traditional print textbooks. ZYBooks contains several animations with explanations that the students can repeatedly play until a concept becomes clear.

ZYBooks also contains a dashboard that shows the class status of various assignments, shown in Figure 4.

Figure 5(A) shows detailed information about the completion of assigned activities by each student. Section 1.5 was the assigned activity for the second week of class, and Figure 5(A) shows that a few students did not attempt this activity or only partially completed it. Note that some students also completed other unassigned sections, e.g. Section 1.1 and 1.2.

Figure 5(B) shows the rate at which students completed the activity assigned for Week 3. From Figure 5(A) and Figure 5(B), we can see interesting behavioral patterns, such as those of Student #8 who completed only 35.71% of the assigned activity in Week 2 (shown in red in Figure 5(A)), but caught up with the assigned activities by Week 3 (shown in green in Figure 5(B)).

We define a punctuality or timeliness measure for each student by summing the participation level of the student for the week an assignment was due, over all assignments. For instance, by the end of Week 3, the timeliness measure for Student #8 is 35.71 + 100 = 135.71.

We calculated the timeliness measure for the students at the end of Week 5, which was the last week ZYBooks assignments were due before the calculation of the Week 8 cumulative score at the

Week 2						Assigned	
	Student Number	Section 1.1	1.2	1.3	1.4	1.5	1.6
	1	0	0	0	0	100	100
	2	0	0	0	0	100	100
	3	100	100	100	0	100	100
	4	0	0	0	0	0	0
	5	0	0	0	0	100	100
	6	100	100	100	100	100	100
	7	0	0	0	0	100	100
	8	83.33	71.42	85.71	0	35.71	0
	9	0	0	0	0	0	0
	10	0	0	0	0	0	0

Figure 5(A). This figure shows the activity for ten students at the end of Week 2. Section 1.5 was the assigned activity, shown by the shaded column. The number in each cell represents the percentage of the assigned activity that was completed by a student, and ranges from 0–100.

Week 3							Assigned
	Student Number	Section 1.1	1.2	1.3	1.4	1.5	1.6
	1	0	0	0	0	100	100
	2	0	0	0	0	100	100
	3	100	100	100	100	100	100
	4	0	0	0	0	0	0
	5	0	0	0	0	100	100
	6	100	100	100	100	100	100
	7	0	0	0	0	100	100
	8	83.33	71.42	85.71	0	100	100
	9	100	100	100	100	100	100
	10	0	0	0	0	0	0

Figure 5(B) This extract shows the activity for students at the end of week 3. Section 1.6 was the assigned activity, shown by the last shaded column. Note that student #8 had completed only 35.71% of the activity at the end of Week 2 (red cell in Figure 5(A)), and completed the entire activity (100%) by the end of Week 3 (green cell in this figure).

Student Number	Timeliness measure (at week 5)	Week 8 cumulative score
1	1500	74.26%
2	1500	96.50%
3	1500	82%
4	400	30.70%
5	1500	85%
6	1500	86.50%
7	1500	100%
8	1435.71	98.47%
9	1287.5	74.88%
10	0	57.50%

Figure 6. This figure shows the timeliness measure computed at week 5 and the Week 8 cumulative score assigned to each student. Note that low timeliness scores are correlated with poor Week 8 cumulative scores, shown by the shaded rows. Note that Student #10 did not complete a single assignment. Student #4 failed to complete most assignments. Students 1–3 and 5–7 completed all assignments correctly on time.

end of Week 8. Figure 6 shows the timeliness measure computed at the end of Week 5, and the Week 8 cumulative score, based on the following assessments:

1) ZYBooks assignments (10 %).
2) Written homework from the print textbook by Mano and Kime (Mano et al., 2008) (40 %).
3) Written quiz, administered in class (50%).
4) Extra credit (10% for on-time submission of cinematic meditation essay).

Note that the maximum score is 110%, and students receiving a score of greater than 90 received an A grade. We manually graded the written homework and quizzes. A computer program automatically graded the ZYBooks assignments.

The timeliness measure described above is computed over all 86 students from the Fall 2016 and Spring 2017 semesters and correlated with the Week 8 cumulative score.

RESULTS

Results from the Cinematic Meditation Exercise

We computed the mean Week 8 cumulative score for the following categories of students: (a) those who submitted the essay for the cinematic meditation assignment, denoted by S and

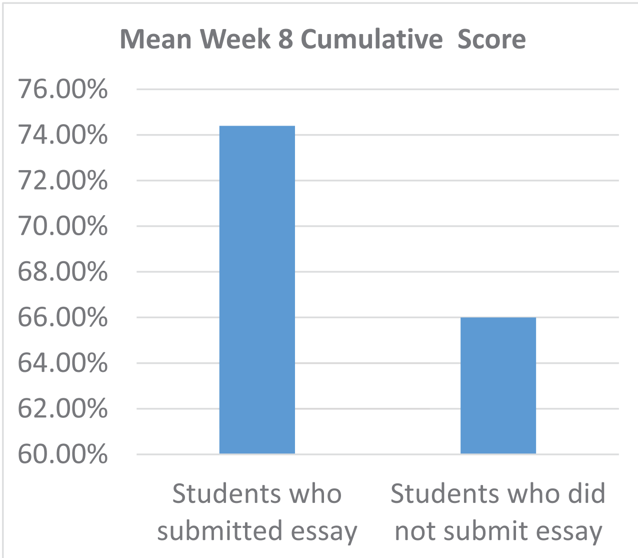

Figure 7. This figure compares the mean Week 8 cumulative score for students who submitted the essay on cinematic meditation versus the students who did not.

(b) those who did not, denoted by D. The mean score for those who submitted the essay was 74.4% and for those who did not submit the essay was 66%, as shown in Figure 7. We conducted a two-sided T-test to determine if the difference in the means is statistically significant. This is a test for the null hypothesis that two independent samples have identical means. The p-value for this test is 0.05, which allows us to reject the null hypothesis of equal means at a significance level of alpha $\leq$ 0.05.

The Pearson correlation between the word-count of the essay submitted by the students and their Week 8 cumulative score is 0.13.

The Week 8 cumulative score is converted to a standard letter grade scale used at most U.S. academic institutions (e.g. an A grade is given to students with a score of >90%). We also computed the percentage of students receiving poor Week 8 cumulative letter grades, defined as grades of C or lower. The average Week 8 cumulative grade in the class was a “B”. We used the following segments of the student population: (a) the students who submitted the essay (b) the students who did not submit the essay (c) all the students. Figure 8 shows the result. Out of the students who submitted the essay, 29% of these received a poor Week 8 cumulative grade. For the students who did not submit the essay, 37.5% received poor Week 8 cumulative grades. For the entire set of students, 33% received poor Week 8 cumulative grades.

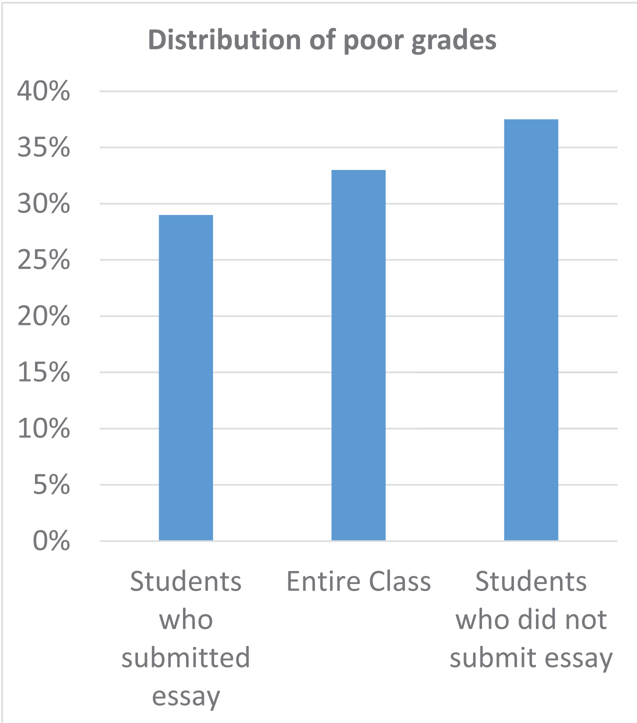

Figure 8. Distribution of poor Week 8 cumulative grades (C or lower) amongst different segments of the student population.

Results Regarding the ZYBooks Assessments

We compute the timeliness measure over assignments given during the first 5 weeks. The correlation between the timeliness measure and the Week 8 cumulative score is 0.4. This is statistically significant (p-value < 0.001). Figure 9 shows the relationship between the timeliness measure and Week 8 cumulative score.

The correlation between the timeliness measure computed at the end of week 5 and the final score at the end of the semester is 0.32 (p-value = 0.02, indicating that the correlation is statistically significant).

DISCUSSION

The results we obtained answer the original research questions as described below.

Q1: Can novel interventions such as cinematic meditation and interactive online books improve student motivation?

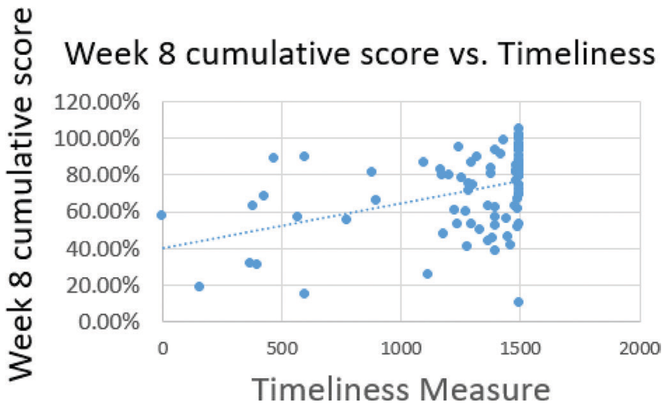

Figure 9. Illustrating the relationship between the Week 8 cumulative score on the y-axis and the measure of timeliness on the x-axis.

We measured the effectiveness of these interventions through written feedback that students submitted via a course survey at the end of the semester.

Figure 10 shows a sample of several positive comments.

Students explicitly mentioned that they found the videos motivational and inspiring. This is consistent with recent studies showing that Generation Z students are attracted to video content (Mims, 2019). Hence, it is advantageous to use teaching material that resonates with their preferences. The

Hi professor, I would like to convey that, I felt very happy on your efforts to make the class environment quite interesting (video clip on last Monday's class). This is a great idea which can motivate students and I would like to see this clip one more time can you please send me the link professor.

You inspired me to relate real world problems with the course and think about them. I really liked the video you showed us on Alan Turing and how you encouraged us to think about the Enigma machine problem.

I get tired of coming to class, pulling out my notebook and pen, copying notes, and then leaving each time. When you used videos, in class activities, and discussions, it kept us engaged and coming to class.

Prof. Rao would begin almost every class by showing us either a video or article that highlighted the importance of the material we were learning and where it could take us. Having this real life view of what the class would prepare us for was a source of inspiration. It definitely made me want to work even harder to master the course. Not only that, it also gave me new ideas for potential careers I can pursue in the future.

He's always scouting different motivational stories, articles, or movies. I love it when he starts off a class with a motivational video, it gets me excited to learn.

Figure 10. Student reactions that indicate their engagement in the cinematic meditation exercise, obtained via end-of-semester course surveys.

use of carefully selected video content also helped the students to think about real-world problems and to identify potential career paths. We used a qualitative method to obtain feedback. In the future, we can administer explicit questionnaires to obtain student responses.

A report by the American Society of Engineering Education (ASEE, 2013) notes that "To support curiosity and interest in engineering, the importance and the "grandness" of engineering methodologies should be explained to younger students in an accessible and motivating way." We addressed this recommendation by the ASEE by considering a "grand challenge" problem of deciphering German communications in World War II, viewing engaging cinematic content, and involving students in discussions.

Question #2: Can we develop techniques for the early identification of at-risk students in a course?

The positive sign of the Pearson correlation between the word-count of the cinematic meditation essay submitted by the students and the Week 8 cumulative score indicates that the longer the essay, the higher the Week 8 cumulative score. Although the correlation is 0.13, we should keep in mind that we obtained this from a single measurement during the first week of class. We can combine this measure with other features to create a predictive model of student performance. It is also easy to compute, easy to automate, and scales well for large class sizes.

The result in Figure 8 shows that students who did not submit the essay on cinematic meditation were more likely to receive a poor grade (of C or lower) in comparison to students who submitted the essay. The increase in the likelihood of receiving a poor grade is 29.5% between these two segments. This indicates that this simple measure of whether or not students submitted the essay has predictive power with respect to subsequent student performance. Hence, one can use the word count measure to identify at-risk students within the first week of class. A possible intervention would be to issue a warning to these students, and encourage them to be diligent about their submissions. A future study could examine whether students who receive this warning demonstrate improved performance over students who do not receive this warning.

The correlation between the timeliness measure and Week 8 cumulative score of 0.4 is statistically significant with a p-value < 0.001. The result in Figure 9 indicates the predictive value of the timeliness measure. We obtained this measure within the first 5 weeks of class. Furthermore, the ZYBooks submissions account for only 10% of the Week 8 cumulative score. The correlation between the timeliness measure and the final score at the end of the semester is 0.32, and is statistically significant with a p-value $= 0.02$.

Macfadyen [10] computed metrics based on student interactions with an online learning management system such as Blackboard. The metrics with the three highest correlations with student final grade were the total number of discussion messages (r = 0.52), total number of online sessions (r = 0.4) and total time online (r = 0.34). Note that our timeliness measure produces results that are consistent with the work of Macfadyen. Furthermore, we created our metric from just five weeks' worth of student interactions with ZYBooks. In contrast, Macfadyen's measures required an entire semester's worth of activity.

The essence of our research is to demonstrate that the relatively simple intervention of cinematic meditation is impactful, and satisfies the dual objectives of motivating students while deriving predictive measures.

The word count measure does not account for aspects of English writing such as grammar or brevity. It is possible that students who submitted shorter essays were better writers and could write succinctly. However, we found that students who wrote the shortest essays received poorer grades as compared to students who wrote the longest essays. Students who wrote the shortest essays also had more errors in grammar, punctuation, and spelling than the students who wrote the longest essays.

Studies show that SAT Essay test scores are related to the length of the essay written by students. For instance, Kobrin et al. (Kobrin et al., 2007) show that the number of words in the essay explained 39% of the variance of essay scores. A more detailed investigation of these issues is outside the scope of this paper.

Question #3: How can we develop objective methods that will scale automatically to large class sizes?

The measures that we have developed include the word count of submitted essays, and an automatically computed timeliness measure derived from web interaction logs generated by students. Due to the inherent automation involved, we can scale these measures easily to handle large class sizes.

Question #4: How can we promote classroom discussion and develop professional skills including writing, communication, and punctuality in STEM courses?

Figure 10 shows that many students found the cinematic meditation exercise to be thought provoking, and this spurred classroom discussion. By administering this exercise in the first week of the course, we set the tone for lively discussions throughout the course. The essay-writing exercise also helps students express themselves, especially in a technology context, which may be a little unexpected for them as this is an introductory STEM course. There appears to be a growing interest among researchers to investigate the combination of humanities with STEM courses (Madden et al., 2013; Boy, 2013). Such an integrated approach improves students' assimilation of course materials, and their understanding of the connections between different disciplines.

The ZYBooks assignments consist of supplementary online readings, and we can automatically measure student completion of these assignments. This leads to quantitative measures of punctuality. We showed the dashboard in Figure 4 to the class every week, in order to spur students to keep up with the assigned work. Instructors can set high expectations, such as asking students to aim for a 100% completion of activities by the assigned date. Research has shown that students typically adjust their behavior to meet teacher expectations (Jussim et al., 1994). The advantage of using an automatic online calculation of student completion of assigned activity is that continuous feedback can be provided to the students with little effort on part of the instructor. Such continuous feedback also resonates with the expectations of the newer generations of students who are accustomed to frequent status updates (Aviles and Eastman, 2012).

Relationship Between Current and Existing Research

Wolfe and Johnson (Wolfe and Johnson, 1995) used a sample of 201 undergraduate students to determine that conscientiousness had a correlation of 0.34 with college GPA. The data-driven measure of timeliness that we have defined in this paper may be related to conscientiousness. We found a correlation of 0.4 between the timeliness measure and the Week 8 cumulative score, which appears to be consistent with the findings of Wolfe and Johnson (Wolfe and Johnson, 1995). Though we have not determined the correlation with college GPA, our results are promising, and we plan to track student performance through college based on our measures. Psychologists have defined the Big Five Inventory (John et al., 1991) consisting of the following personality traits: extraversion, agreeableness, conscientiousness, neuroticism, and openness. These traits were shown to be predictive of college performance (Wolfe and Johnson, 1995). Typically, self-reported measures are collected through questionnaires (Rammstedt and John, 2007). In contrast, we utilize purely data-driven measures based on student behavior. No separate questionnaire needs to be administered to the students, and our measure can be automatically and continuously computed through the online portal.

There are many efforts aimed at enticing more students to join STEM fields, including engineering (Becker, 2010). One direction to make STEM fields more appealing is to combine them with other fields such as arts or humanities. Studies have shown that student engagement is increased by introducing an arts component into traditional STEM courses (Henriksen, 2014). The cinematic meditation intervention introduced in the current paper is an injection of elements of humanities courses into engineering courses. Our research exploring this combination has shown promising early results, and is a departure from the dominant “chalk-and-talk” paradigm in engineering education (Carlson and Sullivan, 1999). The interventions we utilized are relatively easy to replicate, and we have provided detailed descriptions of our computational techniques.

CONCLUSION

We present the results of using two interventions in a first-year course for Engineering majors, entitled "Digital Systems Design." The first intervention consists of using a cinematic meditation exercise to improve student engagement and motivation. The second intervention consists of using an online supplementary textbook, called ZYBooks, which encourages conscientiousness and timeliness amongst students. Our results demonstrate that both these interventions had positive outcomes by improving student motivation, promoting classroom discussion, and helping students assimilate course material. These interventions have the ability to quickly identify at-risk students, starting as early as the first week of class. We constructed a timeliness measure that is based on student logs registered with the ZYBooks portal, and determined that there was a moderate statistically significant correlation ($r = 0.4$, $p < 0.001$) between this timeliness measure and the Week 8 cumulative score attained by the students. The use of these interventions promotes the development of professional skills such as motivation, communication, and conscientiousness, which are highly sought after by prospective employers today. Finally, these interventions provide early identification of at-risk students, which is of value to administrators and faculty members for the improvement of retention and graduation rates.

CONFLICT OF INTEREST STATEMENT

The author, A.R. Rao has no conflict of interests.

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