Using an Instrumented Learning Environment to Understand Procrastination

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***Abstract*— This study aims to identify procrastinating behavior of students by tracking their activities in an undergraduate engineering course and to explore its relationship with course performance. In our research, we have examined methods for instrumenting students' ordinary learning activities in undergraduate engineering courses. More specifically, we provide students with digital smartpens they use to complete their assignments, lecture notes, and exams. We also provide them with an instrumented document viewer that records reading effort for course documents. This technology provides a fine-grained, time-stamped record of writing and reading throughout the course. In the present work, we examine a student's studying effort in relation to the due dates of assignments and compare this with academic achievement in a course. The results show that when a student studies is a powerful predictor of academic success. For example, students who do their work in the 24 hours immediately preceding a due date tend to do poorly, while those who do their work one or two days early, tend to perform well. This work is a first step toward building tools that allow students to monitor their learning habits and use this information to improve their own academic performance.**

Keywords— instrumented learning environment, educational data mining, academic procrastination

I. Introduction

With the growth of online courses, the demand for automated assessment tools is on the rise. This information can be analyzed to provide students with early feedback on their performance in the course. Building tools to measure students' activities and identifying negative behavior such as procrastination allows instructors to provide early warning systems to students which helps them modify their behavior to achieve a better performance in the course. Students who are performing well in the course can also benefit from such tools as the feedback encourages them to keep their performance high. The goal of this study is to understand students' procrastinating behavior using fined-grained records of students' reading and writing activities throughout the course.

Procrastination is defined as postponing a task to a later time [1] and is considered a dysfunctional behavior [2, 3]. Procrastination is quite common and widespread among college and undergraduate students. In a study by Steel [4], the amount of academic procrastination among undergraduate students is estimated to be about 70-95%. Procrastination has been associated with many negative outcomes and is correlated with low academic performance [5, 6] and cheating and plagiarism [7, 8]. Many studies have shown that academic procrastination is negatively related to academic achievement [5, 9, 10, 11, 12]. Procrastination may cause stress and discomfort for students as they find themselves doing assignments at the last minute with limited time [13, 14, 15]. Lack of self-efficacy can be one reason to postpone an assignment [10]. While the subject of procrastination has been well-studied, most studies have relied on surveys and students' self-reports, which may be unreliable and are prone to error or bias [16]. Some studies have used instruments such as learning management system (LMS) [11, 12] or online interactive textbooks such as zyBooks [17] to record students activities and analyze their procrastinating behavior, but most of these studies are either mostly based on reading activities or they use very few writing-related habits of students such as time of submitting assignments [18]. Other studies use information such as dashboard usage and online forum participation to identify procrastinating habits [9].

Our work is methodologically unique in that we use instruments to objectively measure students' learning activities throughout the course. We collect timestamped records of both reading and writing throughout the course. Our analysis of the data we have collected has produced quantitative measures of procrastination. Furthermore, we have found a strong correlation between these measures and course grade.

The rest of this paper is organized as follows. In section II we briefly review related work and background. In section III we explain how we collected the records of students' reading and writing. Section IV is about participants in the experiment and measures of performance and in section V we explain the experiment and analysis performed on the data. Finally, section VI is conclusions and future work.

II. Related Work

In recent years, various learning platforms, dashboards, and course management systems have been designed to support academic instruction [19, 20]. These systems are used in both traditional and online classes. Many of these systems are designed to help teachers track students' submission of deliverables and are a means to provide students with feedback, tools or materials to achieve better performance in the course. Some systems have been designed to provide visualization of students' learning activities [21]. However, most systems are

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able to track only rough information about students' activities including participation, time of first downloading assignments, time of submitting assignments, etc. [18]. Such information provides very limited insights about student's learning activities. In our experiments, by contrast, we collect fine-grained, time-stamped measurements of students' day-to-day study activities.

Most procrastination studies rely on self-reports and questionnaires [5]. However, the validity and reliability of Self-reported measures has been an on-going debate in educational research for many years [22, 23, 6]. Other researchers have considered features such as late submissions, last minute submissions, and failure in submitting assignments as indicators of procrastination [11, 12].

You [11, 12], has considered absence and the frequency of late submission as indicators of procrastination in an e-learning course. In [11], absence is defined as failure to access lecture videos within a designated time period or spending insufficient time watching the videos. You claims that absence and late submissions are negatively and significantly correlated with course performance. In the present work, we have a more direct measure of procrastination and we provide techniques to accurately measure procrastinating behavior according to reading and writing activities throughout the course. We examine the time at which a student actually performs the work for an assignment.

Cerezo et al. [24] have attempted a similar analysis using log data from Moodle. However, unlike our study, they do not have access to detailed measures of students' readings and writings. In another study, Alshammari et al. [17] have used zyBooks in their experiment to record students' activities. zyBooks [25] is an online interactive textbook with interactive questions and assignments. Their analysis is limited to information such as assignment submission time and does not consider the period of time that students have been working on the assignments.

III. User Interfaces for Data Collection

We provide students with instruments that allow us to log and record their learning activities in the course. Our goal is to understand students' behavior in order to give them feedback and recommendations to help them improve their course performance. In this section, we explain details of the instruments and software we utilize to record students' writing and reading data.

A. *Writing Data*

In our studies, students use Livescribe pens to complete all of their coursework including homework, quizzes, lectures notes and exams. These devices work as a regular pen but also digitize the writing with timestamped coordinates. Smartpens are used with dot-patterned paper that allows the devices to capture the exact location of handwritten data. The digitized pen strokes are stored in the pen's memory, and students use software we developed called InkViewer3 to submit their assignments electronically for grading.

We analyze recorded pen strokes to identify writing episodes. A writing episode is a group of consecutive pen strokes for the same assignment where the time gap between the strokes is no more than 10 minutes. The duration of a writing episode is defined as the difference between the ending timestamp of the last stroke and the beginning timestamp of the first stroke in the episode.

B. *Reading Data*

We provide students with an instrumented document viewer, called DocViewer, that records reading activity for course documents including the electronic textbook, homework solutions, graded work, and lecture slides. These materials are provided in a form that can be read only with DocViewer, which helps to ensure that all the reading activities are recorded. DocViewer runs on Windows computers and tablets and is designed to accurately measure reading time. For example, the software dims the screen after 2 minutes of inactivity. This prevents an idle display from being counted as reading.

DocViewer logs a variety of activities including opening a document, changing pages, zooming in, zooming out, highlighting text, and closing a document. The timestamped log files are continuously uploaded to a secure file server. We analyze the log files to identify page viewing episodes which are intervals of time during which a student is reading a particular page. An episode terminates when the student changes the page, closes the document, or opens a new document. We consider episodes of less than 15 seconds to be page navigation rather than reading. We believe that in order to read and understand content on a page, one should spend more than 15 seconds.

IV. Participants and Design

The participants were three groups of undergraduate students at the University of California, Riverside who were enrolled in an entry-level course in statics. Group 1 includes 141 students in the winter quarter of 2015, group 2 includes 56 students in the spring quarter of 2016, and group 3 includes 96 students in the winter quarter of 2017. The winter quarter is the first offering of the statics course for the academic year. Statics is offered in the spring as well, but taking the course during spring is considered off-track. The majority of the students in the winter course are from mechanical engineering, although students from several other engineering majors, including materials science and environmental engineering, also take this course. Statics is a 10-week course that includes two 80-minute lecture periods per week. Students also attend a 50-minute discussion section each week. The course employs a traditional lecture format.

A. *Procedure*

Each week, students were given a homework assignment that included a reading assignment form the textbook and a set of problems to solve. Students were required to complete the problems and submit a digital copy of the work by a specified deadline. We call the assigned pages from the textbook "assigned reading". The assigned reading comprised explanatory text (i.e., chapter text) intended to prepare students to complete the homework problems. In addition to the assigned explanatory text, students also accessed other materials from the textbook, such as the problems at the ends of the chapters and the problem answers (final answers only) at the end of the book. Whereas we use the term "assigned reading" to refer to effort spent on only the assigned explanatory text, we use the term

"textbook reading" to refer to effort spent on all parts of the textbook.

In 2015 and 2016 students were assigned one reading assignment for each of the weekly homework assignments. In 2017, however, they were given a separate reading assignment for each lecture. The students in 2017 were asked to read the same material as in the students in the other offerings, but each reading assignment was divided over two lectures. In all cases, students could choose to read or to not read and they did not directly receive a grade for reading.

B. *Measures of Course Performance*

We use final course grade as the measure of course performance in our study. Course grade for all three groups was based on the following weighting: 5% for class participation, 10% for homework, 10% for the quizzes, 20% for the first midterm exam, 20% for the second midterm exam, and 35% for the final exam.

C. *Measures of behavior*

1) Daily Activity Fraction Measures

We are interested in understanding how academic procrastination is related to students' course performance. Toward this end, we characterize each student's studying in terms of the amount of effort spent during each 24-hour period prior to the due date. For convenience, we refer to each such period as a *day*, which is different from a calendar day. For example, day -1 is the 24 hours immediately preceding the due date, day -2 is the 24 hours immediately preceding day -1, and so on. As assignments were typically assigned every seven days, we consider the effort on only the six days prior to the due date of an assignment.

We characterize procrastination by the distribution of the effort rather than the absolute amount of effort. Consider, for example, two students, *A* and *B*, who both spent three hours on an assignment on the last day, (i.e., day -1). Imagine that *A* also spent three hours on day -2, while *B* did no other work. In this case the two students would have the same absolute amount of effort on the last day. However, their procrastination behavior is different as *A* spent only 50% of his or her effort on the last day, while *B* spent all of his or her effort on the last day.

Daily Textbook Reading Fraction: The fraction of the reading effort on the i^{th} day before the due date (i.e., day -*i*) of assignment *k* is computed as:

$$r'_{k,i} = \frac{r_{k,i}}{\sum_{j=1}^{6} r_{k,j}}; i = 1,2,\ldots,6 \quad (1)$$

where $r_{k,i}$ is the textbook reading time on the i^{th} day before the due date of assignment *k* (in units of hours). $r_{k,i}$ is the sum of all reading episodes that occur on day -*i*. If an episode is only partially on day –*i*, then only that portion is included in the sum.

For each student, we average the Daily Textbook Reading Fraction over all of the assignments to obtain the Average Daily Textbook Reading Fraction:

$$R_i = \frac{\sum_{k=1}^{n} r'_{k,i}}{n} \quad (2)$$

where *n* is the number of homework assignments (*n* = 9).

Daily Homework Writing Fraction: The fraction of the writing effort on the i^{th} day before the due date (i.e., day -*i*) of assignment *k* is computed as:

$$w'_{k,i} = \frac{w_{k,i}}{\sum_{j=1}^{6} w_{k,j}}; i = 1,2,\ldots,6 \quad (3)$$

where $w_{k,i}$ is the writing time on the i^{th} day before the due date of assignment *k* (in units of hours). As before, $w_{k,i}$ is the sum of the writing episodes (or portions thereof) on day -*i*.

For each student, we average the Daily Homework Writing Fraction over all of the assignments to obtain the Average Homework Writing Fraction:

$$W_i = \frac{\sum_{k=1}^{n} w'_{k,i}}{n} \quad (4)$$

Daily Assigned Reading Fraction: The fraction of the assigned reading effort on the i^{th} day before the due date (i.e., day -*i*) of assignment *k* is computed as :

$$a'_{k,i} = \frac{a_{k,i}}{\sum_{j=1}^{6} a_{k,j}}; i = 1,2,\ldots,6 \quad (5)$$

where $a_{k,i}$ is the assigned reading time on the i^{th} day before the due date of assignment *k* (in units of hours). As before, $a_{k,i}$ is the sum of the assigned reading episodes (or portions thereof) on day -*i*.

We compute the Average Assigned Reading Fraction for each student as:

$$A_i = \frac{\sum_{k=1}^{n} a'_{k,i}}{n} \quad (6)$$

2) Centroid Measure

Textbook Reading Centroid: We compute the centroid of the distribution of reading effort as a measure of when the student does the bulk of the reading before an assignment. The centroid rc_k for assignment k is computed in the usual way as:

$$rc_k = \frac{\sum_{i=1}^{6} i * r_{k,i}}{\sum_{i=1}^{6} r_{k,i}} \quad (7)$$

where $r_{k,i}$ is the reading time for assignment k on day -i and i ranges over the six days prior to the due date. If there is no reading activity, rc_k is zero. Otherwise the value ranges from 1 to 6. A small value indicates that the reading was done close to the deadline, while a larger values indicates that reading was started earlier.

For each student, we average the Textbook Reading Centroid over all of the assignments to obtain the Average Textbook Reading Centroid:

$$RC = \frac{\sum_{k=1}^{n} rc_k}{n} \quad (8)$$

Homework Writing Centroid: We compute the centroid of the writing effort for homework assignment *k* in an analogous way to the Textbook Reading Centroid:

$$wc_k = \frac{\sum_{i=1}^{6} i * w_{k,i}}{\sum_{i=1}^{6} w_{k,i}} \quad (9)$$

where $w_{k,i}$ is the writing time for assignment *k* on day -*i* and *i* ranges over the six days prior to the due date.

We also compute The Average Homework Writing Centroid as:

$$WC = \frac{\sum_{k=1}^{n} wc_k}{n} \quad (10)$$

Assigned Reading Centroid: The Assigned Reading Centroid is computed in the familiar way:

$$ac_k = \frac{\sum_{i=1}^{6} i * a_{k,i}}{\sum_{i=1}^{6} a_{k,i}} \quad (11)$$

where $a_{k,i}$ is the assigned reading time for assignment *k* on day -*i* and *i* ranges over the six days prior to the due date. We also compute the Average Assigned Reading Centroid:

$$AC = \frac{\sum_{k=1}^{n} ac_k}{n} \quad (12)$$

3) Homework Measures

We compute three additional measures characterizing when the students write their homework solutions:

Homework Start Gap is a measure of how early the student begins an assignment. It is computed as the difference between the time of the due date and the staring timestamp of the first pen stroke written for the assignment. The value is reported in units of hours. Students who procrastinate will have a smaller Start Gap than students who do not procrastinate. For each student, we average the Homework Start Gap over the nine homework assignments.

Homework Finish Gap is a measure of how late the student finishes an assignment. It is computed as the difference between the time of the due date and the ending timestamp of the last pen stroke written for the assignment. The value is reported in units of hours. Procrastinators tend to finish assignments late and thus will have a smaller Finish Gap than students who do not procrastinate. For each student, we average the Homework Finish Gap over the nine homework assignments.

Homework Effort Density is the ratio of the total homework writing time, excluding periods of inactivity, to the total homework writing time.

$$d_k = \frac{W_k}{T_k} \quad (13)$$

where T_k is the elapsed time from the start of first pen stroke to the end of the last pen stroke of assignment *k*, and W_k is the total time spent actively writing ($W_k = \sum_{i=1}^{6} w_{k,i}$). If a student completes an assignment over several days, the ratio will be small. By contrast, if the student completes an assignment in a single problem-solving session, the value will approach 1. This measure does not directly indicate procrastination, but a student who starts an assignment at the last minute will, by necessity, have a large value of the ratio. Note, however, that a student could begin an assignment early, complete it in a single session, and achieve a high value of the ratio.

For each student, we compute the average Homework Effort Density over all assignments to obtain the Average Homework Effort Density:

$$D = \frac{\sum_{k=1}^{n} d_k}{n} \quad (14)$$

V. Results and Discussion

A. *Daily Activity Fraction Measures*

To examine the relationship between procrastination and course performance, we compute the Pearson correlation between the Average Daily Activity Fractions (R_i, W_i, and A_i) and final course grade for the three course considered separately and for all of the students together. The results are shown in Table I. In general, effort on the last day before the deadline was negatively correlated with grade, while effort on other days was positively correlated. With the exception of the Average Assigned Reading Fraction on day -1 in 2017 which was positively correlated to course grade. In 2017, reading assignments were due by the start of every lecture and the homework assignments were due the day after the second lecture each week. Therefore, assigned reading on day -1 indicated the students' effort to get prepared for the upcoming lecture and is positively correlated to course performance. The Average Daily Reading Fraction and the Average Daily Writing Fraction on day -1 were significantly and negatively correlated with course grade for the three quarters separately and for all students together. This means that the student who read the textbook or

TABLE I. Correlation between course grade and average Daily Activity fractions within 6 days prior to homework assignment deadlines.($^{*}P < 0.05$, $^{**}P < 0.01$)

	Average Daily Textbook Reading Fraction (R_i)				**Average Daily Homework Writing Fraction (W_i)**				**Average Daily Assigned Reading Fraction (A_i)**			
Days before deadline	***2015***	***2016***	***2017***	***All***	***2015***	***2016***	***2017***	***All***	***2015***	***2016***	***2017***	***All***
Day -1	-.294**	-.309*	-.243*	-.286**	-.413**	-.309*	-.438**	-.416**	-.221**	-.241	.024	-.061
Day -2	.182*	.025	.101	.111	.222**	.178	.322**	.251**	.013	.072	.003	.035
Day -3	.050	.354**	.275**	.209**	.204*	.333*	.364**	.312**	.026	.351**	.138	.120*
Day -4	.319**	.286*	.030	.186**	.328**	.114	.222*	.267**	.344**	.216	.107	.244**
Day -5	.121	.178	.140	.201**	.225**	.112	.170	.206**	.070	.215	.108	.138*
Day -6	-.026	-.061	.038	-.064	.089	.056	.195	.115*	.007	-.208	-.020	-.080

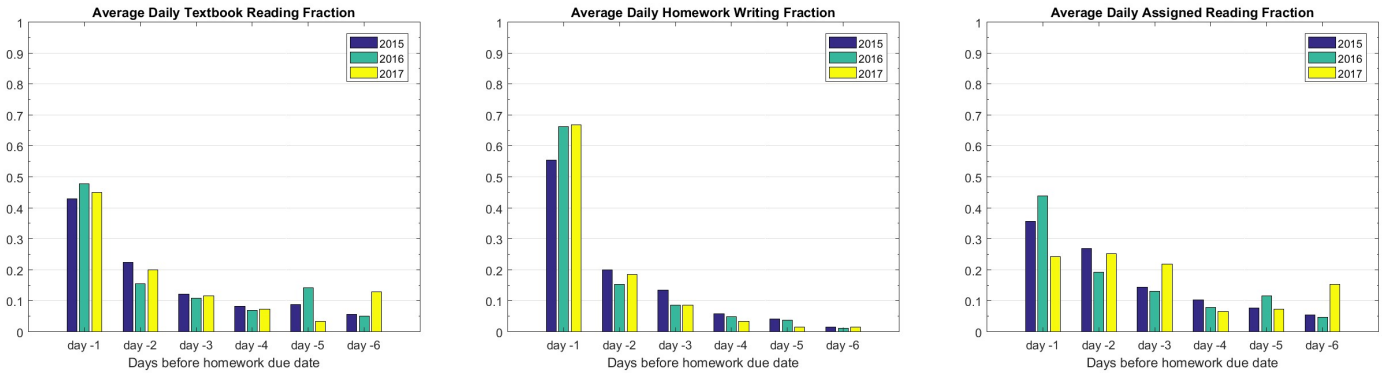

Fig. 1. Average Daily Activity Fraction measures for the three couse offerings.

completed most of their homework on day -1, i.e. procrastinators, tended to perform poorly in the course. The Average Daily Assigned Reading Fraction was significantly correlated to course grade only in 2015. Students did very little reading of explanatory text from the textbook. Therefore the Average Assigned Reading Fraction cannot be a strong measure of students' effort as they did very little reading of the assigned pages. Moreover, most of the students' textbook reading activities were reading pages including homework questions. Thus the Average Textbook Reading Fraction could be an indication of homework writing effort, since most of the textbook reading activity is due to reading the homework questions which mostly happens while students are working on the homework.

For days other than day -1, the Average Daily Activity Fractions were positively correlated with course grade with a few exceptions on day -6. The Average Daily Homework Writing Fraction on day -3 is significantly and positively correlated with course grade for all three groups, and all students together. Also, for all students together, the Average Daily Homework Writing Fraction is positively and significantly correlated with course grade for all days except day -1. On day -1, this value is negatively and significantly correlated with course grade.

As mentioned earlier, in 2015 and 2016 students were assigned one reading assignment for each of the weekly homework assignments, while in 2017 they were given a separate reading assignment for each lecture. Therefore students were assigned smaller subtasks that could be handled easier. The format for 2017, may have provided motivation for students to begin reading earlier than they otherwise would have. As table I and table II illustrate, this could reduce the assigned reading time on day -1 which is an improvement in the procrastinating behavior of students.

Fig. 1 shows the Average Daily Activity Fractions R_i, W_i *and* A_i for the three course offerings. To better

TABLE II. AVERAGE DAILY ACTIVITY FRACTIONS FOR TOP QUARTILE VS. BOTTOM QUARTILE

Days before deadline	Quartile	Textbook Reading			Homework Writing			Assigned Reading		
		2015	*2016*	*2017*	*2015*	*2016*	*2017*	*2015*	*2016*	*2017*
Day -1	**Top**	0.34**	0.39	0.31*	0.44**	0.56	0.49**	0.26**	0.30	0.22
	Bottom	0.49	0.58	0.50	0.63	0.74	0.83	0.39	0.59	0.20
Day-2	**Top**	0.26	0.16	0.22	0.24*	0.17	0.25**	0.30	0.24	0.08
	Bottom	0.23	0.16	0.17	0.18	0.14	0.11	0.29	0.19	0.22
Day -3	**Top**	0.15	0.17	0.18*	0.16	0.15*	0.15**	0.16	0.22**	0.34
	Bottom	0.12	0.06	0.09	0.12	0.05	0.04	0.14	0.05	0.20
Day -4	**Top**	0.11**	0.08	0.10	0.08**	0.05	0.06*	0.16**	0.10	0.08
	Bottom	0.04	0.04	0.09	0.02	0.03	0.01	0.05	0.06	0.07
Day -5	**Top**	0.09	0.17	0.05	0.06**	0.06	0.02	0.08	0.14	0.15
	Bottom	0.07	0.12	0.03	0.02	0.03	0.00	0.07	0.07	0.05
Day -6	**Top**	0.04	0.03	0.14	0.02	0.01	0.02*	0.05	0.00	0.13
	Bottom	0.05	0.03	0.13	0.02	0.01	0.01	0.05	0.05	0.26

Note. Asterisks indicate significant differences between top quartile and bottom quartile students according to independent-samples t-test. * $p < .05$, ** $p < .01$.

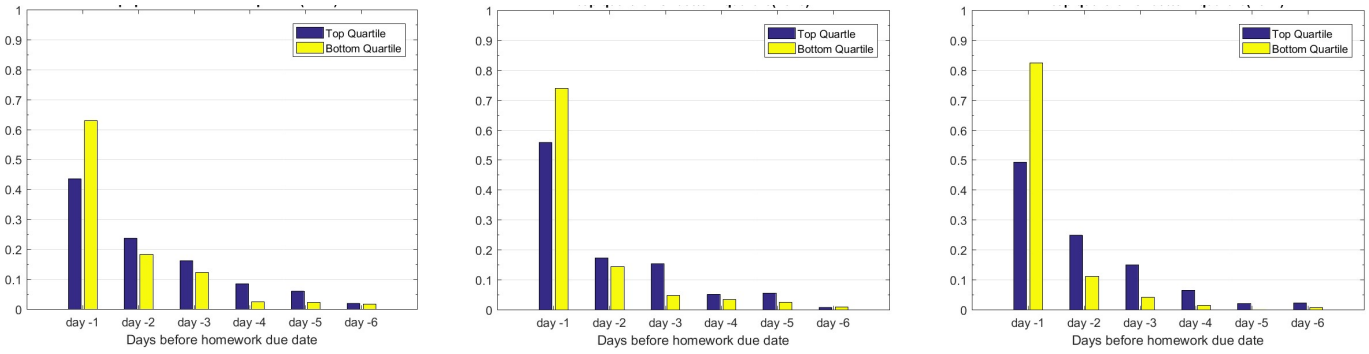

Fig. 2. Average Homework Writing Fraction for the top quartile students vs. the bottom quartile students. Left(2015 quarter), middle (2016 quarter) and right (2017 quarter)

understand the relationship between procrastination and course grade, we compared the Average Daily Activity Fractions for the top 25% students and the bottom 25% students in each course offering.

Table II shows the Average Daily Activity Fractions for the top quartile students and the bottom quartile students within 6 days before the homework deadline. In table II, for each day, two rows of values are reported. The first row is the values corresponding to the top quartile students and the second row is the values for the bottom quartile students. As table II illustrates, the bottom quartile in all three groups spend more time on the activities on day -1 compared to top quartile. However, for the other days, high-performing students spend more time on the reading and writing activities compared to the low-performing students. We conducted independent-samples t-test to examine the difference in the reading and writing activities of the top quartile and the bottom quartile students. The significant differences are indicated with asterisks in table II. On day -1, the Average Daily Textbook Reading Fraction of the top quartile was significantly lower than the Average Daily Textbook Reading Fraction of the bottom quartile for 2015 ($t_{68} = 3.41, p < 0.01$) and 2017 ($t_{46} = 2.59,\ p < 0.05$). Also, the Average Daily Homework Writing Fraction of the top quartile on day -1 was significantly lower than the bottom quartile for 2015 ($t_{68} = 4.89, p < 0.01$) and 2017 ($t_{46} = 4.62,\ p < 0.01$).

Fig. 2 shows the average homework writing fraction of the top quartile and the bottom quartile students in three years. For example, in 2015 the bottom quartile students on average completed 63% of their homework within the last 24 hours before the deadline, while the high-performing students completed only 44% of their homework within that interval. In 2017, this difference is higher and the low-performing students completed 83% of their homework in the last 24 hours, while top-performing students completed about 49% of the homework in the same period.

B. *Centroid Measure*

We computed the Pearson correlation between final course grade and the Average Centroid measures. The result are shown in Table III. For all quarters, the Average Homework Writing Centroid was positively and significantly correlated with course grade. Higher values of the Average Centroid indicates that students have completed the assignments further away from the deadline and this correlates with better course performance. The Average Textbook Reading Centroid was also positively and significantly correlated with course performance in all quarters except 2016. In 2016, the course offering was different from the other two quarters in that some of the students were repeating the course and some of them were non-majors. The fact that the 2016 quarter was off-track could be a reason that the behavior of students was different from the students of the other two quarters.

The Average Centroid measure for all three activities was positively and significantly correlated with course performance for all students combined together ($p < 0.01$).

TABLE III. AVERAGE CENTROID MEASURES FOR TOP QUARTILE VS. BOTTOM QUARTILE

Measure	2015	2016	2017	All
Avg. Textbook Reading Centroid	0.232**	0.174	0.331**	0.245**
Avg. Homework Writing Centroid	0.450**	0.315*	0.480*	0.441**
Avg. Assigned Reading Centroid	0.231**	0.164	0.129	0.242**

TABLE IV. CORRELATION BETWEEN COURSE GRADE AND AVERAGE CENTROID MEASURES. (*P < 0.05, **P < 0.01)

	2015		2016		2017	
Measure	**Top**	**Bottom**	**Top**	**Bottom**	**Top**	**Bottom**
Avg. Textbook Reading Centroid	2.07	1.71	1.98	1.63	2.34	1.70
Avg. Homework Writing Centroid	2.03	1.40	1.83	1.35	1.93	1.12
Avg. Assigned Reading Centroid	1.82	1.45	1.19	0.80	0.64	0.53

TABLE V. CORRELATION BETWEEN COURSE GRADE AND HOMEWORK MEASURES. (*$P < 0.05$, **$P < 0.01$)

Measure	2015	2016	2017	All
Avg. Homework Start Gap	0.336**	0.1779	0.353**	0.339**
Avg. Homework Finish Gap	0.200*	0.410**	0.230*	0.281**
Avg. Homework Effort Density	-0.227**	0.175	-0.206*	-0.171**

In Table IV, we compared the Average Centroid measure for the top 25% students and the bottom 25% students. In all cases the Average Centroid of top 25% students is greater than the bottom 25% students which indicates that the top-performing students perform the activities earlier than the low-performing students.

C. *Homework Measures*

For each student, we computed the Pearson correlation of the course grade and the three homework measures: Average Homework Start Gap, Average Homework Finish gap, and Average Homework Effort Density. The result is shown in Table V.

As table V illustrates, all of the three homework measures were significantly correlated with course performance for all groups except 2016. In 2016 only the Average Homework Finish Gap is positively and significantly correlated with course grade ($p < 0.01$). The Average Homework Start Gap and the Average Homework Finish Gap were both positively correlated with course performance for all groups, which shows students who start and finish homework earlier tend to perform better. On the other hand, the Average Homework Effort Density was significantly and negatively correlated with course performance for all groups except 2016. The negative correlation with course performance shows that cramming before deadline and completing homework assignment intensely and non-stop has negative correlation with the course performance.

VI. CONCLUSION AND FUTURE WORK

In this paper, we examined procrastination of students in an engineering course in statics. We used novel technology to obtain fine-grained, objective measures of students' reading and writing throughout a course. We analyzed the distribution of students' reading and writing effort over various days prior to homework deadlines, and examined the relationship between the distribution and course performance. We found that students who procrastinate and do the bulk of their work in the 24 hours immediately prior to a due date tend to do poorly in the course, while those who do their work one or two days early, tend to perform well. This work is a first step toward creating tools that allow students to monitor their learning habits and use this information to improve their own academic performance. Analyzing students' activities throughout the course enables early predictions of student success or failure and provides warnings and recommendations to at-risk students and can lead to improvement in their performance. This work speaks to the potential benefits of creating instrumented learning environments which can be used both in traditional and online classes.

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