UC Riverside
UC Riverside Electronic Theses and Dissertations

Title

Investigating Students' Course Material Use Through Novel Technology-Enhanced Data Collection

Permalink

Author

Gyllen, Justin

Publication Date

2017

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA
RIVERSIDE

Investigating Students' Course Material Use Through
Novel Technology-Enhanced Data Collection

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Mechanical Engineering

by

Justin Gordon Gyllen

December 2017

Dissertation Committee:
      Dr. Thomas F. Stahovich, Chairperson
      Dr. Suveen Mathaudhu
      Dr. Marko Princevac

The Dissertation of Justin Gordon Gyllen is approved:

_____

_____

_____
                                                    Committee Chairperson

University of California, Riverside

ACKNOWLEDGEMENTS

ABSTRACT OF THE DISSERTATION

Investigating Students' Course Material Use Through
Novel Technology-Enhanced Data Collection

by

Justin Gordon Gyllen

Doctor of Philosophy, Graduate Program in Mechanical Engineering
University of California, Riverside, December 2017
Dr. Thomas F. Stahovich, Chairperson

This dissertation examines students' use of written course materials in introductory engineering courses, begins to elucidate the relationships between students' study habits and their subsequent course performance, and evaluates the impact that carefully designed preparatory assignments has on these relationships. Much of previous educational research into student study habits relies heavily on self-reports – measures which can be unreliable and problematic. This dissertation addresses the issue by employing a custom instrumented document viewing software designed to objectively measure students' actual use of the provided course materials with unprecedented objectivity and detail. The research inquiries investigated in this dissertation consider not only how much time is spent in study, but also what types of content are being used and when the study activities occur.

The findings suggest that engineering students use the textbook at surprisingly low rates throughout the quarter, and that spending a relatively larger portion of one's time on pages containing homework problems is positively related to performance.

Further, students are largely inaccurate in their judgments of how much they actually use the provided course materials. The results suggest that students who are more accurate in their judgments of time spent in study will tend to perform better in the course, highlighting the importance of one's own awareness of study habits. Finally, the results of an experimental intervention suggest that when preparatory assignments are added to the course structure, students viewed a significantly larger percentage of pages that were explicitly assigned to be read and performed significantly better on in-class quizzes. Further, students visited the explanatory text pages of the textbook earlier and more often, with respect to homework assignment deadlines, and this behavior was found to moderate the relationship between preparatory assignment treatment and course performance.

This dissertation makes both applied and methodological contributions to educational research. The findings provide a quantitative analysis of students' actual study habits in engineering courses and begins to illuminate the relationships between study behaviors and course performance. Additionally, this work provides insight into the possible mechanisms that influence the relationships between study behaviors and learning outcomes when adding preparatory assignments to the course structure.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

Overview

In formal education, textbooks are a primary method of disseminating content. Science, technology, engineering, and math (STEM) disciplines, in particular, often use a textbook not only for presenting course content but also for assigning homework. Additional documents, such as lecture notes, homework solutions, and graded work are also regularly provided during the term. Instructors may assume students use these resources with gusto, however their true usage and subsequent utility in STEM education is an empirical question. In order to improve instruction in higher education, a better understanding is needed of the ways in which students use these materials, and how study behaviors relate to academic success. Much of the previous research investigating these questions has relied on student self-reports of their usage of, and attitude towards, these materials, but such self-reports may be inaccurate or misleading. To more precisely investigate the impacts of students' use of course materials, an objective and accurate measurement methodology is essential. My research contributions to date have involved creating and implementing novel technology-enhanced data collection tools and techniques. I have used these tools and techniques to answer questions about what types of course materials (e.g., the textbook, homework solutions, lecture notes, and graded work) students use, how much they use them (i.e., amount of time spent with content and number of visits to content), and when they do so. Further, I investigated the associations between a student's use of these materials and learning outcomes. The objective

measures collected with these tools allowed for increased reliability and validity of such investigations.

Educational Data Mining

Educational data mining is a sub-discipline of data mining focused on extracting and examining large sets of data collected from students in educational settings. Work in this field uses advanced data collection and data mining techniques to better understand students and the ways in which they learn (Romero and Ventura, 2010). Pulling from the playbook of computational data mining, researchers in the field utilize recent advances in educational technologies to extract large quantities of information about students' learning activities.

The objective collection of educationally relevant student data has been of growing interest in fields of educational research. Prior to the introduction of these technologies, journal records (Bash & Kreiner, 2014; Masui, 2014; Phillips & Phillips, 2007; Schuman et. al., 1985) were the best tool for investigating students' study activities. In many cases, students recorded study activities for only a single day, providing a limited measure of study behavior over the whole term. The recent inclusion of online course management systems, content delivery systems, and the like, provide a new opportunity not only for more robust data, but to more objectively collect information that was otherwise self-reported and potentially unreliable. For example, Macfadyen and Dawson collected various measures of students' interactions with a learning management system (e.g., frequencies of files viewed, chatroom participation statistics, forum discussion views, etc.) and investigated their relationships with students'

2

final grades (Macfadyen and Dawson, 2010). The authors ultimately identified a variety of measures that were significantly related to final grade. All of these measures regarded students' interactions with the advanced features of the system, for example, discussion forum messages, direct mail messages, and online assessments attempted and completed to name a few. In another study using a learning management system, Wang and Newlin tracked students' visits to an online course homepage and the number of posts read and written on discussion boards, and found significant positive relationships with final grade (Wang and Newlin, 2000). While these contributions to the literature are important, they are limited in that they identify relationships between the use of the technology and course outcomes. The information provided by these commercial learning management systems can be obscure and limited to the student's interactions with the system as opposed to interactions with course content. It is therefore difficult to generalize the findings to a broader understanding of the importance of traditional study behaviors.

One study conducted by Seaton and colleagues, investigated students' time spent with an electronic textbook provided via a content management system (Seaton et al., 2014). The researchers mined web system log files for webpage access events and measured the time between subsequent events to accumulate viewing time. As a webpage can be left open and "viewed" indefinitely, the researchers employed heavy bounds on the measures to estimate meaningful time engaged with the material. The study investigated, among other things, how much students actually read the provided e-textbook during the semester. The authors report that students only looked at between half and three-quarters of the provided electronic text's content, depending on the course

considered. Further, the study reports that students spend between 10 and 20 hours in the textbook over the entire 15 week term. More work objectively collecting students' use of course materials is needed in order to move forward educational research with more robust and reliable datasets of student behaviors.

Considering these works all together, one major issue in the field of educational data mining is that although the use of more objective methods of measurement results in a higher quantity of data, the information is sometimes of lower quality. In this dissertation, I utilize the principles of educational data mining to collect high resolution data on students' use of traditional course materials. I use technology-enhanced collection techniques to enable insight into patterns of students' usage of course materials with a resolution never before available to educational researchers. This is done in order to collect both high quantity data and high quality information as an improvement to the current limitations to the field.

Theories of Learning & Learning Strategies

This dissertation considers multiple theories of learning in order to understand students' study behaviors and their relationships with academic achievement and learning outcomes. The theories of learning discussed in this chapter inform the hypotheses presented in this dissertation and build the framework with which I interpret the findings.

Time on Task

Time on Task is a classic theory on the science of memory. The original work on this theory dates back to the late 1800's with Ebbinghaus's studies of memory. The work

highlighted a connection between the repetitions of study while learning and recall

outcomes (Ebbinghaus, 1885/1964). The Time on Task theory has been applied in fields

of research focused on education and learning to consider the connection between

amounts of time spent in school and learning outcomes (e.g., Carroll, 1963; Bloom,

1976). Early investigations into education and learning considered broad measures of

time allotted to learning such as years, days, or hours of schooling (Karweit, 1984).

Karweit further illuminated the idea that time engaged in appropriate study activities, as

opposed to simply time allocated to these activities, is more important to relationships

with learning and achievement (Karweit, 1982).

Through the years, Time on Task theory has evolved to incorporate more specific

and accurate measures of time engaged in study, and many significant positive

relationships with learning outcomes have been identified as a result of this advancement.

In fact, with more direct measures of study times, Time on Task is considered among the

most important factors affecting student learning and achievement (van Gog, 2013). In a

recent study, Rawson and colleagues presented a basic model of academic learning that

identified engagement in a study task as a mechanism affecting learning outcomes

(Rawson, Stahovich, & Mayer, 2017). The authors used digital smartpens to measure the

time students spent completing written homework assignments. The study found a

significant positive relationship between this objectively measured homework completion

time and final course grade.

Self-Testing Hypothesis

Research in academic learning has shown that learning outcomes are related to more than just the measured effort of the learner; how the learner chooses to process the information is also important. A student has control over how they process the information presented to them, and this choice in processing is called the learning strategy (Fiorella & Mayer, 2015). One learning strategy in particular, which has been demonstrated as effective in improving learning outcomes, is self-testing (Dunlosky et al., 2013; Fiorella & Mayer, 2015; Kornell & Son, 2009). The Self-Testing Hypothesis supports the idea that practice testing is an effective learning tool as it strengthens recall of the learned material in a fashion that is more aligned with test parameters. Studies of the Self-Testing Hypothesis have been conducted with content of varying complexity and have found that performance in recall is generally better when participants test themselves on the content, as opposed to simply re-studying, in preparation for a recall test (Gates, 1922; Glover, 1989; Karpicke & Aue, 2015; Roediger & Karpicke, 2006; Runquist, 1983). Further, in addition to enhancing recall memory, self-testing helps the learner identify what they do not know, thus informing future study decisions (Kornell & Son, 2009; Dunlosky et al., 2013).

In one study of the effect of testing, researchers presented college students with lists of word pairs for an initial study period (Runquist, 1983). During this initial study period, half of the original list of word pairs were presented a second time in a cued-recall test format. Both 10 minutes later, and 1 week later, the participants were tested on all word pairs again in a cued recall test format. For both the immediate and delayed tests,

recall performance was better for the word pairs that were practice-tested during the initial study period. Another early example examined differences in performance between groups of children, grades 1 through 8, and found that when recitation was incorporated into the study parameters, students were able to recall the material better on subsequent tests (Gates, 1922). The research used two types of content, nonsense syllables and full prose biographical facts, in different participant groups. In the case of more complex prose, the biographical facts, the research found that the positive effect of recitation while studying dropped off after more than 60% of the study time was devoted to recitation. These informative findings speak to the possible advantages and limitations of the self-testing as a learning strategy when more complex content is considered.

Though the testing effect is nearly universally found to improve performance on subsequent recall examinations, much of the previous research on this topic focuses on controlled experiments where participants are directed to participate in specific periods of self-testing. There is a dearth of research regarding the effects of self-testing in educationally relevant contexts (Dunlosky et al., 2013; McDaniel et al., 2012). One study investigating such contexts compared two types of practice via optional online activities. Some concepts in the course were reinforced within the activities by re-presenting the text initially used to introduce those concepts, while others were reinforced through practice testing activities with feedback. In subsequent unit tests, students performed better on the concepts that were reinforced via practice testing rather than re-presented text. This study highlights that the self-testing effect occurs in educationally relevant contexts.

Metacognitive Awareness

Metacognition is the broad cognitive skill, most often described as the process of thinking about one's own thinking (Flavell, 1976). Aspects of metacognition are studied in a plethora of fields from developmental and cognitive psychology to educational research. While metacognition has many facets, in an educational context it can be useful to view metacognition as the awareness and control of one's cognitive processes during learning, as this emphasizes the impact that skills in metacognitive awareness has on formative learning situations.

Metacognitive awareness is a broad concept, and as such, studies on the topic identify assessments that may be associated with skills in metacognitive awareness. Researchers assess parts of a student's monitoring process during learning and investigate the relationships with their study behaviors and leaning outcomes. For example, one common assessment of metacognitive awareness is judgements of learning (JOLs). JOLs are judgements of how well one believes they acquired the information recently presented to them (Koriat, 1997; Pilegard & Mayer, 2015; Rhodes & Tauber, 2011). Another more recent assessment of metacognitive awareness are judgements of understanding (JOUs; i.e., judgements with regard to recognizing how well one believes they understood the material presented to them). JOU's have been demonstrated to be even more highly correlated with learning outcomes than JOLs (Pilegard & Mayer, 2015).

Skills in metacognitive awareness, as measured by these assessments, are important not only for the significant relationships with learning outcomes, but also for their relationships with study behaviors. For example, consider a student with an

upcoming examination they wish to study for. The student will make choices about how long to study and what content to study based on their judged understanding of the topics, how well they feel they have already learned the topics, etc. Previous research has shown relationships between assessments of metacognitive awareness during learning and study behaviors (Son & Metcalfe, 2000). More specifically, skills in metacognitive awareness influence students' self-regulation during learning, a skill shown to be related to learning outcomes especially in technology-enhanced learning environments (Azevedo, 2005; Azevedo, 2007; Schraw, 2010).

Scaffolding and the Zone of Proximal Development

Scaffolding, in an instructional context, is a tool used to more effectively present novel information to a learner that may, as a whole, be beyond their current capabilities (Wood et al., 1976). Wood and colleagues hypothesized that an assisted teaching strategy like this would allow learners to develop task competence at a quicker pace than those who are unassisted. In an initial empirical study, the researchers investigated children, ages 3 to 5, constructing a pyramid out of interlocking blocks with the direct instruction of an adult tutor. The tutor provided scaffolded instruction for the children during the process to drive their understanding of the correct construction procedure. Though no control was administered for the scaffolded instruction, the research ultimately found that the children learned the construction procedure and were able to reconstruct the pyramid a second time without further help from the tutor. Specifically, the proof of concept work highlighted the important roles of the tutor in this scaffolding relationship. Additionally,

9

Wood and colleagues touch on one caveat of the approach. The learner must be able to recognize the solution to the particular novel problem before they are able to produce the solution themselves. This observation touches on a key component of successful scaffolding, that is, the material presented to the learner must be within in the learners Zone of Proximal Development (Vygotsky, 1980). Vygotsky identified this zone as the area between the learner's independent development level and their potential level when under guidance. This is to say that in order for scaffolding to work, the material should be presented in a way that the learner is able to understand the material with guidance, but is unable to gain an understanding without guidance.

Recent advances in educational technologies like intelligent tutoring systems, learning management systems, and content delivery systems provide an ideal opportunity to incorporate successful scaffolding into the instructional design. In early work, Guzdial developed a process of software-realized scaffolding designed to emulate the same quality of scaffolding a good teacher can provide in a classroom environment (Guzdial, 1994). The study highlighted the ability of a software-realized approach to be able to automate the scaffolding process and even incorporate the difficult task of fading scaffolding. Fading is the idea of gradually removing the expert instruction as the learner develops their skills and is a critical piece of successful scaffolding. The idea of using software to implement scaffolding, or to directly develop software scaffolding tools, was further investigated in a study outlining a theoretical framework for the design of such tools (Quintana et al., 2004). Further, Puntambekar and Hubscher present an extensive review of the state of scaffolding applied in current complex learning environments

(Puntambekar and Hubscher, 2005). The authors conclude that important aspects of scaffolding theory, like adaptivity and fading, are being underutilized in current applications and that future work needs to be done to better understand the best approach to implementing successful scaffolding in current learning environments.

Course Structure, Study Behaviors, and Student Outcomes

Intuition suggests that the structure of a course has an effect on student attitudes and performance. Researchers have explored a variety of course structures designed to enhance learning outcomes. One course structure of recent interest is the flipped-classroom model, where students are asked to read materials or watch multimedia presentations outside of class, while lecture is used for gaining skills in hands-on problem solving (Bishop and Verleger, 2013). Likewise, course structures based on active learning approaches incorporate in-class activities designed to increase student engagement with the material and with one another (Prince, 2004). Both of these approaches to course structure may incorporate changes to the frequency of assessments and assignments as part of their model, but there is little research focused directly on the impacts of such changes.

An increase to the frequency of quizzes and exams administered has been demonstrated to have a positive effect on student attitudes and performance across difference disciplines, but the mechanisms mediating this relationship are still unclear. For example, one study found that when the number of exams during an introductory physics course were doubled, an increase in performance on standard numerical problems, less use of cheating websites, and less guessing on homework were observed

11

(Laverty et al., 2012). The authors speculated that the increased number of exams turned them into formative assignments, as opposed to simple assessments. Likewise, they speculated that homework was considered more of a study tool contributing to student success, rather than a chore. This study is one example that makes speculative claims about the influence of assignment frequency on student study behaviors with little quantitative evidence of the mechanisms at work. A possible explanation is that researchers may not have the tools to collect information with a resolution appropriate to study these interactions. Study behaviors are often measured via student self-report so the efficacy and reliability of such measures should be considered.

In one recent comprehensive study, Eddy and Hogan investigated the impacts of direct changes to course structure on students' exam performance, self-reported attitudes toward the course, and self-reported study time allocation (Eddy & Hogan, 2014). The researchers adapted the course structure by including ungraded questions to guide reading, graded preparatory homework assignments, and extra credit in-class questions. The study was conducted across four terms of introductory biology courses and found that, when course structure was adapted in these ways, students performed significantly better on course exams. Further, considering students self-reported study time allocation, the findings indicated students were 2.6 times more likely to report spending time preparing for class and 2 times more likely to complete reading assignments prior to class. However, the increase in preparatory activity was accompanied by a decrease in self-reported review activities. That is, with the course adaptations students were 1.4 times less likely to review their notes after class and 1.9 times less likely to attempt

practice questions at the ends of chapters. This study begins to highlight the possible impacts that direct changes to course structure can have on students' study behaviors and subsequent performance. This work measures studying behaviors via self-report surveys, so the comparative differences in these measures are meaningful but the absolute values of the measures may be unreliable. This dissertation, considers changes to course structure through the inclusion of graded preparatory assignments, and investigates their impacts on student performance as well as study behaviors using more objectively measured data.

Summary

The purpose of this dissertation is to examine factors of course material usage that influence course performance for undergraduate engineering students, and to improve educational research by developing tools and analyses to objectively collect high resolution measures of students' use of course materials. The investigation encompasses both student outcomes impacted by reading as well as controllable factors that may influence these study behaviors. This dissertation will consist of a compilation of three research articles that address the following lines of inquiry:

A. *How is content in the course textbook (e.g., homework problems, homework answers, instructional text, and worked examples) used by students? Are objective measures of students' textbook use predictive of course performance and learning outcomes?*

B. *Are students able to accurately judge the time they spend studying the following course materials: textbook, homework solutions, lecture slides, and graded work?*

Is the discrepancy between a student's judgment of their study time and their

actual study time related to course performance?

C. *Can a student's reading behavior be influenced by adding targeted preparatory*

assignments to the course curriculum? Does the change in student behavior

correspond to a change in student performance?

In order to facilitate the investigation of these lines of inquiry, I developed an

instrumented document viewing application designed to collect objective and accurate

measures of a student's use of course documents. The application has been used in

multiple offerings of introductory mechanical engineering courses, enabling the

collection of data on students' usage of the course textbook, lecture slides, homework

solutions, and assignment grade reports. To address inquiry **A,** I investigated whether

time spent reading different types of content (e.g., homework questions, instructional

text, worked examples, etc.) in the assigned textbook is predictive of student performance

on homework/quizzes, exams, and overall course grade. Further, I elucidate the

differential relationships between usage of these types of content and course

performance. To address inquiry **B**, I directly compare objective measures of material use

collected from the instrumented document viewing application and subjective

measurements of material use taken from student surveys at the end of the quarters. I

examine if students are able to accurately judge the time they spent with the provided

course materials and investigate if errors in students' judgments of study time are related

to course performance and learning outcomes. Finally, to address research inquiry **C**, I

compare one quarter of data collection that included manipulations (i.e., preparatory

assignments) to the course structure to a previous quarter without the manipulations. These preparatory assignments were designed to motivate students to read the text earlier and more often than they otherwise would. I examine various aspects of the influence of these assignments on students' use of course material and subsequent course performance.

This dissertation includes a general methods section, followed by a series of three research articles, organized into chapters. Chapter 2 describes the general methods used in all quarters of data collection. This includes an explanation of the tools developed for this dissertation and procedures used to measure students' use of the course materials investigated. Chapter 3 contains a research article that reports on my investigations surrounding research inquiry **A**. Chapter 4 contains a research article that reports on and summarizes my investigations of research inquiry **B**. Chapter 5 presents a research article that reports on my investigations of research inquiry **C**. Finally, Chapter 6 contains a general discussion and conclusions surrounding the three research inquiries when considered all together.

This work is at the intersection of multiple fields of research and therefore contributes to the fields of mechanical engineering, STEM education, and educational psychology by furthering the understanding of how technology can be used to objectively and accurately measure students' use of course material as it relates to academic success. By elucidating the relationship between course material usage and learning outcomes, as well as the impacts of technology assisted learning on this relationship, this dissertation has the potential to inform teaching interventions and instructional design to promote

academic success. Furthermore, findings from these lines of research will provide educational researchers with evidence-based information regarding students' actual use of provided course materials and the relationships with academic success. Finally, the technology-enhanced data collection techniques described in this dissertation can provide educational psychologists with tools necessary to validate long-standing theories of learning and instruction that to date have been investigated only through self-reported student data.

Research Inquiries and Hypotheses

Research Inquiry 1) How is content in the course textbook (e.g., homework problems, homework answers, instructional text, and worked examples) used by students? Are objective measures of students' textbook use predictive of course performance and learning outcomes?

> **Hypothesis 1)** I hypothesize that students who focus their efforts on textbook pages containing homework problems and homework answer are engaging in a form of the self-testing learning strategy. Therefore, based on previous research regarding the self-testing learning strategy, effort measured on these types of pages will correlate positively with course performance.

Research Inquiry 2) Are students able to accurately judge the time they spend studying the following course materials: textbook, homework solutions, lecture slides, and graded work? Is the discrepancy between a student's judgment of their study time and their actual study time related to course performance?

Hypothesis 2a) I hypothesize that students will be unable to accurately judge the actual time they spend with these materials.

Hypothesis 2b) Further, I hypothesize that the discrepancies between students' judgments and actual study times will be negatively related to learning outcomes.

Research Inquiry 3) Can a student's reading behavior be influenced by adding targeted preparatory assignments to the course curriculum? Does the change in student behavior correspond to a change in student performance?

Hypothesis 3a) I hypothesize that the preparatory assignments will encourage students to visit the textbook earlier, relative to the homework assignment deadlines, than they otherwise would.

Hypothesis 3b) I also hypothesize that in the quarter with preparatory assignments students will demonstrate increased performance on quizzes, exams, and final course grade.

Hypothesis 3c) Further, I hypothesize that engagement in the activity of reading earlier and more often will promote a deeper understanding of the core concepts and moderate the effect of preparatory assignments on overall course performance.

Chapter 2: General Methods

Procedures for Data Collection

Data collection presented in this dissertation took place during three introductory

engineering courses during the academic years of 2015 and 2016. The studies took place

during two offerings of Intro to Mechanical Engineering (ME002 Spring 2015 and

ME002 Winter 2016) and one offering of Engineering: Statics (ME010 Winter 2015). At

the beginning of each quarter, students received a tablet with a custom document viewing

application, called DocViewer, described later in more detail. DocViewer automatically

retrieved, and granted students access to, all course documents made available throughout

the term and recorded how those documents were used. The application was connected to

a secure file server, via Secure File Transfer Protocol, that facilitated the retrieval of the

course textbook, annotated lectures slides, homework solutions, and graded digital copies

of their own submitted homework, quizzes, and exams. Students registered an account on

the server, and authenticated from within DocViewer to ensure they could only access the

documents available to their account. This feature ensured that students could access only

their own reports of graded work and no others. After a document was downloaded from

the file server, students could access it anytime (even without internet connectivity) via a

local document library accessible only from within DocViewer. Additionally, all

documents were encrypted, and the decryption password was stored within DocViewer to

ensure that students could only access the documents from within the application. As

students read all materials throughout the term, the application logged a variety of

information about their interactions with these documents. This information was

collected via a sequential log file that was regularly uploaded to the secure file server for safe keeping. Students were encouraged to use the tablet as it were their own, and to study the provided materials as they naturally chose to.

Additionally, at the beginning of each quarter, students completed a concept inventory that was designed to test their initial understanding of the core concepts that would be expanded upon in the coming course. Students were given credit simply for completion of the survey, but their scores were used as a control measure for any statistical analyses pertaining to course performances and learning gains. At the end of each quarter, students completed an additional survey that asked about their attitudes towards and usage of the technologies during the quarter. Responses were used to improve the application, verify the collected data, and provide further insights into the efficacy of the technologies.

Instrumented Document Viewing Application

I created DocViewer using the C# WinRT API with the open source package mupdf (mupdf.org) as a starting point. This open source package provided the basic functions of loading a pdf document and displaying each page as an image object. I developed a familiar and intuitive touch user interface that utilized simple gestures to navigate the displayed content. Scrolling up and down a page as well as changing pages is achieved by swiping up and down or left and right respectively. Likewise, zooming in and out on a page is achieved by pinching in and out. These actions could also be done with mouse and keyboard if a touchscreen was not available. In this case, the arrow keys are used to change pages, the mouse scroll wheel facilitated zooming in and out, and

movement around the displayed page was accomplished with mouse click and drag motions.
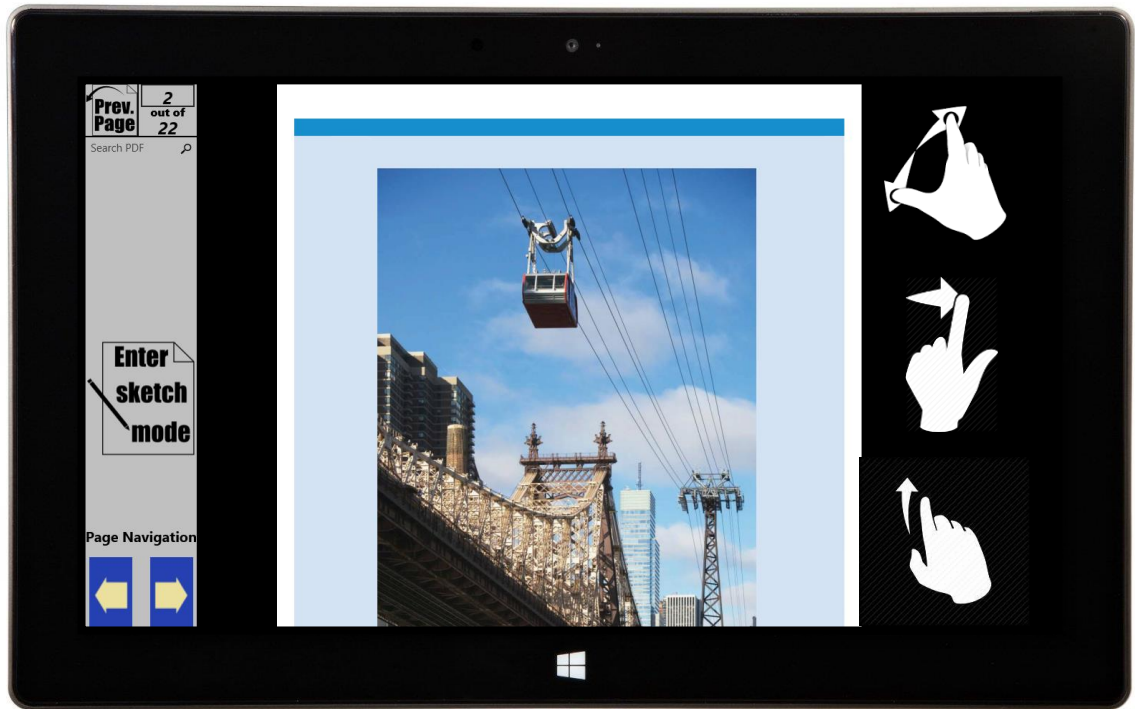
Figure 1: DocViewer User Interface with Gesture Indicators

In addition to the user interface, I developed a variety of *quality of life* features to make DocViewer as useful and accessible as possible. These features will be described in more detail later. I added these features to help ensure that students found the system to be convenient and useful. The goal of the research was to collect accurate measures of students' use of course materials, and this is possible only if students chose to use the instrumented application. DocViewer was published in the Windows Store to allow students to download the application on the provided tablets as well as any personal devices running Windows RT, Windows 7, or Windows 8.

Accuracy of collected data. DocViewer was designed to enable accurate measurement of what, when, and how long a student used course materials. For example, it was designed to display only one page at a time so that there is no ambiguity about what is being viewed. Additionally, DocViewer creates time-stamped log messages, with millisecond resolution, for every interaction that is made with the course materials (e.g., loading a document, changing pages within a document, scrolling or zooming on a page, etc.). Each of these messages contains information about when the activity occurred, as well as which document and page it occurred on. DocViewer was also designed with a timeout function, similar to a computer screen saver, which dims the display after a short period of time with no interactions. This feature allows me to identify the periods of time when a student may have left the application open but diverted their attention away from studying. These periods of *inactive* time are removed from any measures of students' use of the materials, providing a more accurate representation of the student's time engaged with those materials. Finally, course documents are downloaded as encrypted PDFs. The decryption password is built into DocViewer so that it can automatically display the documents. As students do not otherwise have access to the password, they cannot view the documents with other PDF viewers. This design feature is essential for accurate measurement, as it ensures that the documents can be viewed only with the instrumented application and thus all usage can be recorded.

Additional features. DocViewer has been carefully designed to not only objectively collect accurate measures of students' usage of the provided course materials, but also provide a useful and feature rich platform for students to access the content. Additionally, much work has been done to optimize the various features within the application to provide a seamless presentation of the provided course materials. I have made careful consideration to balance these two main functions of DocViewer to provide the best experience for the user as well as the best data collection for the research. I describe, in more detail below, a variety of features contained within DocViewer.

Document selection. First, as described above, all documents were made available to the student in an easy to navigate document library (See Figure 2). The documents are
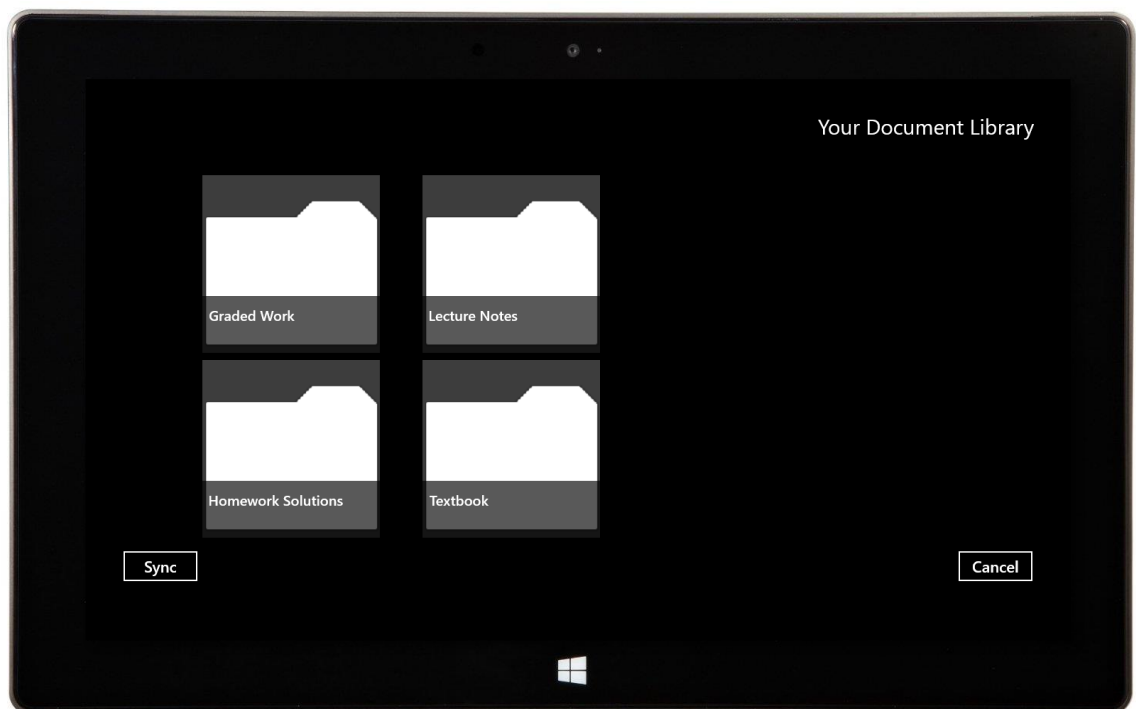
Figure 2: DocViewer Document Library

displayed in categories associated with the document types provided to students (e.g., Textbook, Homework Solutions, Graded Work, Lecture Notes, etc.). To select a document to view, the student need only tap on the desired thumbnail to quickly load that document on the screen. If an internet connection is available, new documents are automatically downloaded from the file server and added to the document library when DocViewer is started. Additionally, students may manually sync their document library with the server in the case that a new document is made available while they are using the application.

Search. This feature allows students to search for key words and phrases within a document. A search bar is presented to the student allowing for quick access to the search functionality for the currently loaded document. Once a search is initiated, a separate screen is displayed that lists all pages within the current document that contain the
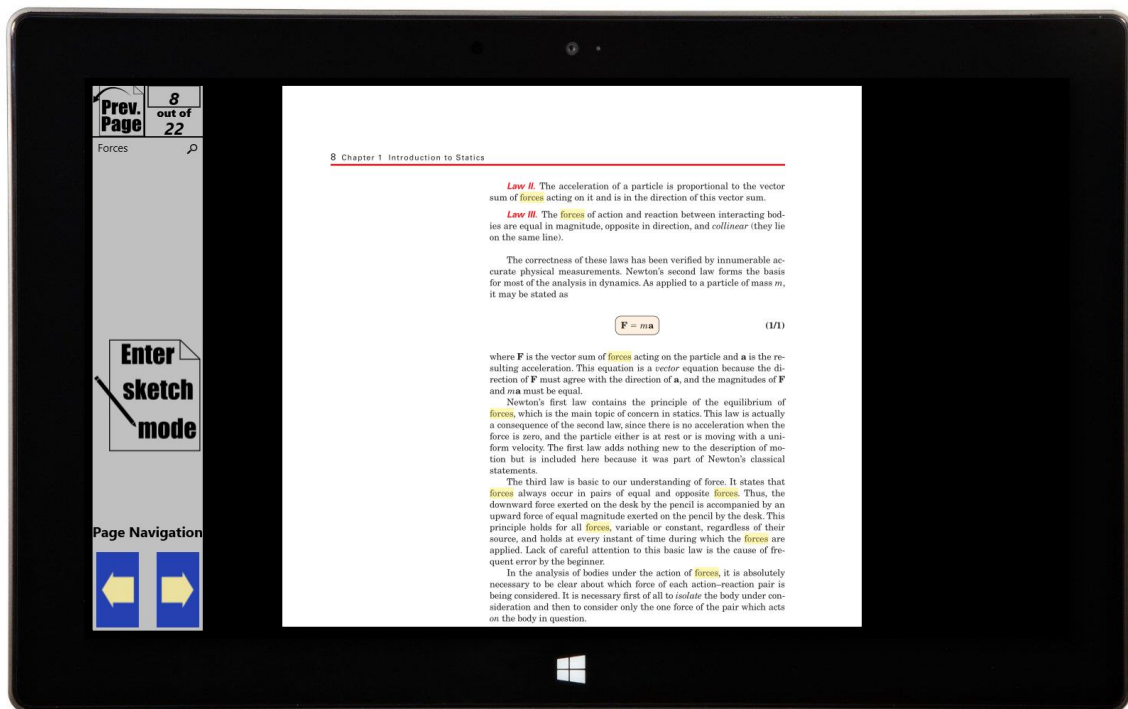
Figure 3: DocViewer Search Result Highlighting

searched content. When the student selects a result from this screen, they are taken directly to that page where all locations of the searched content are highlighted (See Figure 3). This feature allows students to quickly reference, for example, key terms or concepts from lecture, homework problem numbers, and information from tables.

On-page sketching. This is an advanced feature that allows students to take notes directly on the displayed page with their finger or a stylus. The application has a sketching mode and browsing mode. In sketching mode, the student can use a stylus or finer to write on the displayed page. In browsing mode, a finger or stylus can be used to navigate the document. Notes can be erased by tapping an erase button and striking through the notes with a stylus or finger. Notes are copied to the server, and thus are preserved between sessions.
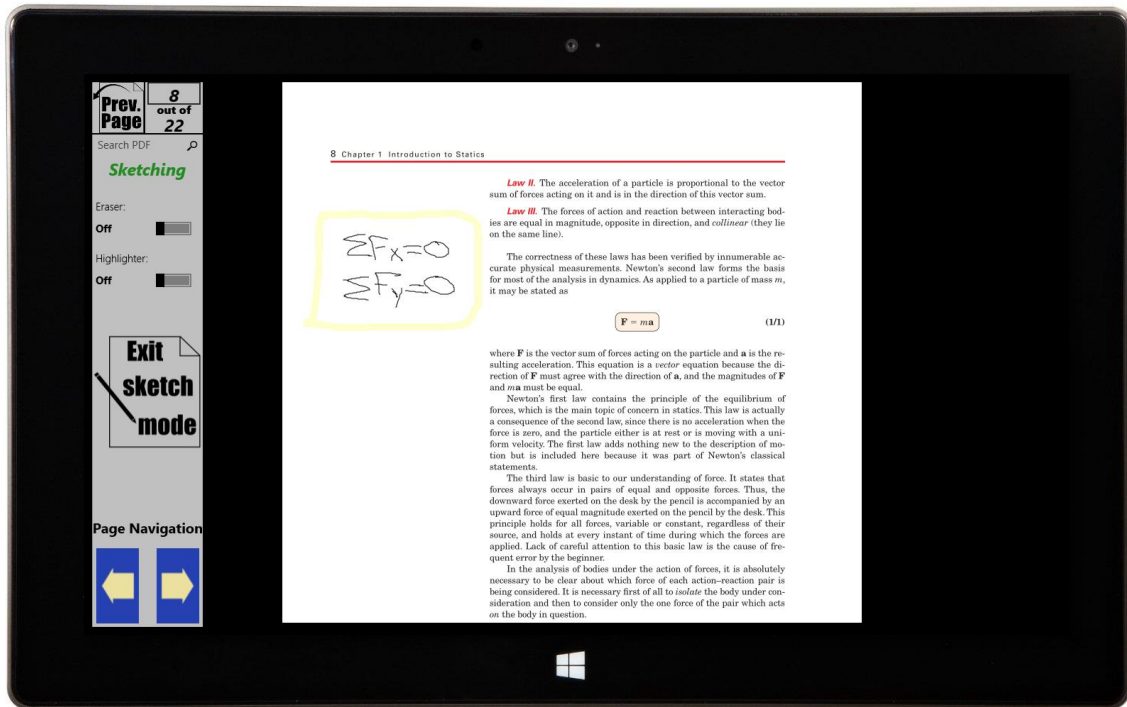
Figure 4: DocViewer On-Page Sketching and Highlighting

On-page highlighting. Similar to the on-page sketching functionality, this feature allows students to highlight any portion of the currently visible page. To add highlights, the student taps a button on a toolbar and uses their finger or stylus to mark the desired text. Highlights can be erased by tapping an erase button and striking through them.

Page pinning. This is a custom bookmarking feature that allows students to save specific pages in a document for quick access in the future. The pinned pages are added to a convenient toolbar at the bottom of the screen so that they can be easily accessed (See Figure 5). A separate list of pinned pages is stored for each available document, and lists are persistent across sessions. This feature allows students to save the pages, for example, that contain homework problems or assigned readings.
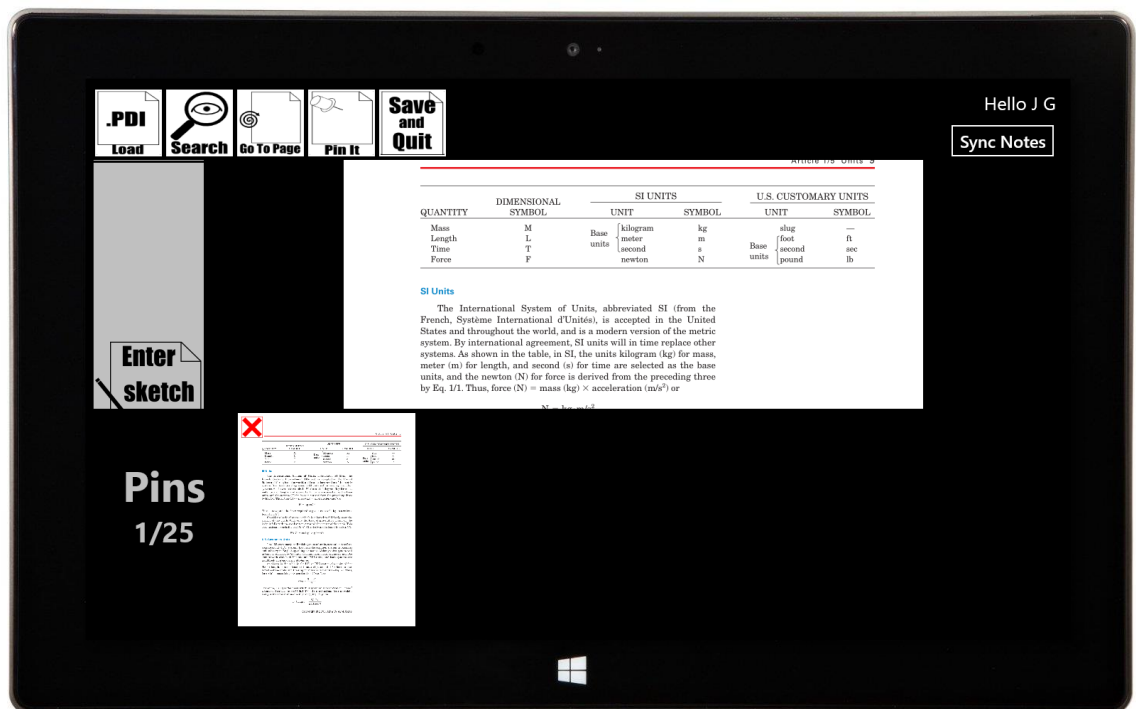
Figure 5: DocViewer Pinned Page

Note and pin syncing. At the end of a session with the document viewing application, all notes, highlights, and pinned pages are synced with the cloud file server. When the application is opened, the sketches, highlights, and pinned pages are retrieved from the cloud. This allows any sketches, highlights, and pinned pages to persist across not only sessions on the same device but also across all devices a student uses.

Information logging. As students use DocViewer to view course documents, a variety of messages describing the interactions are logged to a local file on the device. This log file is periodically uploaded to the cloud file server to ensure that all message are regularly backed up. Every logged message contains the name of the document that was loaded, the page number of the displayed page, and a timestamp indicating when that event occurred. Some messages contain additional information that is specific to the type of event being logged. Below is a description of each message type:

OPEN – This event is logged when a new document is opened for viewing.

PAGE CHANGE – This event is logged when a new page is made visible on the screen, whether by changing pages, selecting a searched result page, or selecting a pinned page.

RE-ORIENT – This event is logged when the user changes the orientation of the tablet from "Landscape" to "Portrait" or vice versa. The new orientation is recorded for this event.

ZOOM – This event is logged when the user zooms in on the currently visible page. As zooming can be done slowly over time, the message is not logged until the screen *comes to rest* and the zooming has finished. Both the previous and new zoom factors are recorded for this event.

POSITION CHANGE – This is event is logged when the user scrolls around the currently visible page. As scrolling can be done slowly over time, the message is not logged until the screen *comes to rest* and the scrolling has finished.

PIN – This event is logged when the user selects the currently visible page to be pinned and saved.

PIN CLICK – This event is logged when the user selects a previously pinned page to view it. The page number of that pinned page is recorded for this event.

GOTO – This event is logged when the user chooses to change to a specific page within the document. The number of the page navigated to is recorded for this event. If an invalid page number is input, this message is not logged.

SEARCHING – This event is logged when the user initiates a search based on an input keyword or phrase. The searched word or phrase is recorded for this event.

SEARCHED – This event is logged when the user selects a page to change to from the search results screen. The number of the selected page is recorded for this event.

INACTIVITY START – This event is logged whenever the currently visible page on the screen is no longer visible. This occurs in a variety of situations described below:

- Whenever search is initiated as the application switches to the search results screen.
- When the user changes to a different application on the device, but leaves the document viewing application running in the background.
- When the inactivity timeout feature triggers as the screen is dimmed in order to obscure the view of the currently visible page.
- When the user selects the "Load New Document" function while currently viewing a document as this feature brings up the document library screen, obscuring the currently visible page.
- When the user puts the tablet device to sleep by closing the lid or pressing the power button once. It is important to capture these actions as the system keeps the application running in the background for a period of time after these actions occur.

INACTIVITY END – This event is logged when the currently loaded page becomes visible again after an inactivity event described above. A variety of situations can trigger this event as described below:

- When search is initiated, and then cancelled, returning the user to the currently visible page.
- When the user returns to the document viewing application while it is running in the background on the device.
- When the user re-interacts with the application effectively ending the inactivity timeout feature that dimmed the screen.

- When the user enters the "load new document" function, bringing up the document library, and then exits the document library screen without choosing a new document to load.
- When the user puts device to sleep, as described above, and then "wakes" the device up again while the application was still running in the background.

EXIT – This event is logged when the user selects the "Save and Quit" function of the application.

Data Extraction and Measure Calculations

Log file preparation. At the end of each quarter, I employ a meticulous log file preparation process to ensure the collection of all event information logged throughout the term. As students use DocViewer throughout the quarter, backups of their log files are automatically uploaded to the cloud file server. The backup files on the server should contain all logged event messages, with the exception of any events from the last time the student used the application. Thus, when students return their tablets at the end of the quarter, I retrieve the final copies of the event logs from the tablets. Sometimes, data transmission errors may result in missing data within a log file. Thus, to ensure that all messages are properly examined, all log file backups are combined with the final device copy. Duplicate log messages are deleted and the remaining messages are sorted in temporal order. This process produces a single sequential log file that contains all messages logged on the device throughout the quarter. This preparation process is done separately for each device a student may have used throughout the term.

Extraction of reading episodes. Once the log files have been combined, cleaned, and sorted, I extract episodes of reading. For the work presented in this dissertation, an

episode is defined as a period of time during which one page of a document is continuously visible on the screen. Per this definition, OPEN, PAGE CHANGE, and INACTIVITY END always mark the beginning of an episode of page viewing. Likewise, INACTIVITY START, SEARCHING, and EXIT always mark the end of the current page viewing episode. While a student is currently in an episode of page viewing, the events RE-ORIENT, ZOOM, POSITION CHANGE, and PIN do not end the current episode as the page remains visible on the screen during these events.

I developed a state machine algorithm in MATLAB to sequentially step through each log file and extract page viewing episodes. Each episode is characterized by the document and page that was viewed, the time at which the viewing started, and the duration of the view.

Reading measure calculations. Once the reading episodes have been extracted, the list of episodes for each student is investigated to measure various aspects of the usage of the course materials. I have developed a data analytics tools in MATLAB that takes as input the extracted lists of episodes, and computes various measures of reading. This tool has a user interface that allows the user to select which students' data are to be included in the analyses, and which measurements are to be made. A screenshot of the user interface is presented in Figure 6. This tool enables the classification of document type (e.g., textbook, homework solution, graded work report, lecture slide, etc.) based on the document name, the identification of textbook content type (e.g., explanatory text, worked example, homework problem, etc.) based on document name and the page number, as well as the classification of "assigned reading" based on document name,

page number and episode timestamp. Not only can I determine the amount of total time spent reading course materials, I can calculate more specific measures for different types of content separately. These features allow for more advanced measures of reading times to be calculated, for example, the total time spent viewing assigned pages in the textbook that contained fully worked examples. This tool calculates the user-selected measures for each student and outputs the information to excel and MATLAB for further analyses.
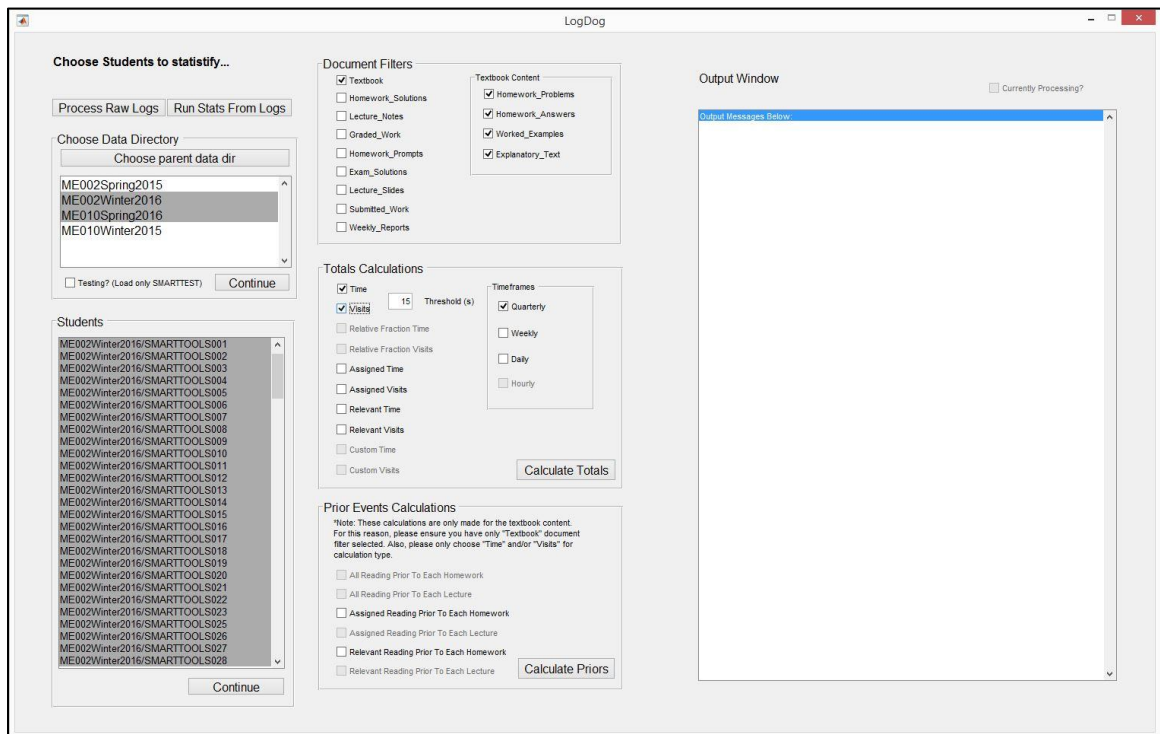
Figure 6. MATLAB Episode Data Analytics Tool Interface

Chapter 3: Students' Use of Course Textbook

Abstract

Time-on-task has been recognized as an important variable in academic learning, but self-report measures of study time are problematic. Therefore, the present study employs an automated system for recording time spent reading a course textbook. College students in an introductory engineering course accessed their textbook online. The book contained pages of instructional text, worked examples, homework problems, and answers to homework problems. An instrumented document viewing program called "DocViewer" recorded the time each student spent on each page, thus providing detailed measures of reading habits. Across the 10-week course, students spent an average of 1.9 hours reading instructional text, 1.4 hours on worked examples, 22.1 hours on homework problems, and 0.9 hours on homework answers, indicating a preference for practicing to solve test problems (i.e., self-testing) rather than being told (i.e., receiving direct instruction). Furthermore, course grade (based largely on solving problems on exams and quizzes) correlated significantly and positively with time viewing homework problems, but not with time viewing either instructional text or worked examples, indicating that achievement was related to time spent practicing for solving test problems but not to time spent being instructed. Results suggest a revision of the time-on-task hypothesis to include the value of spending time on tasks aligned to test requirements.

Objective

Suppose a college instructor assigned an online textbook in a STEM course but no one read it (or barely read the instructional text in it). Although instructors in STEM college courses frequently require the use of textbooks, there is growing evidence that students make little use of them (e.g., Berry, Cook, Hill, & Stevens, 2010; Junco & Clem, 2015; Seaton et al., 2014; Sikorski et al., 2009; Smith & Jacobs 2003). Additionally, as publishers continue to migrate textbooks from print to electronic form, it is worthwhile to investigate how students read e-textbooks in STEM courses. The present work investigates these questions.

As summarized in Table 1, in the present study students in a 10-week introductory engineering course on "Statics" were assigned a digital textbook that contained five types of pages: *Instructional Text, Worked Examples, Homework Problems*, *Homework Answers,* and *Other*. The *Instructional Text* and *Worked Examples* constitute what can be called *learning by being told*, whereas the *Homework Problems* and *Homework Answers* constitute what can be called *learning by practicing*. The primary goals of the present study are to determine how much time students spend on each of these four types of pages and the extent to which time spent on each correlates with course grade.

Table 1

Five Types of Content in an Engineering Textbook

Textbook Content Types	Description
Instructional text	Explanatory material, including both text and graphics, presenting the principles of statics.
Worked examples	Worked examples illustrating how the principles of statics are applied to solve problems.
Homework problems	End-of-chapter problems that students solve for homework assignments.
Homework answers	Final numerical answers to the end-of-chapter homework problems.
Other	Other types of content including table of contents, index, and appendices.

Theory and Predictions

Time on task. This work is motivated by the hypothesis that time on task

provides a measure of a student's engagement during learning, and that this measure is

among the most important factors affecting learning and achievement (van Gog, 2013).

The time-on-task hypothesis has deep roots in the science of learning, dating back to

Ebbinghaus's (1885/1964) classic studies showing a connection between time spent

studying a word list and learning outcomes. In educational contexts, student engagement

during learning—reflected in time on task—is often measured as the amount of time that

students spend on learning (Carroll 1963; van Gog, 2013). Through the years, the theory

has evolved to incorporate the idea that engaged time on task, as opposed to simply time

allocated to students for learning, is a more important factor in predicting positive

learning outcomes (Karweit 1984).

Recently, Rawson et al., (2016) presented a basic model of academic learning that

considered the fact that "engagement (as indicated by the amount of time that students

allocate to a task) is a mechanism affecting learning outcomes (as indicated by achievement)" (p. 2). The researchers used digital smartpens to objectively measure time spent on writing homework assignments and found a significant positive correlation between this measure and final course grade. Our present research also considers the importance of time engaged in learning activities and seeks to collect objective measures of students' engagement with the assigned course e-textbook.

Self-testing as a learning strategy. Research has shown that academic learning depends not only on what is presented—such as a textbook—but on how the learner chooses to process the presented information, which can be called the learning strategy (Fiorella & Mayer, 2015). When students read a book—such as an e-textbook in the present study—they can control the reading process by choosing which pages to view and how long to view them. In regard to the types of pages summarized in Table 1, a student using a learning strategy based on *learning by being told* would focus heavily on the *Instructional Text* pages and the *Worked Example* pages, whereas a student using a learning strategy based on *learning by practicing* would focus heavily on the *Homework Problem* and *Homework Answer* pages.

Solving problems (i.e., learning by practicing) represents a form of self-testing, in which a learner engages in the kinds of activities that are required on the test, although learning by practicing is not always indicative of self-testing. There is a considerable body of evidence that self-testing can be an effective learning strategy (Dunlosky et al., 2013; Fiorella & Mayer, 2015; Karpicke & Aue, 2015; Roediger & Karpicke, 2006), although only a fraction of the research base involves educationally relevant material

(e.g., Johnson & Mayer, 2009). The most common form of self-testing involves studying

a list of words and then trying to recall it. A *testing effect* occurs when students perform

better on a subsequent recall test when they spend learning time trying to recall the words

on a list they were given rather than restudying them. The major learning mechanism

underlying the testing effect is that learners strengthen their skill in retrieving the targeted

material, which is a cognitive process that is also required on a subsequent recall test. In

short, the act of taking a test—even a practice test—can be an aid to learning. The present

study extends research on self-testing to the domain of learning from an online textbook

in an academic setting, although solving practice problems may involve more than self-

testing.

More specifically, asking students to solve problems is consistent with the long-

standing research base on the positive role of practice with feedback in achieving

expertise within a domain (Dunlosky et al., 2013; Ericsson, 2016; Hattie, 2009). In

particular, certain aspects of practice have been shown to be particularly effective such as

spacing practice activity over time rather than concentrating it all at one time (i.e., spaced

practice effect), interleaving different types of problems rather than blocking problems by

type (i.e., interleaved practice effect), and practicing on problems at an increasing level of

challenge with appropriate feedback (i.e., deliberate practice effect). The present study

examines how students manage the way they practice on solving problems within the

context of using an online textbook in an academic setting.

Based on the time-on-task hypothesis and the self-testing hypothesis, we focus on

two key questions in the present study: (1) Which kinds of pages in the course e-

textbook do students view during learning? If students see their goal as being exposed to the material—that is, learning by being told—they should direct their efforts towards the *Instructional Text* pages and the *Worked Example* pages. If students see their goal as being able to perform well on the homework problems—that is, learning by practicing—they should direct their efforts towards the *Homework Problem* pages and *Homework Answer* pages. (2) How are the learner's reading strategies (i.e., how much they engage in each of the four types of pages) related to academic achievement in the course? According to an updated version of the time-on-task hypothesis and the self-testing hypothesis, the degree to which students focus on *Homework Question* and *Homework Answer* pages should correlate positively with academic performance, such as course grade.

Related Research on Textbook Reading

Previous research has found that STEM students identify themselves as "readers" in surprisingly low rates. For example, just over 20% of students in an Introductory Physics course reported that they used the textbook for more than just referencing problems and equations (Cummings, French, & Cooney, 2002). Similarly, Podolefsky and Finkelstein (2006) conducted a survey of 1000 participants across multiple Introductory Physics course offerings and found that only a little more than one third of the students reported reading more than 80 percent of the assigned readings. The same study also found that students' self-reports of reading effort were not predictive of course performance or learning outcomes.

A potential methodological problem in much of the current research investigating students' textbook reading strategies is the reliance on surveys and self-reported data (e.g., Berry, Cook, Hill, & Stevens, 2010; Cummings, French, & Cooney, 2002; Landrum, Gurung, & Spann, 2012; Podolefsky & Finkelstein, 2006; Schuman, Walsh, Olson, & Etheridge, 1985; Sikorski et al., 2002; Smith & Jacobs, 2003). This sort of data can be highly subjective and relies on retrospective reporting. For instance, Schuman et al., (1985) found little correlation between students' self-reported study time and their grade. The authors speculated, "Students may not know how much they study, and there may also be some bias in willingness to report honestly" (p. 961). Additionally, Smith and Jacobs (2003) found a negative correlation between anticipated grade and self-reported time spent using the textbook each week. In this case the authors concluded, "It is possible that a higher fraction of the weaker students consciously inflated their hours, or included inefficient time in their estimate" (p. 101). In our present research, we aim to overcome these methodological limitations by using computer-based technology to accurately and objectively measure students' use of the textbook.

In recent years, the emergence of online content delivery systems [e.g., CourseSmart Analytics (https://www.vitalsource.com), OpenDSA (Shaffer, Karavirta, Korhonen, & Naps, 2011), LON-CAPA (Kashy et al., 1993), and zyBooks (https://zybooks.zyante.com)] has provided one approach for measuring student reading effort. Studies using online content delivery systems to measure reading effort have found that students read at very low rates (Junco & Clem, 2015; Seaton et al., 2014). For example, one study examined the reading logs of thousands of students across multiple

37

offerings of an Introductory Physics course (Seaton et al., 2014). In this study, reading time was assumed to be the time between subsequent page access events, but as a webpage can be displayed indefinitely, the researchers employed an upper bound on page viewing time. Assuming that meaningful page views had durations of between 10 seconds and 30 minutes, they found an average reading time of approximately 10 to 20 hours per student during the 15-week term. While weblogs provide a more objective measure of reading than surveys do, in the present study we developed an instrumented document viewing program that provides an even more precise method of measuring reading time.

Method

Participants and Course Setting

The participants were 143 undergraduate students enrolled in a course on Statics at [deleted for masked review] during the winter quarter of 2015. Every student who enrolled in the course consented to participate in this study. Statics is an introductory mechanical engineering course focused on the equilibrium of bodies subjected to forces. Mechanical engineering undergraduate students who follow the recommended course plan take this course during the winter quarter of the sophomore year. Table 2 presents demographic information for the participants. The vast majority of students were men (87%) and engineering or computer science majors (85%). Sixteen of the participants did not complete a survey soliciting their year in school, but of the remaining students, all but 9% reported being undergraduates within their first 4 years. We followed guidelines for ethical treatment of human subjects and obtained IRB approval for the study.

Table 2

Participant Characteristics for Chapter 3

Variables	N	%
Gender		
Male	125	87.4
Female	18	12.6
Major		
Bioengineering	3	2.1
Chemical Engineering	2	1.4
Computer Engineering	14	9.8
Computer Science	12	8.4
Electrical Engineering	5	3.5
Environmental Engineering	9	6.3
Materials Science and Engineering	12	8.4
Mechanical Engineering	65	45.5
Other	21	14.7
Year		
Freshman	8	5.9
Sophomore	72	49.3
Junior	20	14.0
Senior	15	10.3
5th year and beyond	12	8.8
Unknown	16	11.8

Materials and Apparatus

The materials comprised an online textbook and a document-viewing program. The measures comprised reading measures and test measures.

Course e-textbook. The course e-textbook was *Engineering Mechanics: Statics, 8th edition* (Meriam, Kraige, and Bolton, 2014). We provided all students with a copy of the e-textbook. Students did not receive a print version of the book. The chapters in the book are organized into sections containing *Instructional Text* related to a particular topic. As the term suggests, *Instructional Text*, which includes both text and graphics,

presents the principles of statics. Each section included *Worked Examples* which are problems with annotated solutions illustrating how the principles of statics are used in problem solving. Each section also contained *Homework Problems* which are Statics problems that students solve on their own paper. The final numerical answers to the homework problems are listed in the *Homework Answers* section in the back.

The course covered material from the following six chapters of the textbook: Introduction to Statics, Force Systems, Equilibrium, Structures, Distributed Forces, and Friction. These chapters span a total of 398 pages of content, of which 133 contain *Instructional Text,* 56 contain *Worked Examples,* 192 contain *Homework Problems,* and 17 contain *Homework Answers.* Students were instructed to read 92 of the 133 *Instructional Text* pages and 39 of the 56 *Worked Example* pages. Additionally, only 42 of the 192 *Homework Problem* pages contained problems that were assigned to students during the term. While homework problems were assigned from the *Homework Problems* pages in the textbook, the assignments often contained modifications to the numerical values in the questions so that the answers did not directly match those found in the *Homework Answer* pages. For example, the assignment might specify a change to a length, angle, or magnitude of a force. 8 of the 17 *Homework Answer* pages contained answers to assigned homework problems.

Instrumented document viewer. To track students' reading habits, we created an instrumented document viewing program called "DocViewer." The program was built using the open source μPDF (mupdf.com) PDF rendering software system. The viewer was designed for use on a Windows RT tablet and is typically operated in full-screen

mode. DocViewer provides functions for keyword search, bookmarking pages, and writing notes using either a stylus or a finger on the touch screen.

The user interface of the program is designed to enable accurate measurement of reading time. In particular, only a single page can be displayed at any given time so that there is no ambiguity about what page a student is viewing. Additionally, to ensure accurate measurement of engaged reading time, the program dims the display after 10 minutes of inactivity during which the student provides no input via the touch screen or keyboard. When the screen is dimmed, the student can "wake" the program by touching the screen. We provided students with the e-textbook and other course documents as encrypted PDFs. The decryption password was built into DocViewer so that it could automatically display the documents. As students did not otherwise have access to the password, they could not view the course documents with other PDF viewers.

DocViewer creates a log file of time-stamped page viewing events. An event occurs each time there is a change to the displayed document. For example, opening or closing a document, panning or zooming the display, and navigating to a new page are all recorded in the log. The program periodically uploads the log file to a secure file server.

Each student was provided with a Windows RT tablet on the second day of the quarter. The students were then required to register for an account and install DocViewer from the Windows Store. DocViewer then automatically retrieved an encrypted copy of the course e-textbook from our secure file server.

41

DocViewer automatically uploads event logs to the server when the tablet is online. However, it is possible for a student to use the tablet without an internet connection. To ensure that all viewing data was collected, we manually extracted the log files from the tablets when students returned their equipment at the end of the quarter.

Reading measures. As described in Table 3, we consider 14 measures of reading. These measures are based on the notion of a *page visit*, which we define as a time interval of at least 15 sec during which a particular page is continuously visible on the tablet. We consider intervals of less than 15 sec to be page navigation rather than reading. A student may pan or zoom the view of a page without ending the current page visit. Navigating to a new page or exiting the program, however, ends a page visit. Ten minutes of inactivity typically ends the current page view. As previously noted, the screen dims after ten minutes of inactivity. However, if the student wakes the program within 30 sec of dimming, the page visit continues. In computing the duration of a page visit, we subtracted any time the student spent performing keyword search, as the search tool obscured the displayed document. We found that, in some cases, DocViewer did not properly log an exit event when the program was closed. In these cases, we took the page visit duration for the final page to be the student's average page visit time. We calculated a student's total reading time as the sum of the page visit durations. Thus, the total time excluded page navigation (views less than 15 sec in duration) and keyword search.

Our measures of reading include both the total number of page views and the total viewing time for the entire e-textbook, as well as for each of the four types of pages (i.e., *Instructional Text, Worked Examples, Homework Problems*, and *Homework Answer*). We

also characterize viewing time with a relative measure of time describing the fraction of the total time spent viewing each page type. For example, if a student viewed the textbook for a total of 100 minutes, and 20 minutes of that time was spent viewing *Worked Examples*, then the relative viewing time for *Worked Examples* would be 20%. In computing the various reading measures, we excluded viewing of the table of contents, index, and appendices. On average, students spent 6.6 minutes during the quarter on such materials.

To illustrate our reading measures, consider a simplified example in which a student had the following reading activity: page 1 for 3 sec, page 2 for 50 sec, page 10 for 70 sec, page 22 for 12 sec, and page 10 for 80 sec. In this case, there would be only three page viewing events, one event on page 2, and two events on page 10. As the time spent on each of pages 1 and 22 is less than 15 sec, this activity would not comprise page viewing events and thus these episodes would contribute neither to the number of page views nor the viewing time. Imagine that page 2 is *Instructional Text*, while page 10 is *Homework Problems*. In this case, the total time for *Instructional Text* would be 50 sec, while the total time for *Homework Problems* would be 150 sec. Likewise, there would be no reading time for *Worked Examples* or *Homework Answers*. Finally, the relative reading time would be 25% for *Instructional Text*, 75% for *Homework Problems*, 0% for *Worked Examples*, and 0% for *Homework Answers*.

Table 3

Quantitative Reading Measures for Chapter 3

Textbook Viewing Measures	Description
Total Viewing Time	Total time spent viewing the textbook
Instructional Text Viewing Time	Time spent viewing pages containing Instructional Text
Worked Example Viewing Time	Time spent viewing pages containing Worked Examples
Homework Problem Viewing Time	Time spent viewing pages containing Homework Problems
Homework Answer Viewing Time	Time spent viewing pages containing Homework Answers
Total Page Visits	Total number of visits to pages in the textbook
Instructional Text Page Visits	Number of visits to pages containing Instructional Text
Worked Example Page Visits	Number of visits to pages containing Worked Examples
Homework Problem Page Visits	Number of visits to pages containing Homework Problems
Homework Answer Page Visits	Number of visits to pages containing Homework Answers
Relative Viewing Time for Instructional Text	The percentage of time spent on pages containing Instructional Text
Relative Viewing Time for Worked Examples	The percentage of time spent on pages containing Worked Examples
Relative Viewing Time for Homework Problems	The percentage of time spent on pages containing Homework Problems
Relative Viewing Time for Homework Answers	The percentage of time spent on pages containing Homework Answers

Test measures. We considered several test measures including homework and

quiz score (based on 10 homework assignments and 10 weekly quizzes), exam score

(based on 3 exams), course grade (excluding class participation), Force Concept

Inventory (FCI; Hestenes et al., 1992), Statics Concept Inventory (SCI; Steif and Danzler,

2005), and a post-study survey. The FCI measures students' understanding of Newtonian concepts of forces as taught in an introductory physics course, while the SCI measures understanding of the concepts taught in a statics course. The homework assignments, quizzes, and exams contained statics problems requiring free-form solutions with diagrams and equations. The final exam also included two multiple choice questions and a professional ethics question.

Quiz and exam problems were graded using a rubric that examined the correctness of the major elements of the solution such as free body diagrams, geometric calculations, and equilibrium equations. The credit for the problem was divided over these elements according to their complexity, and points were deducted for errors. One problem on each homework assignment was also graded using this rubric scheme, while the remaining problems were graded based on completion and correctness of the final answers.

The course grade was based on the following weighting: 5% for class participation, 10% for the homework score, 10% for the quiz score, 20% for the first midterm exam score, 20% for the second midterm exam score, and 35% for the final exam score. However, in our present analysis, we exclude class participation from the final course grade as this does not directly represent competence with the subject matter. For our short-term measure of achievement, we combine homework and quiz grades with equal weights. Similarly, when considering the combined exam grade, we weight each midterm by 0.2 and the final exam by 0.35.

The post-study survey included three 5-point Likert scale questions:

How important was the <u>textbook</u> to your learning of statics?
(1) Very unimportant
(2) Unimportant
(3) No opinion
(4) Important
(5) Very important

How convenient was the tablet (DocViewer) for reading course documents?
(1) Inconvenient
(2) Somewhat inconvenient
(3) No opinion
(4) Somewhat convenient
(5) Convenient

Do you prefer an electronic textbook or a paper textbook?
(1) Strongly prefer paper
(2) Prefer paper
(3) No opinion
(4) Prefer electronic
(5) Strongly prefer electronic

Procedure

At the start of the class, students completed the Force Concept Inventory

(Hestenes, et. al. 1992) to assess their prior knowledge of mechanics concepts. Each

week, students attended three hours of lecture focusing on the core concepts of statics and

one hour of discussion focusing on relevant problem solving skills. Throughout the

course, students were assigned weekly reading assignments and homework problem sets

from the course e-textbook. The reading assignments comprised *Instructional Text* and

Worked Example pages from sections relevant to the week's content. The homework

assignments contained problems from the *Homework Problem* pages. Each week,

students completed quizzes with problems similar to the most recently submitted

homework assignment. At the end of the course, students completed the Statics Concept

Inventory (Steif & Danzler 2005) and the post-study survey.

<div align="center">**Results and Discussion**</div>

Question 1: What Do Students Read?

According to the self-testing hypothesis, the most effective reading strategy is to

practice solving problems by focusing on the homework pages, which we measured by

three metrics—viewing time, number of page visits, and relative viewing time. The

second column of Table 4 shows the mean viewing time (and standard deviation) for each

of the four page types over the 10-week quarter. Overall, students spent 26.3 hours ($SD =$

16.5 hours) on average reading the textbook (or 2.6 hours per week), including all types

of content (i.e., *Instructional Text*, *Worked Examples*, *Homework Problems*, and

Homework Answers). Due to violations of normality we assessed the data using a

nonparametric Friedman test, with type of content as a within-subjects factor and viewing

time as the dependent variable, and found a significant difference among the four types of

content, $\chi^2(3) = 274.66$, $p < .001$. Students spent the overwhelming majority of their

reading time viewing *Homework Problem* pages ($M = 22.1$, $SD = 13.4$), and very little

time reading *Instructional Text* ($M = 1.9$, $SD = 3.1$) and *Worked Examples* ($M = 1.4$, $SD =$

1.7).

Table 4

Measures of Reading for Each Content Type

Content Type	Mean Viewing Time, hrs (SD)	Mean Number of Page Visits (SD)	Mean Relative Viewing Time, % (SD)
All Content (w/o Other)	26.3 (16.5)	307.7 (191.3)	n/a
Instructional Text	1.9 (3.1)	48.8 (48.0)	6.8 (7.6)
Worked Examples	1.4 (1.7)	27.2 (25.7)	5.1 (4.7)
Homework Problems	22.1 (13.4)	204.9 (122.0)	84.8 (11.1)
Homework Answers	0.9 (1.4)	23.1 (31.1)	2.9 (3.5)
Other	0.1 (0.24)	3.8 (5.3)	0.4 (0.8)

The third column of Table 4 shows the mean number of page visits (and standard deviation) for each of the four page types over the 10-week quarter. Due to violations of normality we assessed the data using a nonparametric Friedman test, with type of content as a within-subjects factor and number of page visits as the dependent variable, and found a significant difference among the four types of content, $\chi^2(3) = 292.76$, $p < .001$. Similar to the pattern for viewing-time, there were far more page visits to *Homework Problem* pages ($M = 204.9$, $SD = 122.0$) than for *Instructional Text* ($M = 48.8$, $SD = 48.0$) and *Worked Examples* ($M = 27.2$, $SD = 25.7$).

The fourth column of Table 4 shows the relative viewing time (and standard deviation) for each of the four page types over the 10-week quarter. Due to violations of normality we assessed the data using a nonparametric Friedman test, with type of content as a within-subjects factor and relative viewing time as the dependent variable, and found a significant difference among the four types of content, $\chi^2(3) = 274.66$, $p < .001$. Students spent the majority of their time in the textbook viewing pages containing

Homework Problems (M = 84.8, SD = 11.1) and a significantly smaller percentage of their time on *Instructional Text* (M = 6.8, SD = 7.6) and *Worked Example* (M = 5.1, SD = 4.7) pages.

Question 2: How Does Student Achievement Correlate with What Students Read?

According to the time-on-task hypothesis student reading effort (particularly on pages involving homework problems) should correlate positively with course grades. Table 5 shows the correlation between each of 14 viewing measures and course grade, exam grade, homework and quiz grade, and the SCI score. Although all three types of measures (i.e., viewing time, number of page visits, and relative viewing time) show similar patterns, we focus on relative viewing time (in the bottom four rows) as an inclusive measure of selective viewing. Focusing on homework problems (measured by Relative Viewing Time for Homework Problem Pages) is significantly and positively correlated not only with homework and quiz grade but also with exam and course grades, whereas focusing on *Instructional Text* (measured by Relative Viewing Time for Instructional Text) and *Worked Examples* (measured by Relative Viewing Time for Worked Examples) is significantly and negatively correlated with all three grades. One should be careful to interpret these findings to mean worked examples and instructional texts are bad for learning the material. In fact, there is a considerable amount of research speaking to the effectiveness of worked examples given the right conditions (e.g., Paas, Renkl, and Sweller, 2003; Renkl, 2002; Ward and Sweller, 1990). One possible explanation for the negative correlations we observed is that the lower performing students feel the need to use the *Work Example* and *Instructional Text* pages more often.

Table 5

Correlations Between Reading Measures and Performance Measures

Textbook Viewing Measures	HW & Quiz Grade	Exam Grade	Final Course Grade	SCI Score
Total Viewing Time	.350**	.069	.137	-.060
Instructional Text Viewing Time	-.084	-.164†	-.160†	-.045
Worked Example Viewing Time	-.054	-.171*	-.156†	-.057
Homework Problem Viewing Time	.424**	.140†	.214*	-.051
Homework Answer Viewing Time	.308**	.062	.126	-.030
Total Page Visits	.336**	.020	.092	-.112
Instructional Text Page Visits	.025	-.102	-.083	.003
Worked Example Page Visits	.020	-.154†	-.127	-.087
Homework Problem Page Visits	.416**	.075	.157†	-.144
Homework Answer Page Visits	.357**	.118	.183*	-.064
Relative Viewing Time for Instructional Text Pages	-.283**	-.277**	-.303**	-.024
Relative Viewing Time for Worked Example Pages	-.241**	-.273**	-.269**	-.098
Relative Viewing Time for Homework Problem Pages	.247**	.298**	.304**	.046
Relative Viewing Time for Homework Answer Pages	.161†	.036	.074	.044

Note. SCI = Statics Concept Inventory, † $.05 < p < .10$, *$p < .05$, **$p < .01$.

Table 6 presents these same analyses while also controlling for the three measures of prior knowledge (high school grade point average, SAT score, and Force Concept Inventory score). The pattern of correlations remains the same when controlling for these measures – significant negative correlation between *Instructional Text* and *Worked*

Examples with all grades as well as significant positive correlations between *Homework*

Problems and all grades.

Table 6

*Partial Correlations Between Reading Measures and Performance Measures Controlling
For Measures of Prior Knowledge*

Textbook Viewing Measures	HW & Quiz Grade	Exam Grade	Final Course Grade	SCI Score
Total Viewing Time	.320**	.097	.158	-.011
Instructional Text Viewing Time	-.009	-.186	-.160	.057
Worked Example Viewing Time	-.003	-.193†	-.165	-.035
Homework Problem Viewing Time	.370**	.168	.229*	-.012
Homework Answer Viewing Time	.226**	.057	.101	-.045
Total Page Visits	.171	-.067	-.017	-.100
Instructional Text Page Visits	-.045	-.197†	-.178	.047
Worked Example Page Visits	-.078	-.247*	-.228*	-.045
Homework Problem Page Visits	.268*	.026	.085	-.159
Homework Answer Page Visits	.209†	.065	.104	-.058
Relative Viewing Time for Instructional Text Pages	-.292*	-.287*	-.312**	.037
Relative Viewing Time for Worked Example Pages	-.309**	-.358**	-.376**	-.083
Relative Viewing Time for Homework Problem Pages	.287*	.344**	.359**	.044
Relative Viewing Time for Homework Answer Pages	.086	-.007	.014	-.046

Note. SCI = Statics Concept Inventory, † .05 < *p* < .10, **p* < .05, ***p* < .01.

The pattern of results is consistent with the self-testing hypothesis which holds

that practicing the activity required for the test is an effective study strategy. Similarly,

this pattern extends the time-on-task hypothesis by highlighting the value of spending

time on activities most closely related to the test activities. Achievement on the Statics Concept Inventory (SCI) did not correlate significantly with any measure of reading effort ($p >= .144$ in all cases), perhaps because the e-textbook did not specifically address the kinds of items on the SCI.

Supplemental Questions

How does students' prior knowledge correlate with reading strategies? One might expect that a student's prior knowledge would impact the amount of time the student needed to spend reading the e-textbook. Thus, we examined the Pearson correlation between each of the 14 viewing measures and three measures of prior knowledge including SAT score, high school grade point average (GPA), and performance on the Force Concept Inventory (FCI). As presented in Table 7, SAT score is correlated negatively with most of the 14 measures of reading. However, only four of the correlations are significant. Both the total viewing time and the total page visits are significantly and negatively correlated with SAT score, as are both *Homework Problem* viewing time and page visits. High school GPA is correlated positively with most of the 14 measures, although only two correlations are significant. Both total viewing time and *Homework Problem* viewing time are significantly and positively correlated with high school GPA. Finally, performance on the FCI is negatively correlated with most of the 14 measures. Both the viewing time and page visits for *Homework Problems* are significantly and negatively correlated with FCI score. Additionally, total page visits and page visits to *Worked Examples* are also significantly and negatively correlated with FCI score. Finally, total viewing time approaches a significant negative correlation with FCI

score. In the present study, high SAT and high FCI scores appear to signify high levels of cognitive ability that enables students to learn the material quickly, whereas high GPA appears to signify high levels of academic motivation that supports persistence in learning.

Table 7

Correlations Between Reading Measures and Prior Knowledge Measures

Textbook Viewing Measures	SAT Score	High School GPA	FCI Score
Total Viewing Time	-.239[*]	.194[*]	-.144[†]
Instructional Text Viewing Time	-.099	.046	.020
Worked Example Viewing Time	-.155	.066	-.066
Homework Problem Viewing Time	-.241[*]	.208[*]	-.169[*]
Homework Answer Viewing Time	-.082	.083	-.043
Total Page Visits	-.226[*]	.137	-.209[*]
Instructional Text Page Visits	-.099	.113	-.083
Worked Example Page Visits	-.153	.060	-.211[*]
Homework Problem Page Visits	-.249[**]	.123	-.229[**]
Homework Answer Page Visits	-.135	.144	-.072
Relative Viewing Time for Instructional Text Pages	.083	-.115	.058
Relative Viewing Time for Worked Example Pages	.052	-.135	-.090
Relative Viewing Time for Homework Problem Pages	-.086	.116	-.037
Relative Viewing Time for Homework Answer Pages	.064	.046	.108

Note. † .05 < p < .10, *p < .05, **p < .01.

How do students' reading preferences correlate with reading strategies? One might expect that a student's personal preferences about reading textbooks would influence

the way they read their e-textbook. Thus, we examined the correlation between reading preferences, measured with the three survey questions presented above, and the 14 measures of e-textbook reading. As shown in Table 8, there were no significant correlations between media preference (i.e., electronic vs. paper) and the reading measures. This finding is consistent with theories on learning with instructional media that hold that media do not cause learning but instructional methods cause learning (Clark, 2001). Perceived convenience of the DocViewer correlated positively with most measures of reading, although only four of the correlations were significant. More specifically, perceived convenience correlated positively and significantly with total page visits as well as page visits to *Instructional Text*, *Worked Example*, and *Homework Problem* pages. This pattern is consistent with emotional design theories that propose people make more use of technologies that they like using (Norman, 2004). Similarly, perceived importance of the textbook correlated positively with most measures of reading. Here, eight of the correlations were positive and significant including, viewing time and page visits for all content, *Instructional Text*, *Worked Examples*, and *Homework Problems*. Thus, students who feel the textbook is important to their learning tend to use it more than students who do not. This pattern is consistent with expectancy-value theories of academic motivation, which hold that learners exert more effort when they value the material they are learning (Wigfield, Tonks, & Klauda, 2009).

Table 8

Correlations Between Reading Measures and Self-reported Perceptions of the Textbook

Textbook Viewing Measures	Perceived Importance of Textbook (M=3.1, SD=1.1)	Perceived Convenience of DocViewer (M=2.9, SD=1.6)	Media Preference (Electronic vs Paper) (M=2.8, SD=1.4)
Total Viewing Time	.223[*]	.168[†]	.011
Instructional Text Viewing Time	.185[*]	.097	.044
Worked Example Viewing Time	.226[*]	.159[†]	.067
Homework Problem Viewing Time	.199[*]	.162[†]	.000
Homework Answer Viewing Time	.030	.039	-.038
Total Page Visits	.252[**]	.270[**]	.012
Instructional Text Page Visits	.245[**]	.179[*]	.014
Worked Example Page Visits	.307[**]	.232[**]	.070
Homework Problem Page Visits	.202[*]	.256[**]	.007
Homework Answer Page Visits	.088	.163[†]	-.016
Relative Viewing Time for Instructional Text Pages	.095	-.024	.002
Relative Viewing Time for Worked Example Pages	.119	.028	-.014
Relative Viewing Time for Homework Problem Pages	-.083	.019	.005
Relative Viewing Time for Homework Answer Pages	-.081	-.014	.024

Note. † $.05 < p < .10$, * $p < .05$, ** $p < .01$.

General Discussion

Empirical Contributions

The first major finding of this study is that when college students in an engineering course view their e-textbook, they tend to focus on *Homework Problems* pages (i.e., pages that allow them to practice solving problems) and they tend not to look at pages containing *Instructional Text* or *Worked Examples* (i.e., pages that tell them information). The second major finding of this study is that the amount of effort that students put into viewing *Homework Problem* pages correlates positively with achievement in the course, whereas the amount of effort that students put into viewing pages containing *Instructional Text* and *Worked Examples* correlates negatively with achievement in the course.

Theoretical Contributions

The pattern of results is consistent with the self-testing hypothesis, which holds that the activity of taking a practice test—such as solving homework problems—improves learning by providing a form retrieval practice. The results also help to modify the time-on-task hypothesis to include the idea that academic achievement is related to effort on study tasks that are aligned with assessment, such as practicing in solving problems when the assessment involves solving problems.

Practical Contributions

Clearly, students in engineering courses do not put much effort into reading the instructional material in their e-textbooks, skipping over a majority of the pages with *Instructional Text* or *Worked Examples*. This suggests that e-textbooks in engineering

should not be counted on to provide a rich base of conceptual knowledge for learners. Instead, students focus on the practical issue of completing homework problems, suggesting that e-textbooks in engineering may best be used for building procedural and strategic knowledge in learners.

Methodological Contributions

The DocViewer built for this project is an effective tool for assessing how students read e-textbooks in academic courses. It has potential to contribute to future research on the relation between student study strategies and learning in many academic subjects.

Limitations and Future Directions

The present study involved one cohort in one course, so it would be useful to compare it with other studies. It is possible—although unlikely—that students used some resource other than the e-textbook for instructional content, so future research should stringently monitor student use of external sources of information. However, the large amount of time students spent viewing *Homework Problems* provides strong evidence that students used the e-textbook as their primary source for the textbook. At the time this study was conducted, the textbook was recently released, thus limiting the possibility of pirated versions being available online. Additionally, students were provided the electronic version of the textbook free of charge, thus minimizing barriers for the students to access this material. An additional way to minimize the possibility of students using a text other than the e-textbook would be to employ a custom textbook designed specifically for the course. Additionally, because of the positive correlation between

perceived convenience of the DocViewer and the amount of reading, care must be taken to ensure that document viewing software is carefully designed to match the needs of the students.

Finally, the validity of the three self-report measures should be interpreted in light of the fact that each is on a single item. We used only one item to tap each of the three self-report factors because our main goal was not to develop a separate psychometrically-tuned instrument for each factor but rather to take a preliminary look a few potentially interesting factors as a part of a supplementary analysis.

Conclusion

Prior research suggests that students often do not do the required reading for courses. Our study, which used computer-based technology to obtain detailed measures of reading habits, provides strong evidence of this. We found that college students in an introductory engineering course read surprisingly little of their online course textbook. Across a 10-week course, the students spent an average of 1.9 hours reading *Instructional Text*, 1.4 hours on *Worked Examples*, 22.1 hours on *Homework Problems*, and 0.9 hours on *Homework Answers*, indicating a preference for practicing to solve test problems rather than being told. Students' course grades correlated significantly and positively with time viewing *Homework Problems*. However, course grades were not positively correlated with viewing either *Instructional Text* or *Worked Examples*. These results suggest that achievement was related to time spent practicing for solving test problems rather than time spent being told, suggesting a revision of the time-on-task hypothesis to include the value of spending time on tasks aligned to test requirements.

References

Berry, T., Cook, L., Hill, N., & Stevens, K. (2010). An exploratory analysis of textbook usage and study habits: Misperceptions and barriers to success. *College Teaching*, *59*(1), 31–39. http://doi.org/10.1080/87567555.2010.509376

Carroll, J. B. (1963). A model of school learning. *Teachers College Record*, *64*, 723–733.

Clark, R. E. (2001). *Learning with media.* Greenwich, CT: Information Age Publishing.

Cummings, K., French, T., & Cooney, P. J. (2002). Student textbook use in introductory physics. Paper presented at *Physics Education Research Conference* 2002, Boise, Idaho.

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest, 14,* 4-58.

Ebbinghaus, H. (1885/1964). *Memory.* New York: Dover.

Ericsson, K. A. (2016). *Peak: Secrets from the new science of expertise.* Boston: Houghton Mifflin Harcourt.

Fiorella, L., & Mayer, R. E. (2015). *Learning as a generative activity.* New York: Cambridge University Press.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement.* New York: Routledge.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, *30*(3), 141-158.

Johnson, C. I., & Mayer, R. E. (2009). A testing effect with multimedia learning. *Journal of Educational Psychology, 101,* 621-629.

Junco, R., & Clem, C. (2015). Predicting course outcomes with digital textbook usage data. *The Internet and Higher Education*, *27*, 54–63. http://doi.org/10.1016/j.iheduc.2015.06.001

Karpicke, J. D., & Aue, W. R. (2015). The testing effect is alive and well with complex materials. *Educational Psychology Review, 27,* 317-326.

Karweit, N. (1984). Timed-on-task reconsidered: Synthesis of research on time and learning. *Educational Leadership, 41,* 32–35.

Kashy, E., Sherrill, B. M., Tsai, Y., Thaler, D., Weinshank, D., Engelmann, M., & Morrissey, D. J. (1993). CAPA-An integrated computer-assisted personalized assignment system. *American Journal of Physics,* 61(12), 1124-1130.

Landrum, R. E., Gurung, R. A. R., & Spann, N. (2012). Assessments of Textbook Usage and the Relationship to Student Course Performance. *College Teaching*, *60*(1), 17–24. http://doi.org/10.1080/87567555.2011.609573

Meriam, J. L., Kraige, L. G., & Bolton, J. N. (2015). *Engineering Mechanics: Statics* (8th ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.

Norman, D. A. (2004). *Emotional design.* New York: Basic Books.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational psychologist*, *38*(1), 1-4.

Podolefsky, N., & Finkelstein, N. (2006). The Perceived Value of College Physics Textbooks: Students and Instructors May Not See Eye to Eye. *The Physics Teacher*, *44*(6), 338–342. http://doi.org/10.1119/1.2336132

Rawson, K., Stahovich, T. F., & Mayer, R. E. (2016). Homework and achievement: Using smartpen technology to find the connection. *Journal of Educational Psychology.* http://dx.doi.org/10.1037/edu0000130

Renkl, A. (2002). Worked-out examples: Instructional explanations support learning by self-explanations. *Learning and instruction*, *12*(5), 529-556.

Roediger, H. L., & Karpicke, J. D. (2006). The power of testing memory: Basic research and implications for educational science. *Perspectives on Psychological Science, 1,* 181-210.

Schuman, H., Walsh, E., Olson, C., & Etheridge, B. (1985). Effort and reward: The assumption that college grades are affected by quantity of study. *Social Forces*, *63*(4), 945–966. http://doi.org/10.2307/2578600

Seaton, D. T., Kortemeyer, G., Bergner, Y., Rayyan, S., & Pritchard, D. E. (2014). Analyzing the impact of course structure on electronic textbook use in blended introductory physics courses. *American Journal of Physics*, *82*(12), 1186–1197. http://doi.org/10.1119/1.4901189

Shaffer, C. A., Karavirta, V., Korhonen, A., & Naps, T. L. (2011, November). Opendsa: beginning a community active-ebook project. In *Proceedings of the 11th Koli Calling International Conference on Computing Education Research* (pp. 112-117). New York: ACM.

Sikorski, J. F., Rich, K., Saville, B. K., Buskist, W., Drogan, O., Davis, S. F., Griggs, R. A., Jackson,. S. L., Marek, P., Boyce, T. E., Geller, E. S., Harvey, J. H., & Hofmann, W. J. (2002). Faculty forum. *Teaching of Psychology*, *29*(4), 312-320.

Smith, B. D., & Jacobs, D. C. (2003). TextRev: A window into how general and organic chemistry students use textbook resources. *Journal of Chemical Education*, *80*(1), 99. http://doi.org/10.1021/ed080p99

Steif, P. S., & Dantzler, J. A. (2005). A statics concept inventory: Development and psychometric analysis. *Journal of Engineering Education*, *94*(4), 363.

van Gog, T. (2013). Time on task. In J. Hattie & E. M. Anderman (Eds.), *International guide to student achievement* (pp. 432–433). New York: Routledge.

Ward, M., & Sweller, J. (1990). Structuring Effective Worked Examples. *Cognition and Instruction*, *7*(1), 1–39. https://doi.org/10.1207/s1532690xci0701_1

Wigfield, A., Tonks, S., & Klauda, S. L. (2009). Expectancy-value theory. In K. R. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 55-76). New York: Routledge.

Chapter 4: Judgments of Course Material Use

Abstract

Most studies of student study strategies rely on students' self-reported judgments of study time (JOST). The present work examines the accuracy of such self-reports for college students. In a 10-week Mechanical Engineering course, 100 college students accessed their textbook, homework solutions, graded work, and lecture slides via a computer-based course management system that recorded objective measures of reading time. In addition, the students provided subjective judgments of the amount of time they spent reading these materials. Students significantly overestimated time with the textbook ($d = 1.27$), homework solutions ($d = 1.19$), graded work ($d = 0.39$), and lecture slides ($d = 1.10$). The difference between objective and subjective judgments of study time correlated significantly and negatively with final course grade for the textbook ($r = -.30$), homework solutions ($r = -39$), and lecture slides ($r = -.24$), but not for graded work ($r = -0.07$). This work calls into question the utility of self-report data in studies of student study habits, and showcases the value of technology-based objective measures of such habits.

Introduction

It is common in higher education research to use student self-reports to examine students' strategies and behaviors (Fiorella & Mayer, 2015). The National Survey on Student Engagement (NSSE), for instance, has become a standard for aggregated statistics on undergraduate engagement indicators and high impact practices. The 2016 NSSE annual report, which included data from 557 participating universities, revealed that self-reported study time for first-year students accounted for 30% of the variance in retention rates and 42% of the variance in graduation rates (National Survey of Student Engagement, 2016). However, the validity and reliability of such self-reported data has been a topic of debate in educational research for many years (Gonyea, 2005; Porter, 2011; Schuman, 1985). Although research on study strategies and behaviors often relies on self-reported judgments, such measures may be subject to error or bias. Further, researchers may lack the necessary objective measurements to test the validity of students' self-reported judgments of studying. The present study uses both traditional survey responses and a technology-enhanced data collection technique to examine the differences between students' judgments of their study time (JOST) and their actual time spent in studying course materials. Further, we explore how the discrepancies between these measures relates to course performance.

Theoretical Framework and Predictions

Metacognition refers to awareness and control of one's own cognitive processing (Flavell, 1979; Mayer, 2016). In particular, metacognitive awareness includes monitoring one's cognitive processing during learning, and has been linked to academic success

63

(Schraw, 2006; Schraw and Dennison, 1994; Veenman et al., 2006; Young & Fry, 2008; Wang, Haertel, & Walberg, 1990) including learning effectiveness in online learning environments (Azevedo & Aleven, 2013). Some common assessments of metacognitive awareness include: (a) ease of learning (EOL) – judging how hard it will be to learn some material before learning, (b) judgments of learning (JOL) – recognizing how well one learned or predicting test performance, and (c) feeling of knowing (FOK) – recognizing difficulties in learning or predicting difficulty in performing (Mayer, 2016; Rhodes & Tauber, 2011; Schraw, 2009, 2010). A more recent addition is judgments of understanding (JOU) – recognizing how well one understands the material (Pilegard & Mayer, 2015a, 2015b). Research shows that the monitoring of study that takes place during judgments of learning are predictive of accuracy in recall of the studied content (Dunlosky and Nelson, 1992), and that student academic performance is affected by study behaviors (Fiorella & Mayer, 2015; Metcalfe, 2009; Metcalfe and Finn, 2008).

In the present study we extend the concept of metacognitive awareness to include the learner's judgment of the amount of time spent with instructional materials, which we call judgment of study time (JOST). Study time (or time on task) is considered one of the most important factors affecting student learning and academic success (Rawson, Stahovich, & Mayer, 2017; van Gog, 2013). Therefore, in this study we examine the proposal that skill in judging one's study time could be an important metacognitive skill, supporting academic success. More specifically, we evaluate the accuracy of students' subjective judgments of time spent reading course materials by comparison to objective measures of study time and examine the relation between this accuracy and course grade.

In short, we investigate two research questions in the present study: (1) Are students' judgments of their study time comparable to their actual study time? (2) Is the discrepancy between a student's judgment of study time and actual study time related to course performance?

Concerning research question one, in light of previous research showing poor metacognitive awareness in online learning environments (Azevedo & Aleven, 2013; Pilegard & Mayer, 2015a, 2015b), we expect students to be inaccurate in making judgments of study time.

Concerning research question two, based on an extension of previous research on judgments of learning and metacognitive awareness, we expect that students who are more aware of their study habits will be able to more accurately judge time spent in study. Furthermore, as skills in metacognitive awareness have been shown to be important for academic success, we would expect to see that the discrepancies between judgments and actual study time would be negatively related to learning outcomes.

Literature Review

Comparing Self-Report and Objective Measures

A large body of research has focused on comparing student self-reported grade point average (GPA), class rank, and test scores to objective database records (Cole & Gonyea, 2010; Kuncel et. al, 2005; Mayer et. al, 2007). Although previous research generally indicates strong correlations between the two measurement types, a large percentage of students tend to over-report their GPA and test scores, with lower achieving students over-reporting to a greater degree (Kuncel et. al, 2005; Mayer et. al.,

2007). These findings suggest that students have trouble reporting--or are intentionally

misreporting--even easily recalled achievement indicators such as GPA and test scores,

calling in to question the reliability of using students' self-reports in investigations of

academic performance. It stands to reason that if easily recalled achievement indicators

are often misreported, measures that require more careful estimation and recall, such as

self-reported study time, may be even more prone to error. In a recent study, researchers

surveyed three cohorts of students on how much time they typically spent completing

homework assignments during the term, and used digital smartpens to accurately measure

the actual time spent (Rawson, Stahovich, & Mayer, 2017). The study revealed only a

weak correlation between self-reported time and actual time (r's range from .16 to .35).

Additionally, the researchers reported that the vast majority of students over-reported the

time spent completing homework (between 85.5% and 88.5% of the students in each

cohort over-reported).

Self-Reported vs. Objectively Measured Studying Time

The time-on-task theory posits that time spent studying a topic is related to

knowledge gained on that topic and is an important factor in student achievement (Carroll

1963; van Gog, 2013). The majority of research examining this theory uses students' self-

reported study time as the measure of time spent engaged with the course textbook (e.g.,

Berry, Cook, Hill, & Stevens, 2010; Cummings, French, & Cooney, 2002; Landrum,

Gurung, & Spann, 2012; Sikorski et al., 2002; Smith & Jacobs, 2003). For decades, there

has been concern about using such self-reported measures (Schuman et. al., 1985), but

little research has been done to investigate the validity of self-reports because objective measures of study time are difficult to collect and analyze.

In the current literature, the most accurate accounts of students' study time come from time-use journals, journals in which students log studying activities for a short period of time (e.g., Bash & Kreiner, 2014; Masui, 2014; Phillips & Phillips, 2007; Schuman et. al., 1985; Stinebrickner & Stinebrickner, 2004). Time-use journals have been used as a quasi-objective counterpart for comparison with traditional self-reports. In one study, Bash and Kreiner surveyed students on their average weekly study time, excluding time completing homework, and compared those responses to daily time-use journals completed over one week. The research suggested that students' perceived study time (via traditional self-report) and study time as indicated by the journals are moderately correlated ($r = .32$), but that students underestimate their actual study time (Bash & Kreiner, 2014). While time-use journals may be more accurate than traditional self-reports (Stinebrickner and Stinebrickner, 2004), they are burdensome to use. In many studies, for example, students record study time for only a single day, thus providing a limited measure of behavior over the term. Additionally, the correlations between study time from time-use journals and from self-reports may suggest that journals are subject to the same judgment errors that plague self-reports.

Studying Time and Students' Performance

Previous research has shown little correlation between learning outcomes and self-reported time spent in various study activities, such as reading the textbook (Daniel & Woody, 2013; Podolefsky & Finkelstein, 2006), completing homework assignments

67

(Rawson, Stahovich, & Mayer, 2017), or all study activities combined (Schuman et. al., 1985). Schuman and colleagues found that neither self-reported study time nor time-use journals were significantly correlated to students' test scores, overall grade in the course, or GPA (Schuman et. al., 1985). Likewise, Rawson, Stahovich, and Mayer (2017) reported a negative, and non-significant, relationship between students' self-reported time spent completing homework and course grade ($r = -.16$; Rawson, Stahovich, & Mayer, 2017).

In contrast, recent investigations using technology-enhanced data collection techniques to measure students' actual study times found they correlate significantly and positively with measures of course performance (Junco & Clem, 2015; Rawson, Stahovich, & Mayer, 2017). For example, Rawson and colleagues used digital smartpens to accurately measure time spent completing homework problems, and found a positive and significant correlation with course grade ($r = .44$). Similarly, Junco and Clem collected students' interactions with an online e-textbook and found that the number of days students read was a significant positive predictor of course grades and GPA (Junco & Clem, 2015).

Collectively, these works provide support for our two hypotheses that students will be inaccurate when judging their own study time, and that the magnitude of the error in self-reporting will be negatively related to course performance.

Method

Participants and Design

The participants were 100 college students enrolled in a 10-week course on "Introduction to Mechanical Engineering" at our university during the 2016 academic year. The majority were male, (85%), Mechanical Engineering Majors (88%), and in their first year of college (73%). We followed guidelines for ethical treatment of human subjects and obtained IRB approval for the studies. Additionally, all students enrolled in the course provided consent for the use of the data on their study habits. The course is designed as an introduction to the major topics for an undergraduate mechanical engineering degree. Students following the recommended course plan for the degree typically take this course in the winter term of their first year.

Materials and Apparatus

The apparatus consisted of a Windows Surface tablet for each student in the class. The tablets provided access to four types of written course materials used in the course: the textbook, homework solutions, graded work, and copies of the instructors annotated lecture slides. All of the materials, including the course textbook, were provided to the students free of charge. These materials were provided in an electronic form that could be read on a tablet with custom document viewing software (DocViewer) that recorded time spent on each page of the materials.

We built DocViewer using the open source PDF rendering software, μPDF (mupdf.com). DocViewer was preinstalled on the Windows Surface tablets that we provided to the students (the software could also be installed on a personal computer).

DocViewer is designed to enable the accurate measurement of a student's use of the provided course materials. This accuracy achieved through a variety of software features. First, the software displays only a single page at any given time so there is no ambiguity about what the student is currently viewing. Second, the software dims the display after two minutes of inactivity during which the student does not interact with the tablet. When the screen dims, the student may wake the program by clicking or tapping on the screen. This feature ensures that the measurements include only the time during which a student is engaged with the reading materials. Finally, all materials were provided as encrypted PDFs that could be read only with DocViewer, helping to ensure that all usage of the materials was measured.

Measures

Actual Study Time. As students used DocViewer to view their course materials, the application created log files containing time-stamped reading events, including when a student opened or closed a document and when a student paned, zoomed, or changed pages within a document. During the term, the log files were periodically uploaded to a secure file server. At the end of the term we analyzed each student's logged events and extracted page viewing *episodes*. An episode is defined as an interval of at least 15 seconds during which a particular page was continuously visible on the screen. For example, panning and zooming do not mark the end of a page viewing episode, whereas changing the page or loading a new document does. Each extracted episode contained the document name and page number, as well as the starting timestamp and duration of the episode. In calculating the duration of a page viewing episode, we subtracted any inactive

time in which the screen was dimmed due to inactivity. Episodes with a total duration less than 15 seconds are considered page navigation, not reading for understanding, and were excluded from further analysis.

From each student's list of episodes, we calculated the average weekly viewing time for each of the four types of course materials: textbook, homework solutions, lecture slides, and graded work reports. It should be noted that our measure of objective study time is the amount of time that the student was exposed to the material rather than a measure of how intensely the student was studying the material.

Judgments of Study Time. At the end of the term, students completed a post-study questionnaire in which they were asked to self-report, among other things, the amount of time they spent reading each of the four types of course materials. These four judgments of study time (JOST) were worded as follows:

> On average, how many hours a week did you spend…
> - Reading the textbook?
> - Reviewing homework solutions?
> - Reviewing graded work reports?
> - Reviewing annotated lecture slides?

Students responded by entering a decimal value representing the number of hours for each type of course material listed. These responses were used as the measures of subjective study time for each course material type for each participant.

As a validity check for our data collection, another question asked: "What percentage of the time did you spend reading the textbook with the document viewer we provided rather than other means such as a physical textbook, a PDF, etc?" Students responded by entering a percentage between 0% and 100%.

Course Performance. We consider two measures of course performance in our investigations of the relationship between discrepancies in JOST and course performance (research question 2): Weighted Exam Average and Final Course Grade. Final course grades were determined based on the following weighting: 5% for class participation, 10% for homework, 10% for quizzes, 5% for preparatory assignments, 20% for the first exam, 20% for the second exam, and 30% for the final exam. For the purpose of these investigations, the class participation was removed from Final Course Grade as these points were simply based on attendance and not performance. Weighted Exam Average is calculated by averaging the grades earned on the first, second, and final exams using the same relative weights used in computing Final Couse Grade. All analyses yielded the same pattern of significant effects for both measures, so in the results section we present only the results for which Final Course Grade is the measure of academic performance.

Procedure

At the beginning of the term, we provided students with Windows Surface tablets for use in the course. Students returned the tables after the final exam. The tablets had DocViewer preinstalled and the course Textbook immediately available. Students attended three hours of lecture per week, which focused on course content, and one hour of discussion focused on problem solving skills. Students were assigned weekly problem sets and chapter text readings from the provided course textbook. Each week, students received solutions to the most recently submitted homework problems, annotated lecture slides from that week, and a report on the grading of the previous week's homework

assignment. The report contained a digital copy of the students' handwritten homework submission and grading feedback provided by the teaching assistant.

Throughout the term, DocViewer recorded students' use of the provided course materials. At the end of the term, students completed the post-study questionnaire reporting their weekly average usage of the various types of course materials. Survey responses provided a subjective measure of students' judgments of their study time while the DocViewer log files provided an objective measure. At the end of the quarter, we also recorded the Weighted Exam Average and Final Course Grade for each student. We included a student's data in this study, only if the student completed the course (i.e., received a final grade) and completed the post-study questionnaire.

Results

Students Overestimate their Study Time

The first prediction is that students will overestimate the amount of time they spend with their course materials. Table 9 shows the mean and standard deviation of the subjective time and objective time spent for each of the four types of course materials. We conducted paired-samples t-tests to examine the differences in objective study time and subjective study time for each of the four types of materials. As can be seen in Table 9, the average weekly objective study time (as measured by the DocViewer software) was significantly lower than the subjective study time for each of the four types of instructional materials: textbook, $t_{99} = 9.687$, $p < .001$, $d = 1.27$; homework solutions, $t_{99} = 9.243$, $p < .001$, $d = 1.19$; graded work, $t_{99} = 2.739$, $p = .007$, $d = 0.39$; and lecture

slides, t_{99}= 7.968, $p < .001$, d = 1.10. The percentage of students who over-reported their study time was 92% for textbook, 82% for homework solutions, 76% for graded work, and 78% for lecture slides. Overall, these results support the first prediction that students tend to overestimate the amount of time they spend studying instructional materials.

Table 9

Descriptive Statistics for All Course Materials

Type of course material	Subjective time		Objective time		d
	M	SD	M	SD	
Textbook**	2.17	1.73	0.54	0.53	1.27
Homework solutions**	1.34	1.25	0.26	0.29	1.19
Graded work*	1.40	5.01	0.02	0.04	0.39
Lecture slides**	1.70	1.92	0.20	0.27	1.10

Note. Asterisks indicate significant differences between mean Subjective and Objective study time per week for the respective material type. * $p < .01$, ** $p < .001$.

Subjective and objective study time were positively and significantly correlated for the textbook ($r = .231$, $p = .021$)[1], homework solutions ($r = .395$, $p < .001$), and lecture slides ($r = .243$, $p = .015$), but not for graded work ($r = -.042$). This finding is consistent with previous research reporting a moderate correlation between actual and self-reported time spent completing homework (Rawson, Stahovich, & Mayer, 2017).

---

[1] The results reported regarding textbook study time (i.e., t-tests, % over-reported, and correlations) include the full sample (N = 100). However, we acknowledge that some students may have had access to the textbook outside of DocViewer. Therefore, we ran additional analyses to exclude students who reported using something other than the DocViewer to access the textbook more than 10% of the time ($N_{Excluded}$ = 28). The pattern of significant results for analyses in this subsample (N = 72) did not differ from those for the full sample.

These correlations suggest that students are not making random errors when they give inflated judgments of study time.

Accurate Judgments of Study Time Predicts Course Grade

The primary prediction in this study is that the degree of error in estimating study time is related negatively to course grade. Table 10 shows the Pearson correlations between the absolute difference between objective and subjective study time and course grade. The difference between objective and subjective study time correlated significantly and negatively with course grade for each type of material except graded work. The patterns of results is similar when considering Weighted Exam Average as the measure of course performance. Additionally, the results did not differ significantly when the sign of difference between the objective and subjective study time (i.e., over-report is positive and under-report is negative) was considered in the correlations.

Table 10

Correlations between Course Performance and Absolute Difference between Subjective and Objective Course Material Usage

Course Material Type	Absolute Difference with Final Course Grade
Textbook	-.305**
Homework Solutions	-.392**
Graded Work	-.074
Lecture Slides	-.240*

Note. *p < .05, **p < .01.

When considering the course material types separately, we find the error in judgment of time spent with Homework Solutions to have the strongest relationship with course performance. This is likely a result of the fact that this content was available

exclusively through DocViewer, resulting in higher accuracy of both the students' self-reports and the objectively measured usage. With regard to the Textbook material, students could have had access to this content from a secondary source outside of DocViewer. This fact, though considered in the presented work, can contribute to error in students' judgments as students may have included time spent with a secondary copy of the text in their estimates. Similarly, in regards to Lecture Slides, students' estimates of time spent with this material may have been elevated by erroneous inclusion of time spent studying their own notes rather than the slides provided by the instructor. The Graded Work, though also available exclusively through DocViewer, was actually used so little that the errors in judgment may have overwhelmed the true (objective) time. In effect, the judgment for this content type may have been mostly noise, resulting in the small correlation value that was observed. In summary, the nature of the various types of content may explain the differential relationships we see between the four material types and course performance.

Consistent with our prediction, these finding indicate that students who perform less accurately on making judgments of study time tend to achieve lower grades in the course, and vice versa. In short, accuracy of metacognitive awareness as measured by judgments of study time are related to academic success.

Discussion

Empirical Contributions

The primary finding is that the discrepancy between a student's self-reported usage and their actual usage of the course materials is predictive of course performance. That is, students who are less accurate in their judgment of the time spent with the course materials tend to perform more poorly in the course. A related finding presented is that students in an undergraduate engineering course tend to over-report their time spent viewing the course materials.

Practical Contributions

We show that students in an undergraduate engineering course are unable to accurately judge their time spent with provided course materials. Additionally, we show that accuracy in judgment of time spent with materials is predictive of performance on exams and in the course overall. Though the findings are correlational and cannot provide causal proof, they suggest that students could benefit from a greater awareness of time spent studying course materials.

Theoretical Contributions

The pattern of results presented is consistent with previous research examining students' ability to self-report on their study habits. Additionally, the results are consistent with findings in educational research surrounding judgments of learning and metacognitive awareness and their relationships with academic success. The results suggest that applying these principles to students' judgments of their own study time provides a means to predict academic success in an engineering course.

Methodological Contributions

This study provides a method for using computer-based software to accurately measure students' time spent with course materials, which allows for measuring students accuracy in making self-reported judgments of time spent with course materials.

Limitations and Future Directions

The present study included students from one cohort of an introductory engineering course. Further studies would be helpful to examine the generalizability of the findings to a broader population of students. We acknowledge that students could have had access to a copy of the textbook outside of DocViewer, which could decrease the accuracy of study measures related to the textbook. However, when more stringent inclusion criteria were used to exclude students who reported making even a small amount of use of a secondary copy of the textbook, the pattern of significant results did not differ from those calculated from the full student sample. Additionally, the correlations between judgments of study time and actual study time for the textbook were similar in strength and significance to those calculated from homework solutions and lecture slides – materials that were unavailable outside of DocViewer.

References

Azevedo, R., & Aleven, V. (Eds.). (2013). *International handbook of metacognition and learning technologies.* New York: Springer.

Bash, K. L., & Kreiner, D. S. (2014). Student Perceptions of Study Time. *Psi Chi Journal of Psychological Research*, *19*(1), 3–9.

Berry, T., Cook, L., Hill, N., & Stevens, K. (2010). An exploratory analysis of textbook usage and study habits: Misperceptions and barriers to success. *College Teaching*, *59*(1), 31–39. http://doi.org/10.1080/87567555.2010.509376

Carroll, J. B. (1963). A model of school learning. *Teachers College Record*, *64*, 723–733.

Cole, J. S., & Gonyea, R. M. (2010). Accuracy of Self-reported SAT and ACT Test Scores: Implications for Research. *Research in Higher Education*, *51*(4), 305–319. https://doi.org/10.1007/s11162-009-9160-9

Cummings, K., French, T., & Cooney, P. J. (2002). Student textbook use in introductory physics. Paper presented at *Physics Education Research Conference* 2002, Boise, Idaho.

Daniel, D. B., & Woody, W. D. (2013). E-textbooks at what cost? Performance and use of electronic v. print texts. *Computers & Education*, *62*, 18–23. https://doi.org/10.1016/j.compedu.2012.10.016

Dunlosky, J., & Nelson, T. O. (1992). Importance of the kind of cue for judgments of learning (JOL) and the delayed-JOL effect. *Memory & Cognition*, *20*(4), 374–380. https://doi.org/10.3758/BF03210921

Fiorella, L., & Mayer, R. E. (2015). *Learning as a generative activity: Eight learning strategies that promote understanding.* New York: Cambridge University Press.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American psychologist*, *34*(10), 906.

Gonyea, R. (2005). Self-reported Data in Institutional Research: Review and Recommendations. Retrieved from http://sshl.sysu.edu.cn/docs/2013-03/20130327172420936127.pdf

Junco, R., & Clem, C. (2015). Predicting course outcomes with digital textbook usage data. *The Internet and Higher Education*, *27*, 54–63. https://doi.org/10.1016/j.iheduc.2015.06.001

Kuncel, N. R., Credé, M., & Thomas, L. L. (2005). The Validity of Self-Reported Grade Point Averages, Class Ranks, and Test Scores: A Meta-Analysis and Review of the Literature. *Review of Educational Research*, *75*(1), 63–82. https://doi.org/10.3102/00346543075001063

Landrum, R. E., Gurung, R. A. R., & Spann, N. (2012). Assessments of Textbook Usage and the Relationship to Student Course Performance. *College Teaching*, *60*(1), 17–24. http://doi.org/10.1080/87567555.2011.609573

Masui. (2014). Do diligent students perform better? Complex relations between student and course characteristics, study time, and academic performance in higher education. *Studies in Higher Education*, *39*(4), 621–643. https://doi.org/10.1080/03075079.2012.721350

Mayer, R. E. (2016). Role of metacognition in STEM games and simulations. In H. F. O'Neil, E. L. Baker, & R. S. Perez (Eds.), *Using games and simulations for reaching and assessment* (pp. 183-205). New York: Routledge.

Mayer, R. E., Stull, A. T., Campbell, J., Almeroth, K., Bimber, B., Chun, D., & Knight, A. (2007). Overestimation Bias in Self-reported SAT Scores. *Educational Psychology Review*, *19*(4), 443–454. https://doi.org/10.1007/s10648-006-9034-z

Metcalfe, J. (2009). Metacognitive Judgments and Control of Study. *Current Directions in Psychological Science*, *18*(3), 159–163. https://doi.org/10.1111/j.1467-8721.2009.01628.x

Metcalfe, J., & Finn, B. (2008). Evidence that judgments of learning are causally related to study choice. *Psychonomic Bulletin & Review*, *15*(1), 174–179. https://doi.org/10.3758/PBR.15.1.174

National Survey of Student Engagement (2016). *Engagement Insights: Survey Findings on the Quality of Undergraduate Education—Annual Results 2016*. Bloomington, IN: Indiana University Center for Postsecondary Research

Phillips, B. J., & Phillips, F. (2007). Sink or Skim: Textbook Reading Behaviors of Introductory Accounting Students. *Issues in Accounting Education*, *22*(1), 21–44. https://doi.org/10.2308/iace.2007.22.1.21

Pilegard, C., & Mayer, R. E. (2015a). Within-subject and between-subject conceptions of metacomprehension accuracy. *Learning and Individual Differences, 41,* 54-61.

Pilegard, C. & Mayer, R. E. (2015b). Adding judgments of understanding to the metacognitive toolbox. *Learning and Individual Differences, 41,* 62-72.

Podolefsky, N., & Finkelstein, N. (2006). The Perceived Value of College Physics Textbooks: Students and Instructors May Not See Eye to Eye. *The Physics Teacher*, *44*(6), 338–342. https://doi.org/10.1119/1.2336132

Porter, S. R. (2011). Do College Student Surveys Have Any Validity? *The Review of Higher Education*, *35*(1), 45–76. https://doi.org/10.1353/rhe.2011.0034

Rawson, K., Stahovich, T. F., & Mayer, R. E. (2017). Homework and achievement: Using smartpen technology to find the connection. *Journal of Educational Psychology, 109,* 208-219. http://dx.doi.org/10.1037/edu0000130

Rhodes, M. G., & Tauber, S. K. (2011). The influence of delaying judgments of learning on metacognitive accuracy: a meta-analytic review.

Schraw, G., (2009). Measuring metacognitive judgements. In J. Hacker, J. Dunlosky, A. C. Graesser (Eds.), *Handbook of metacognition in education* (pp. 415-429). New York, NY: Routledge.

Schraw, G. (2010). Measuring self-regulation in computer-based learning environments. *Educational Psychologist, 45*, 258-266.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting Self-Regulation in Science Education: Metacognition as Part of a Broader Perspective on Learning. *Research in Science Education*, *36*(1–2), 111–139. https://doi.org/10.1007/s11165-005-3917-8

Schraw, G., & Dennison, R. S. (1994). Assessing Metacognitive Awareness. *Contemporary Educational Psychology*, *19*(4), 460–475. https://doi.org/10.1006/ceps.1994.1033

Schuman, H., Walsh, E., Olson, C., & Etheridge, B. (1985). Effort and Reward: The Assumption That College Grades are Affected by Quantity of Study. *Social Forces*, *63*(4), 945–966. https://doi.org/10.2307/2578600

Sikorski, J. F., Rich, K., Saville, B. K., Buskist, W., Drogan, O., Davis, S. F., Griggs, R. A., Jackson,. S. L., Marek, P., Boyce, T. E., Geller, E. S., Harvey, J. H., & Hofmann, W. J. (2002). Faculty forum. *Teaching of Psychology*, *29*(4), 312-320.

Smith, B. D., & Jacobs, D. C. (2003). TextRev: A window into how general and organic chemistry students use textbook resources. *Journal of Chemical Education*, *80*(1), 99. http://doi.org/10.1021/ed080p99

Stinebrickner, R., & Stinebrickner, T. R. (2004). Time-use and college outcomes. *Journal of Econometrics*, *121*(1–2), 243–269. https://doi.org/10.1016/j.jeconom.2003.10.013

Tourangeau, R., Rips, L. J., & Rasinski, K. (2000). *The Psychology of Survey Response*. Cambridge University Press.

van Gog, T. (2013). Time on task. In J. Hattie & E. M. Anderman (Eds.), *International guide to student achievement* (pp. 432–433). New York: Routledge.

Veenman, M. V. J., Hout-Wolters, B. H. A. M. V., & Afflerbach, P. (2006). Metacognition and learning: conceptual and methodological considerations. *Metacognition and Learning*, *1*(1), 3–14. https://doi.org/10.1007/s11409-006-6893-0

Wang, M. C., Haertel, G. D., & Walberg, H. J. (1990). What Influences Learning? A Content Analysis of Review Literature. *The Journal of Educational Research*, *84*(1), 30–43. https://doi.org/10.1080/00220671.1990.10885988

Young, A., & Fry, J. D. (2008). Metacognitive Awareness and Academic Achievement in College Students. Journal of the Scholarship of Teaching and Learning, 8(2), 1–10.

Chapter 5: Impact of Preparatory Assignments

Abstract

The structure of a course plays an important role in how students choose to study and subsequently how they perform. Previous research has begun to highlight the impacts that different course structures can have on students' study behaviors and course performance. This study investigates the impacts that graded preparatory assignments, designed to promote students to use the textbook earlier and more often, have on student study behaviors and subsequent course performance. Under the preparatory assignment treatment, students visited the explanatory text ($t_{137} = 3.613$, $p < .001$) and homework problem ($t_{137} = 4.071$, $p < .001$) portions of the textbook significantly more frequently. Further, students visited a significantly larger percentage of assigned pages from the textbook when preparatory assignments were administered. In a more detailed analysis of student study behaviors, a custom measure of reading time was calculated – weighting the time spent with materials according to when the activity occurred. Investigations of this novel reading measure demonstrated that students under the preparatory assignment treatment tended to read the explanatory text and worked example pages earlier relative to homework assignment deadlines. This behavior of reading earlier and more often significantly moderated the interaction between the preparatory assignment treatment and students final course grades. These findings suggest that preparatory assignments indeed influenced students to visit more of the textbook, and earlier then they normally would, and found this study behavior to significantly influence students' short-term performance.

Introduction

Educators and researchers in higher education agree that student attitudes and learning outcomes are impacted by the structure of a course. In general, a course structure comprises the frequency of various activities and assessments given to students both in and out of the classroom. Much research has been done to investigate different aspects of course structure and their impacts on students' attitudes and performance (e.g., Connor-Greene, 2000; Eddy & Hogan, 2014; Freeman et al., 2011; Laverty et al., 2012; Seaton et al., 2014). For example, some studies manipulate the frequency of quizzes and exams administered during the course and investigate the impacts on student performance. Although effects on student performance have been demonstrated, the mechanisms of this impact are yet to be fully understood. For example, one study reported students' performance on numerical exam problems improved when the number of exams during the term was increased from three to six (Laverty et al., 2012). While the authors speculated that the increased frequency of exams promoted students to take other assignments, such as homework, more seriously leading to the increase in performance, there was no means to verify this. In another study, researchers introduced in-class multiple choice questions and weekly peer-graded practice exams (Freeman, et al., 2007). The authors reported a significant decrease in failure rates and a significant increase in midterm and final exam performance. The authors concluded that the course reforms required students to participate and practice more often, which likely promoted the discipline and intellectual tools needed to be successful. However, there was no means to examine this proposed mechanism.

While there have been many studies measuring the effect of a treatment to course structure, relatively few investigate the underlying mechanisms. One such study, conducted by Connor-Greene, used self-reports of students' study behaviors to get at these mechanisms. In this study, researchers included daily essay quizzes designed to promote students to synthesize assigned reading material with previous discussion topics (Connor-Green, 2000). This research reported that when the quizzes were introduced, 92% of the students reported always or almost always completing the assigned readings prior to class, in contrast to just 12% when daily quizzes were not given. One limitation of this work is that student behaviors were collected through self-reports, which can unreliable. In a more recent study, investigators used an online course management system to distribute reading assignments and objectively measured students' differential use of the material across multiple terms (Seaton et al., 2014). Seaton and colleagues studied a variety of course structures and found that when increasing the number of exams during a term, students visited a larger percentage of pages in the textbook, visited the text more consistently, and spent more time reading throughout the term. Further, the study examined the behavior of cramming as a possible mechanism by using an autocorrelation function to quantify the periodicity of daily page access records. These analyses identified a reduction in the cramming behavior during the courses with treatment. One issue with this work is that the researchers measured study time by analyzing webpage access records from the online course management system. As a webpage can be opened and viewed indefinitely, the actual time students spent engaged with the reading material is difficult to measure accurately. The work we present in this

study employs a document viewing application equipped with an on-screen timeout feature that identifies when a student is not actively engaged with the presented material.

In the presented work, we employ an instrument document viewing application designed to objectively and accurately measure students' use of the provided course materials, and investigate changes in study behaviors that may lead improved course performance. We investigate the behavior of reading earlier and more often, with respect to homework assignment deadlines, as a possible mechanism affecting the relationship between course structure and student performance. This study behavior is quantified using a novel measure that identifies the centroid of students' reading distribution within specific windows of time throughout the term.

Related Work on Quizzes

A subset of research manipulating course structure focuses on the introduction of regular quizzes and reports mixed impacts on student performance. For example, one study compared two offerings of the same course and found that, when including weekly quizzes on assigned readings, there was no significant increase in performance on exams (Haberyan, 2003). Another study found negative correlations between effort on computerized multiple choice chapter quizzes (number of quiz attempts and time spent on quizzes) and exam grades (Brothen and Wambach, 2001). On the other hand, some previous research has also reported positive and significant impacts on performance (Dobson, 2008; Eddy & Hogan, 2014; Heiner et al., 2014; Narloch et al., 2006). On closer inspection, one can find a common thread among studies that report an improvement to student performance. These quizzes were designed and implemented as

preparatory tools to promote students to study novel material earlier and more often. For example, one study implemented online quizzes with the intention of encouraging students to visit the textbook and lecture notes prior to scheduled class periods (Dobson, 2008). The author reported significantly higher exam performance when quizzes were administered and hypothesized that students must have had more effective class preparation, though no measure was reported to back the claim. In another study, Eddy and Hogan manipulated the course structure by adding weekly graded preparatory assignments, in-class engagement exercises, and graded review assignments and found that students performed significantly better on exams and overall in the course (Eddy & Hogan, 2014). Further, the authors surveyed students on their study behaviors and found that students self-reported spending significantly more time studying each week and reported completing significantly more of the reading assignments prior to class.

Theoretical Framework and Predictions

This work is informed by the theories of Instructional Scaffolding and the Zone of Proximal Development. Scaffolding is the concept of presenting small portions of novel material to learners in a way that builds their knowledge progressively. This process, initially premised by Wood et al., is hypothesized to enable the learner to solve problems that would be beyond their grasp without assistance (Wood et. al., 1976). This process allows learners to focus on the elements of the material that are within their current competency and apply their skills to effectively gain knowledge on the new material. A key component of successful scaffolding is presenting information that is within the learner's Zone of Proximal Development. This entails the presentation of material that

the student may not be able to grasp without guidance or assistance, but still allows them to learn from the experience (Quintana et al., 2004). Scaffolding in a problem-based learning environment provides structure to learning tasks and can guide students to focus on elements that are most closely related to learning goals (Hmelo-Silver et al., 2007). Recent advances in educational technology provide the means to not only implement scaffolding into instruction but also test the efficacy of these implementations.

In this work, we administer graded preparatory assignments carefully designed to advance students' knowledge in a way that effectively moves their Zone of Proximal Development forward. The assignments introduce the new concepts in a way that requires the student to read relevant sections of the text, prior to the full presentation in lecture, in order to perform well. Within this framework, we would hypothesize that the preparatory assignment treatment would encourage students to read more of the chapter text prior to completing the weekly homework assignments. We also hypothesize that students would ultimately have a deeper understanding of course concepts and would perform better not only on short term assessments (quizzes), but also on long term assessments (exams), and in the course overall.

The Present Study

In the present research we investigate the effects of graded preparatory assignments on students' study behaviors and course performance. We employ a technology-enhanced data collection technique to measure students' actual usage of course materials throughout the term and examine if the preparatory assignment treatment created measurable change in student study behaviors. Further, we explore if

this preparatory assignment treatment, and possible changes in study behavior, are associated with changes in course performance and learning outcomes. This work is guided by the following research questions:

1) Are students' study behaviors affected by the introduction of graded preparatory assignments designed to promote students to read the textbook earlier and more often?

2) Does a change in study behavior, due the introduction of graded preparatory assignments, correspond to a change in course performance?

Method

Participants and Course Settings

The participants were 139 undergraduate students in two offerings of an Introduction to Mechanical Engineering course at the University of California, Riverside. The courses were taught during the spring quarter of 2015 and the winter quarter of 2016. Every student who was enrolled in the courses consented to participate in the study. We followed guidelines for the ethical treatment of human subjects and obtained IRB approval prior to the study. Introduction to Mechanical Engineering is a course designed to introduce students to the topics that will be covered throughout the undergraduate mechanical engineering curriculum. Students who follow the recommended course plan take this course during the winter term of their first year. Table 11 provides demographic information for the two course offerings considered in this study. The majority of students in both course offerings were male (69% and 74.2%), and mechanical engineering majors (66.7% and 79.4%).

Materials and Technologies

    Course textbook. The textbook used in both offerings of the course was *An Introduction to Mechanical Engineering, 3rd edition* (Wickert and Lewis, 2012). We provided all students with an electronic version of the textbook, free of charge, for use throughout the term. Students did not receive a printed copy of the textbook. The following five chapters of the textbook were covered during the course: Technical Problem-Solving and Communication Skills, Forces in Structures and Machines, Materials and Stresses, Fluids Engineering, Thermal and Energy Systems. Each chapter

Table 11

Participant Characteristics for Chapter 5

Participant Characteristics	Spring 2015		Winter 2016	
	N	%	N	%
Gender				
Male	29	69.0	72	74.2
Female	9	21.4	13	13.4
Prefer not to Answer	0	0.0	2	2.1
Missing	4	9.5	10	10.3
Major				
Mechanical Engineering	28	66.7	77	79.4
Computer Science	0	0.0	1	1.0
Materials Science and Engineering	1	2.4	1	1.0
Other	9	21.4	8	8.2
Missing	4	9.5	10	10.3
Year				
Freshman	20	47.6	62	63.9
Sophomore	11	26.2	3	3.1
Junior	7	16.7	11	11.3
Senior	0	0.0	4	4.1
5th Year and Beyond	0	0.0	7	7.2
Missing	4	9.5	10	10.3

comprises three general types of content (see Table 12): *Explanatory Text* which

introduces new principles and material, *Worked Examples* which show how principles are

applied to solve problems, and *Homework Problems* at the end of the chapter. Each week,

students were assigned *Explanatory Text* and *Worked Examples* pages to be read prior to

completing a set of problems from the *Homework Problems* pages.

Table 12

Content Types in the Textbook

Content Type	Description
Explanatory Text	Instructional text, equations, and diagrams used to introduce and explain the core principles of each topic.
Worked Examples	Sample problems with fully worked-out solutions used to demonstrate how core principles are applied to solve real problems.
Homework Problems	End-of-chapter problems, without solutions, that are assigned to students for homework.

Custom document viewer. DocViewer is a custom document viewing

application built from open source PDF rendering software. It was designed for use on

Tablets and PCs running the Windows operating system. DocViewer was preinstalled on

Windows Surface tablets issued to each student at the beginning of the term. Students

retained possession of the tablets until the final exam. DocViewer is instrumented to

enable accurate measurement of students' use of course materials including the textbook,

lecture slides, homework solutions, and graded work. The program includes several

features to help ensure accurate measurements of reading. First, the interface of the

document viewer displays only one page of a document at any time so that there is no

question as to what the student is currently viewing. Second, the display dims to grey

after a short period of time during which the student does not interact with the current page. While the display is dimmed, the student cannot see the content until they "wake" the program by tapping or clicking on the screen. This feature ensures that we measure only time the student is actively engaged with the currently visible page. Lastly, all course documents are distributed as encrypted PDFs. The password to unlock the documents is built into the software so that the students cannot view these materials with any other PDF viewers. This helps to ensure that we measure every interaction the student has with the course materials.

As students used DocViewer throughout the term, a log file of time-stamped events recorded when they opened or closed a document, changed pages within a document, or panned and zoomed on a page. At the end of the term, we processed each student's log file to extract page viewing *episodes*. An *episode* is defined as an interval of time, at least 15 seconds in duration, during which a single page of a document is continuously visible on the screen. While panning or zooming does not mark the end of an episode, changing the page or loading a new document does. An episode is comprised of the starting timestamp and duration of viewing, as well as the name of the document and page number that was viewed. In calculating the duration of an episode, we remove any inactive time (i.e., time elapsed while the screen was dimmed due to inactivity) from the total. Episodes with durations less than 15 seconds were considered page navigation and were excluded from the present analyses.

During the spring 2015 offering of the course, DocViewer was designed to dim the display after 10 minutes of inactivity. To improve accuracy of reading-time

measurements, for the winter 2016 term we reduced this to two minutes. To allow comparison of the data from the two course offerings, we down-sampled the higher resolution episodes collected during the winter 2016 offering to, in effect, achieve a 10-minute timeout. Consider, for example, a sequence comprising two-minutes of viewing terminated by the two-minute timeout, 12 minutes of inactivity, and then five minutes of viewing. With a10-minute rather than a 2-minute timeout, much of the 12 minutes of inactivity would be considered active viewing time. More specifically, after down-sampling, this would become 10 minutes of viewing, four minutes of inactivity, and five minutes of viewing.

Measures of Reading

  Textbook Reading. We analyzed each student's list of page viewing episodes and extracted various measures of textbook usage throughout the term – see Table 13 for the comprehensive list. We calculate both total time spent in the textbook and number of unique visits to pages in the textbook. Total time spent is determined by summing the durations of all episodes for the textbook. Likewise, the number of visits to pages is determined by counting the number of episodes. We categorized each page of the textbook as one of the three types of content – *Explanatory Text, Worked Examples,* or *Homework Problems* – according to the majority of the content on the page. We then determined total time spent and number of page visits for each individual type of content separately. We calculate these measures both as a summation across the entire term as well as per day of the term.

Table 13

Quantitative Reading Measures for Chapter 5

Measure Name	Description
Textbook Time	Total time spent viewing pages from the textbook.
Explanatory Text Time	Total time spent viewing textbook pages whose content is a majority *Explanatory Text*.
Worked Example Time	Total time spent viewing textbook pages whose content is a majority *Worked Examples*.
Homework Problem Time	Total time spent viewing textbook pages whose content is a majority *Homework Problems*.
Textbook Visits	Total number of visits to pages in the textbook.
Explanatory Text Visits	Number of visits to pages of the textbook for which the content is a majority *Explanatory Text*.
Worked Example Visits	Number of visits to pages of the textbook for which the content is a majority *Worked Examples*.
Homework Problem Visits	Number of visits to pages of the textbook for which the content is a majority *Homework Problems*.
Assigned Textbook Percentage	Percentage of assigned textbook pages read while the respective homework assignment was available.
Assigned Explanatory Text Time	Time spent on pages that were assigned to read and whose content is a majority *Explanatory Text*.
Assigned Worked Example Time	Time spent on pages that were assigned to read and whose content is a majority *Worked Examples*.
Assigned Homework Problem Time	Time spent on pages that were assigned to read and whose content is a majority *Homework Problems*.
Explanatory Text WPMT	Weighted Prior Mean Time measure for pages whose content is a majority *Explanatory Text*.
Worked Example WPMT	Weighted Prior Mean Time measure for pages whose content is a majority *Worked Examples*.
Homework Problem WPMT	Weighted Prior Mean Time measure for pages whose content is a majority *Homework Problems*.

Weighted Prior Mean Time measurement. As a means of quantifying when a student reads, we compute the weighted average time of the reading performed prior to each assignment deadline. Consider the example in Figure 7 which illustrates a hypothetical reading distribution over a window of seven days leading up to the submission of homework assignment HW_j. We define T_i as the amount of reading done on the ith day of the homework window, with $i = 7$ being the first day of the window and $i = 1$ being the due date. Likewise, we define $t_i = i$ as the weighting factor for each day. From this, we compute the centroid τ_j of the reading distribution as:

$$\tau_j = \frac{\sum_{i=1}^{7}(T_{ij} * t_{ij})}{\sum_{i=1}^{7}(T_{ij})} \tag{1}$$

If there is no reading done, the value of τ_j is zero. Otherwise, the value ranges from 1.0 to 7.0. A large value of τ_j indicates that reading is done early in the window, whereas a small value indicates that reading is done just before the due date. We define the Weighted Prior Mean Time (WPMT) as the average value of τ_j over all N assignments:

$$WPMT = \frac{\sum_{j=1}^{N}(\tau_j)}{N} \tag{2}$$

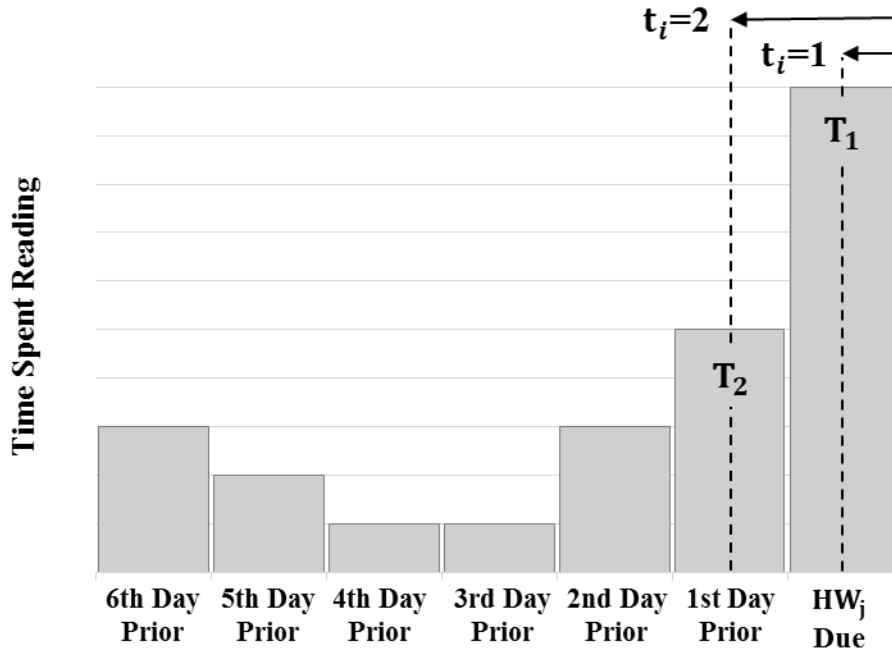We compute WPMT for each content type separately.

Figure 7: Weighting Scheme for WPMT Calculations.

Reading of assigned pages. Each homework assignment included assigned readings of *Explanatory Text* and *Worked Example* pages. The assignments also included problems to be solved from the *Homework Problem* pages. For each assignment, we calculated the time spent viewing the assigned pages by summing the durations of all episodes that occurred on those pages. We also computed the fraction of the assigned pages visited prior to the assignment deadline.

Measures of Performance

We use three measures of quantify academic performance. We use average grade on in-class quizzes as a measure of short-term performance. These quizzes were administered weekly during lecture and contained one problem related to the most recently submitted homework assignment. We use the grade on the cumulative final

exam as a measure of long-term performance. Finally, we use the final course grade

computed with the weights in Table 14 as a measure of overall achievement in the course.

In both, quarters, 5% of the final grade actually assigned to students was based on lecture

attendance. We exclude this in our analysis as it does not reflect performance. Likewise,

in the quarter containing the preparatory assignments, 5% of the grade was based on

completion of the preparatory assignments. We also exclude this from our grade

calculations to enable meaningful comparisons between the two quarters. All quizzes and

exam problems were graded using a rubric that considered the correctness of various

elements of the solutions such as diagrams, geometric calculations, and equations. Credit

was deducted for basic errors in calculations while larger conceptual errors incurred

greater deductions. One problem from each homework assignment was graded using a

rubric while the remaining problems were graded based on completion and correctness of

the final answer.

Table 14

Final Course Grade Calculation Weighting

Course Item	Weighting
Homework Problem Sets	10
Quizzes	10
Exam 1	20
Exam 2	20
Final Exam	30

Procedure

    At the beginning of each course, we administered a survey to all students. The

survey, which is designed to measure students' prior knowledge of concepts related to

forces, serves as a control in our statistical analyses. The course included 3 hours of

lecture each week during which new content was presented, and 1 hour of discussion during which problem solving skills were reviewed. Each week, students were assigned a homework assignment and completed an in-class quiz. The homework assignments contained *Explanatory Text* and *Worked Examples* pages to be read, and a set of problems from the *Homework Problem* pages to be solved. The in-class quizzes, which typically lasted about 15 min, tested students on material covered in the most recently submitted homework assignment. On the first day of class, students were given access to the instrument document viewing application that contained the course textbook. As students viewed the textbook throughout the quarter, DocViewer recorded their interactions with the material.

During the quarter with treatment, students were assigned additional preparatory assignments to be completed prior to eight of the lectures. The preparatory assignments were not given during the two weeks in which scheduled midterm exams occurred. The assignments contained between five and ten multiple choice problems, and were administered via an online course management system. These preparatory assignments were contained problems on topics that would be covered in the following lecture periods and tested in the subsequent homework assignment. Students needed to read the relevant pages of the textbook in order to acquire the knowledge necessary to perform well on these assignments. This preparatory assignment treatment was designed to promote students to read the textbook earlier and more often with respect to homework deadlines.

Statistical Analysis Plan

All participants included in these analyses had to meet two criteria for inclusion. The student must have earned a final grade in the course. Additionally, the student must have visited the *Homework Problem* pages in at least three different weeks of the term. We acknowledge that students may have had access to the textbook outside of the instrumented document viewer (e.g., physical copy, downloaded pdf, etc.). This criteria ensures that the included students used the textbook to view the homework problems for at least half of the homework assignments, indicating a level of intent to use the document viewer for accessing the textbook. Any students who did not meet the two criteria were excluded from our analyses. When considering the *Homework Problem* page viewing criteria, we removed 21 students in the control quarter and 18 students in the treatment quarter.

To determine if students' study behaviors changed in the presence of the preparatory assignments (research question **1**), we compare measures of textbook reading between the two terms and explore differences in completion of assigned reading. First, we report descriptive statistics on students' use of the textbook as a whole as well as the use of each content type separately. Further, we use independent samples *t*-tests to examine any significant differences in this usage across quarters to explore if the preparatory assignment treatment had any significant effect on students' time spent reading content in the textbook. Next, we examine assigned pages to explore if the preparatory treatment had a significant effect on students' completion of the reading assignments. We report the total percentage of assigned pages read as well as time spent

reading the pages that were assigned. Further, we use independent samples *t*-tests to identify if, between the two quarters, students spent significantly different amounts of time reading pages that were explicitly assigned, and if they visited a significantly different percentage of these pages.

Finally, we examine patterns in students' daily usage of the textbook. We explore, qualitatively, students' daily time spent reading *Homework Problem, Explanatory Text,* and *Worked Example* pages between the two quarters. Additionally, we quantify the activity of reading this content earlier and more often by computing the WPMT measure for each content type separately and exploring differences in this measure using independent samples *t*-tests.

In investigating if changes in student behavior corresponded to a change in student performance (research question **2**), we first employ ANCOVA to examine any significant differences in measures of performance between the two quarters while controlling for students' incoming prior knowledge. Next, we examine if the behavior of reading the textbook earlier and more often, quantified by the WPMT measure for each content type, is significantly related to performance in the course. We report the Pearson Product Moment correlations between the WPMT measures and measures of course performance separately by quarter to examine if this behavior is differentially related to performance when the preparatory assignment treatment is administered. Additionally, to further examine these differential associations we evaluated the interaction between quarter and WPMT using Multiple Linear Regression. This allows us to determine if the effect of quarter (i.e., whether or not preparatory assignments were administered) on final

course grades is significantly moderated by WPMT (i.e., whether the students read earlier and more often) while controlling for students' incoming prior knowledge.

Results and Discussion

Textbook Reading

Table 15 contains descriptive statistics for each of the reading measures as well as *t*-test statistics for Equality of Means between the control quarter (Q1) and the treatment quarter (Q2). Using independent samples *t*-tests, we find that when the preparatory assignments were added to the course structure, students visited the textbook significantly more often ($t_{137} = 3.845, p < .001$). Specifically, students visited the *Homework Problem* ($t_{137} = 4.071, p < .001$) and *Explanatory Text* ($t_{137} = 3.613, p < .001$) pages more times, on average, with no significant difference in *Worked Example* visits. Although visits to the textbook significantly increased, there was no significant difference in time spent with the textbook in total, nor any of the content types contained within.

Table 15

Sample Descriptives and t-tests for Reading Measures

Reading Measure	Q1 (N=42)		Q2 (N=97)		t-test		
	M	SD	M	SD	t_{137}	p	d
Textbook Time	15.80	11.13	14.56	9.15	.683	.496	.122
Textbook Visits	264.50	144.10	438.92	277.91	3.845	<.001	.788
Explanatory Text Time	4.82	3.94	5.50	5.18	.759	.449	-.148
Worked Example Time	1.60	1.53	1.34	1.52	.913	.363	.170
Homework Problem Time	9.38	6.98	7.73	4.11	1.734	.085	.288
Explanatory Text Visits	106.86	72.02	203.23	165.98	3.613	<.001	.753
Worked Example Visits	48.02	40.23	61.24	61.96	1.270	.206	.253
Homework Problem Visits	108.88	61.08	174.45	96.23	4.071	<.001	.814

Note. The four measures of "Time" are presented in hours. Q1 represents term without preparatory assignments while Q2 represents term with preparatory assignments included.

Assigned Reading

  We calculate the average percent of assigned pages read prior to each assignment due date. We found that students visited only 20.7% of the assigned pages during the control quarter, whereas students visited 31.12% in the quarter with preparatory assignment treatment. An independent samples t-test concluded this increase in percentage of assigned pages visited was significant ($t_{137} = 3.81$, $p < .001$).

  Further, we examined the amount of assigned reading for each homework assignment separately and compared across the two quarters (See Figure 8). Comparisons for homework assignments one and two are not considered as different pages were assigned to be read during the two quarters. Additionally, homework 4 was excluded as there were no assigned readings from the textbook. All other homework assignments contained the same problems and assigned readings for both the control and treatment quarters.
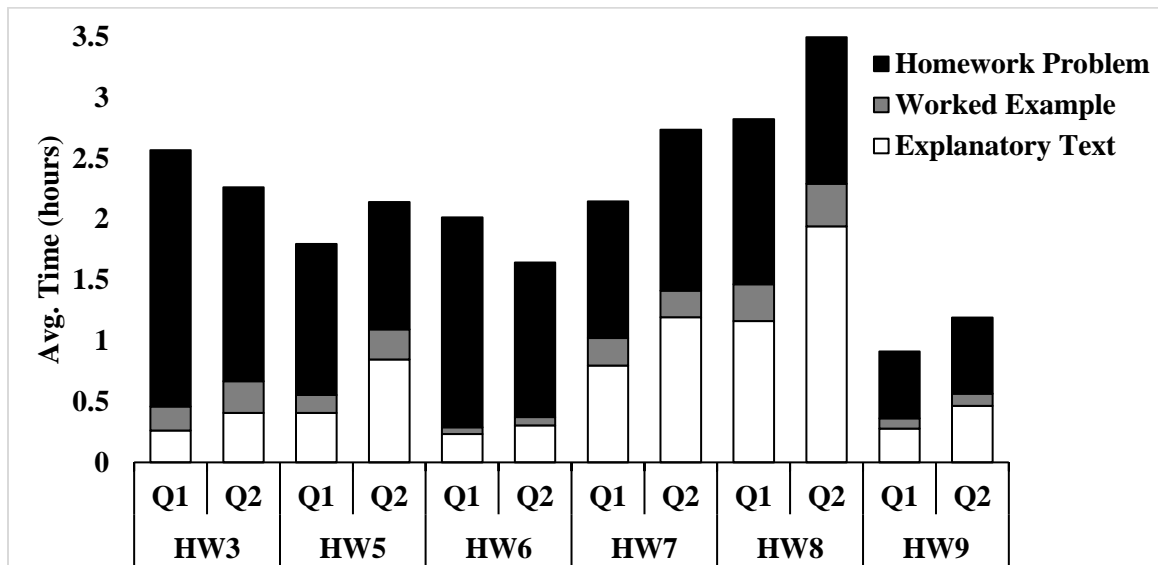

Figure 8: Comparing Average Time Spent Reading Assigned Pages

We find that time spent viewing assigned pages containing *Worked Examples* are not significantly different between terms for any of the homework assignments considered. Similarly, we find time spent reading *Homework Problem* pages is significantly different only for homework three ($t_{137} = 2.345$, $p = .020$), and trended towards significance for homework six ($t_{137} = 1.885$, $p = .062$). In both cases, students in the quarter without preparatory treatments spent significantly more time on these pages. A possible explanation for this finding is that exams were scheduled in the same weeks these homework assignments were due. Students in the control quarter, without preparatory assignments, may have chosen to study for the exams by revisiting assigned homework problems instead of re-reading relevant sections of the text. Finally, when considering assigned *Explanatory Text* pages, we find significantly more assigned reading time in the quarter with preparatory treatment for homework assignments five ($t_{137} = 2.762$, $p = .007$), eight ($t_{137} = 2.529$, $p = .013$), nine ($t_{137} = 2.026$, $p = .045$), and trending towards significance for homework seven ($t_{137} = 1.910$, $p = .058$). We find no significant difference in reading assigned *Explanatory Text* pages for homework assignments three and six. Again, these weeks contained scheduled exams and thus no preparatory assignments were administered. This provides a possible explanation for the lack of significant difference in time spent with assigned *Explanatory Text* pages during these weeks.

Considering these findings collectively, we have much evidence to support the hypothesis that the addition of graded preparatory assignments does influences students'

compliance with assigned readings overall, but especially for the *Explanatory Text* pages that explain the core principles.

Patterns of Daily Reading

Next we explore, qualitatively, the patterns in students' daily use of the textbook. We find a consistent pattern of "cramming" in days leading up to the deadline of each assignment. The majority of these activity spikes are made up of time spent viewing pages containing the *Homework Problems*, with a significantly smaller proportion of the reading time devoted to pages containing *Explanatory Text* or *Worked Examples* (See Figures 9A and 9B). Note that these spikes are not exactly aligned to the day of quarter as there were small differences in homework deadlines and exam dates between the two quarters.

We find a similar pattern of reading activity when preparatory assignment are added to the course structure (See Figure 9B) – the majority of time spent on pages containing homework problems in the days leading up to a deadline. Although, another pattern of activity emerges in the form of peaks of *Explanatory Text* reading prior to the deadline of a preparatory assignment. Clear examples of this activity can be found on Figure 9B, on days 29, 36, and 57. We can see that students are changing their reading behaviors in the presence of the preparatory assignments, viewing more of the chapter text between homework assignment deadlines.
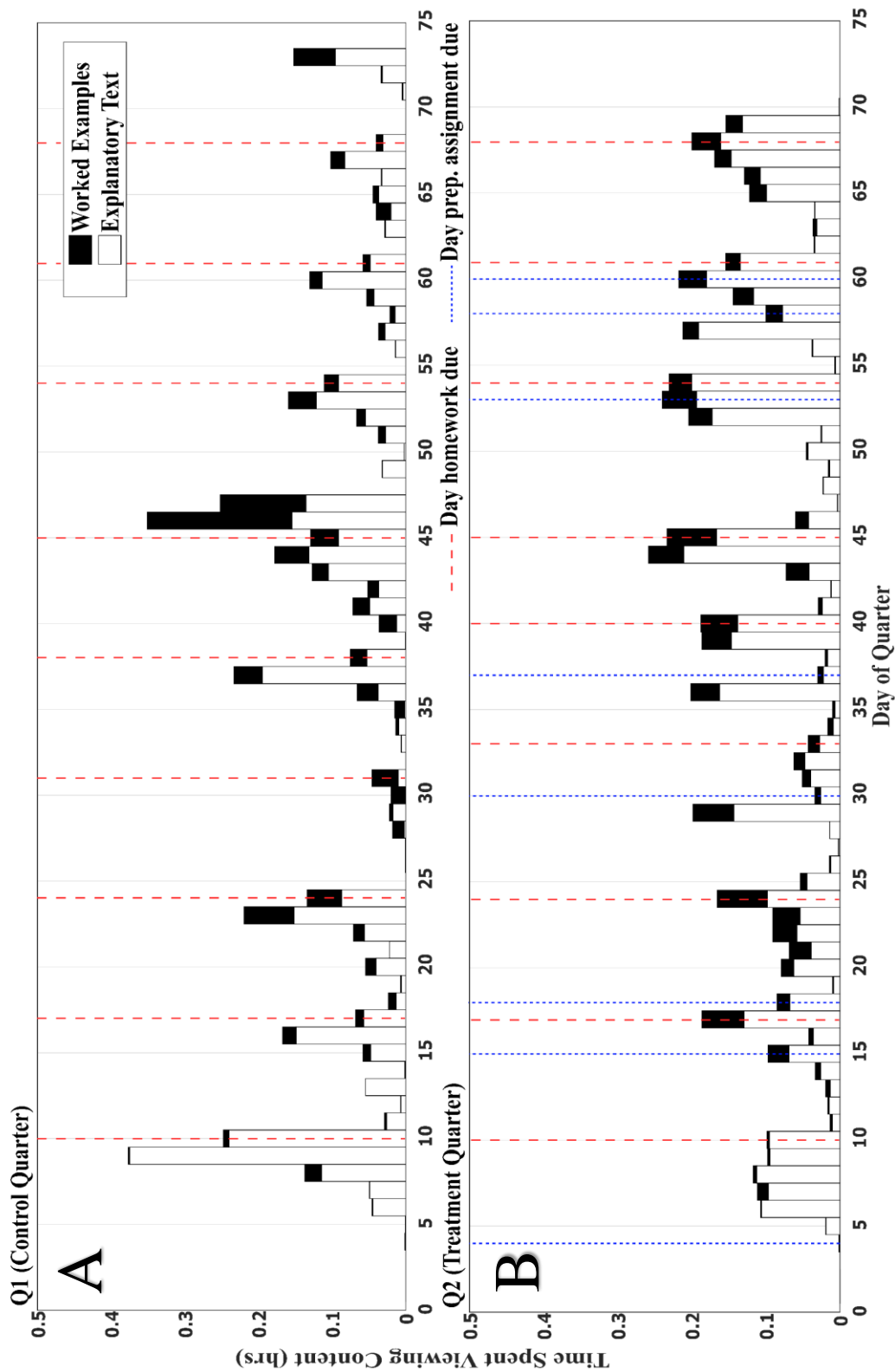
Figure 9: Comparison of Daily Textbook Viewing Patterns

Next we quantify these differences in patterns of daily reading by examining the WPMT measure. Table 16 provides descriptive statistics and *t*-test for Equality of Means for each content type considered. We find that students visited *Explanatory Text* and *Worked Example* pages earlier in the quarter with preparatory assignments added, and the difference was significant (Explanatory Text WPMT: $t_{137} = 5.622, p < .001$) and Worked Example WPMT: $t_{137} = 5.814, p < .001$).

Table 16

Sample Descriptives and t-tests for WPMT Measures

Reading Measure	Q1 (N=42)		Q2 (N=97)		*t*-test		
	M	SD	M	SD	t_{137}	*p*	d
Explanatory Text WPMT	1.59	.765	2.41	.796	5.622	<.001	1.05
Worked Example WPMT	1.00	.709	1.88	.865	5.814	<.001	1.12
Homework Problem WPMT	1.36	.763	1.47	.584	.900	.370	.157

Note. WPMT denotes the Weighted Prior Mean Time measure. Q1 represents term without preparatory assignments while Q2 represents term with preparatory assignments included.

We do not find a significant difference in Homework Problem WPMT between the two quarters. This finding indicates that students' homework completion behavior was unchanged when preparatory assignments were added to the course structure. The preparatory treatments were designed to encourage students to visit the *Explanatory Text* and *Worked Example* pages earlier and more often, and we see a quantifiable change in this behavior. We would not expect to find any significant change to *Homework Problem* viewing beahvior under the preparatory assignment treatment.

Course Performance

To investigate changes in course performance (research question **2**), we first
conducted One-Way ANCOVA to determine if there is a statistically significant
difference in student performance, between the quarter with preparatory treatment and the
quarter without, when controlling for incoming prior knowledge. A number of students in
both quarters did not complete pretest survey resulting in no measure of prior knowledge
for these individuals. For this reason, 15 additional students are removed from the
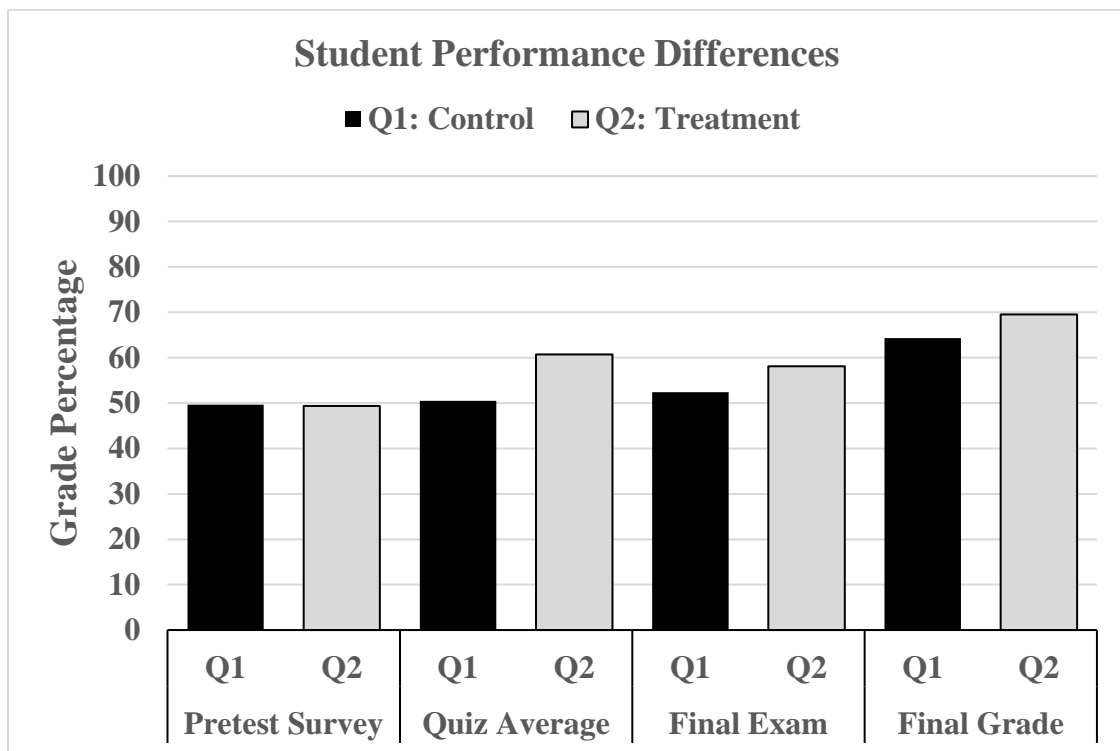following analyses in which this measure is used as a control.

Figure 10: Comparing Measures of Course Performance

We find a significant effect of preparatory treatment on average quiz grade
($F_{(1,121)} = 5.729$, $p = .018$), but no significant effect on final exam grade ($F_{(1,121)} = 2.252$,
$p = .136$). This finding suggests that the inclusion of graded preparatory assignments did

have a direct significant effect on students' short-term achievement but this improvement did not carry over to long-term assessments. When considering final course grade, conceptualized as the measure of overall achievement in the course, we find an effect of preparatory treatment trending towards significance ($F_{(1,121)} = 3.669$, $p = .058$). This initial finding indicates the positive impact of graded preparatory assignments on students' short-term achievement, though more investigation is necessary to determine the full impact.

Next, we consider the relationships between WPMT measures of reading and measures of course performance and find that WPMT measures of all three content types are significantly and positively related to short-term achievement (see Table 17). Long-term achievement, measured using final exam grade, is significantly related only to Homework Problem WPMT in the quarter without preparatory assignment treatment. Further, the measure of students' overall achievement, final course grade, is significantly and positively related to Explanatory Text WPMT and Homework Problem WPMT but not Worked Example WPMT for both quarters.

Table 17

Correlations between Measures of Reading and Course Performance in Chapter 5

	ET WPMT	WE WPMT	HP WPMT
Quiz Average			
Q1	.594**	.518**	.664**
Q2	.400**	.215*	.361**
Final Exam			
Q1	.271	.151	.385*
Q2	.170	.034	.155
Final Grade			
Q1	.416**	.284	.557**
Q2	.244*	.102	.361**

Note. † $.05 < p < .10$, $*p < .05$, $**p < .01$. ET represents Explanatory Text, WE represents Worked Examples, and HP represents Homework Problem. Q1 represents term without preparatory assignments while Q2 represents term with preparatory assignments included.

Additionally, when comparing the differential relationships by quarter we find, for all content types, a stronger relationship between WPMT and performance in the quarter without preparatory assignment treatment. This finding further illuminates the impact of preparatory assignments on students' study behaviors. In the quarter without preparatory treatment, the activity of studying earlier and more often, as quantified by WPMT measures, has a stronger relationship with performances as students were not explicitly being encouraged to engage in this activity. During the quarter with preparatory treatment, more students displayed this behavior more often, a possible result of the preparatory assignments, thus reducing the predictive ability of the measure in relation to course performance. Another possible interpretation of this finding is that those students

who naturally perform the activity of reading earlier and more often, without explicit encouragement, tend to already perform better on assessments of achievement.

Multiple Linear Regression was conducted to predict final course grade from Quarter (i.e., preparatory treatment), Explanatory Text WPMT, and the interaction between Quarter and Explanatory Text WPMT, controlling for students' incoming prior knowledge (see Table 18). This model was significant ($F_{(4, 119)} = 24.064$, $p < .001$, $R^2 = .447$) and predicted 44.7% of the variance in Final Course Grade.

Table 18

Multiple Regression Analysis Predicting Final Course Grade

	b	*SE*	*β*	*t*	*p*
Intercept	.197	.059	--	3.344	.001
Prior Knowledge	.544	.066	.563	8.249	<.001
Quarter	.129	.070	.334	1.859	.066
ET WPMT	.012	.003	.534	3.873	<.001
Quarter x ET WPMT	-.008	.004	-.498	-2.018	.046

Note. Quarter (i.e., preparatory treatment group) was coded as 0 = Spring 2015 when no assignments were given and 1 = Winter 2016 when preparatory assignments were given. ET WPMT represents the Explanatory Text Weight Prior Mean Time measure.

Students who read earlier and more often demonstrated significantly higher Final Course Grades (Explanatory Text WPMT: $b = .012$, $p < .001$), however there was a significant interaction between Quarter and Explanatory Text WPMT ($b = -.008$, $p = .046$). The interaction suggests that when controlling for prior knowledge, the effect of quarter on final course grade was significantly moderated by Explanatory Text WPMT. This further supports and expands on the correlational findings that Explanatory Text WPMT was less predictive of course performance when the preparatory assignments were present. These findings begin to explore the possible mechanisms that affect the

relationship between course structure and student performance, highlighting one significant moderator in the relationship between the addition of preparatory assignments and students' subsequent course performance.

Discussion

Empirical Contributions

This study contributes several findings to the field of education psychology and instructional design. The first major finding of the study is that the introduction of graded preparatory assignments, designed to promote students to read the textbook earlier and more often, creates significant measurable changes in students' textbook reading behaviors. With the addition of these assignments to the course structure, students visit *Explanatory Text* and *Homework Problem* content more often. Additionally, *Explanatory Text* and *Worked Example* pages were visited earlier relative to homework assignment deadlines. Students also visited an overall larger percentage of pages explicitly assigned to be read.

In addition to changing textbook reading behaviors, students' short term performance in the course improved, as marked by significant increases to average quiz grades when graded preparatory assignments were administered. Additionally, we find that those students who engaged in the activity of reading *Explanatory Text* and *Homework Problem* pages earlier, relative to each homework assignment deadline, performed better in the course overall.

Practical Contributions

The findings support the possibility of using graded preparatory assignments to influence students to visit the textbook earlier and more often. Additionally, the findings

highlight the importance of reading *Explanatory Text* and *Homework Problem* pages earlier and more often relative to homework assignment deadlines. Those students who engaged in textbook study more prior to the assignment deadlines tended to perform better on short-term assessments and overall in the course.

Methodological Contributions

The document viewer used in this study provides a means to objectively collect the high-resolution information on student reading habits this is necessary to investigate the impacts of instructional design, such as changes to course structure. Additionally, the WPMT measure provides the means to incorporate not only how much time students spend in study, but also when the studying occurred – an important aspect in the relationship between study and performance.

Limitations and Future Directions

The present study includes a small sample of engineering students across only two terms. A larger sample of students, taught using the same course structures, would allow the findings to be generalizable to a larger population of students.

Ongoing improvements to the document viewing application took place during the data collection for this study. One improvement was made to the "time-out" functionality of the viewer in an attempt to gather more accurate measurements of students' time spent fully engaged with the electronic textbook. This required the use of a down-sampling procedure to make the data sets comparable across the two quarters. The down-sampling procedure may explain the lack of significant differences in time spent with the textbook when we do in fact find a significant difference in the number of visits.

112

Further investigations should use the smaller time-out limit to more accurately explore differences in students' time spent with the textbook.

We acknowledge that students may have had access to the course textbook outside of the instrumented document viewing application. Although, we did take steps to include only those students who exhibited adequate intent to use the document viewer for viewing homework problems, the possibility remains that some students may have spent time in the textbook that went unmeasured in our data sets. The best way to minimize this situation is to provide students with a custom textbook that is altogether unavailable outside of the instrumented document viewing application. Even under these circumstances, there is no way to measure completely students' time spent studying the applicable material (e.g., students may study in groups). Nevertheless, as there is no reason to believe that students' use of a secondary copy of the textbook differed between the two quarters, the comparisons between them are valid.

Conclusion

This work provides a means to test mechanisms that may be affecting the relationships between student performance and changes to course structure. In this research we implemented preparatory reading assignments designed to promote students to read the textbook earlier and more often. We objectively measured changes in students' study habits via a technology-enhanced data collection technique in the presence of these added assignments and investigated changes in student performance. We found that with the addition of these preparatory assignments, students visited the textbook significantly more often, specifically visiting the *Explanatory Text* twice as

often. Further, we computed a Weight Prior Mean Time to examine when, in relation to assignment deadlines, students did their reading. Based on this measure, we found that students visited the *Explanatory Text* and *Worked Example* content significantly earlier. Further, we showed that students performed significantly better on short-term assessments in the presence of the preparatory assignments, and that there was a significant interaction between overall performance in the course and the Explanatory Text WPMT measure of reading. This finding indicates that the activity of reading relevant sections of the *Explanatory Text* earlier has a significant effect on the relationship between the preparatory treatment and changes in course performance.

References

Brothen, T., & Wambach, C. (2001). Effective Student Use of Computerized Quizzes. *Teaching of Psychology*, *28*(4), 292–294. https://doi.org/10.1207/S15328023TOP2804_10

Connor-Greene, P. A. (2000). Assessing and Promoting Student Learning: Blurring the Line between Teaching and Testing. *Teaching of Psychology*, *27*(2), 84–88. https://doi.org/10.1207/S15328023TOP2702_01

Dobson, J. L. (2008). The use of formative online quizzes to enhance class preparation and scores on summative exams. Advances in Physiology Education, 32(4), 297–302. https://doi.org/10.1152/advan.90162.2008

Eddy, S. L., & Hogan, K. A. (2014). Getting Under the Hood: How and for Whom Does Increasing Course Structure Work? CBE-Life Sciences Education, 13(3), 453–468. https://doi.org/10.1187/cbe.14-03-0050

Flavell, J. H. (1976). Metacognitive Aspects of Problem Solving. *The Nature of Intelligence*, 12, 231-235.

Freeman, S., Haak, D., & Wenderoth, M. P. (2011). Increased Course Structure Improves Performance in Introductory Biology. CBE-Life Sciences Education, 10(2), 175–186. https://doi.org/10.1187/cbe.10-08-0105

Freeman, S., O'Connor, E., Parks, J. W., Cunningham, M., Hurley, D., Haak, D., Dirks, C., Wenderoth, M. P. (2007). Prescribed Active Learning Increases Performance in Introductory Biology. CBE-Life Sciences Education, 6(2), 132–139. https://doi.org/10.1187/cbe.06-09-0194

Haberyan, K. A. (2003). Do Weekly Quizzes Improve Student Performance on General Biology Exams? The American Biology Teacher, 65(2), 110–114. https://doi.org/10.1662/0002-7685(2003)065[0110:DWQISP]2.0.CO;2

Heiner, C. E., Banet, A. I., & Wieman, C. (2014). Preparing students for class: How to get 80% of students reading the textbook before class. American Journal of Physics, 82(10), 989–996. https://doi.org/10.1119/1.4895008

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006). Educational Psychologist, 42(2), 99–107. https://doi.org/10.1080/00461520701263368

Kortemeyer, G. (2016). Work Habits of Students in Traditional and Online Sections of an Introductory Physics Course: A Case Study. Journal of Science Education and Technology, 25(5), 697–703. https://doi.org/10.1007/s10956-016-9624-6

Laverty, J. T., Bauer, W., Kortemeyer, G., & Westfall, G. (2012). Want to Reduce Guessing and Cheating While Making Students Happier? Give More Exams! The Physics Teacher, 50(9), 540–543. https://doi.org/10.1119/1.4767487

Narloch, R., Garbin, C. P., & Turnage, K. D. (2006). Benefits of Prelecture Quizzes. Teaching of Psychology, 33(2), 109–112. https://doi.org/10.1207/s15328023top3302_6

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A Scaffolding Design Framework for Software to Support Science Inquiry. Journal of the Learning Sciences, 13(3), 337–386. https://doi.org/10.1207/s15327809jls1303_4

Seaton, D. T., Kortemeyer, G., Bergner, Y., Rayyan, S., & Pritchard, D. E. (2014). Analyzing the impact of course structure on electronic textbook use in blended introductory physics courses. American Journal of Physics, 82(12), 1186–1197. https://doi.org/10.1119/1.4901189

Wickert, J., Lewis, K. (2012). *An Introduction to Mechanical Engineering* (3rd ed.). Stamford, Connecticut; Cengage Learning.

Wood, D., Bruner, J. S., & Ross, G. (1976). The Role of Tutoring in Problem Solving. Journal of Child Psychology and Psychiatry, 17(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Chapter 6: General Conclusions

The work presented in this dissertation employed a technology-enhanced data collection technique to measures students' usage of the provided course materials in introductory engineering courses. To facilitate this work I developed DocViewer, described in Chapter 2, which objectively measures students' interactions with the provided course textbook, homework solutions, annotated lecture slides, and reports of graded work. Through this technology-enhanced data collection approach, I was able to measure students' actual usage of these materials and illuminate the relationships between material use and student performance with more reliability than is available in previous research.

Research Inquiry 1

The first line of inquiry, presented in Chapter 3, addressed how content in the course textbook (e.g., homework problems, homework answers, instructional text, and worked examples) is being used by students, and whether that use is predictive of course performance and learning outcomes. In this work, I include an in-depth examination of students' use of the various types of content in the textbook. Additionally, I investigate the relationship between these measures of textbook use and students' performance in the course. Finally, the relative viewing times for each content type are used as indicators of students' preference of study strategy, and are investigated as predictors of course performance.

The findings suggest that students spend very little time viewing the textbook in general – just 26.3 hours on average during the 10-week term – a finding that is

consistent with much of the previous research. Further, the study illuminated the rather surprising finding that students spend the vast majority of this time on pages containing the end-of-chapter homework problems. Students spent 22.1 hours on average (84% of their total time) on homework problem pages, suggesting that they use the textbook for completing their homework assignments and little else. Only 1.9 hours and 1.4 hours were spent on pages containing instructional text and worked examples respectively, even though with each homework assignment numerous pages of these types were explicitly assigned to be read. The findings surrounding students' overall use of the instructional text and worked examples, though startling, are in concert with previous research investigating viewing time recorded with online course management systems (Fouh et al., 2014; Junco and Clem, 2015; Seaton et al., 2014). One possible explanation for the surprisingly low time spent with these materials comes from the nature of the material itself. In many STEM disciplines, a heavy focus is made on applying concepts to solve problems. Often the concepts are simple to explain and become clearer once applied to solve increasingly complex problems, and thus it is possible that only 2 hours of reading time is required. However, it is still an open question how much time is actually required, and this likely depends on the complexity of the material.

An investigation of the relationship between these measures of textbook use and students' performance in the course demonstrated that total time spent viewing the textbook overall was significantly and positively related to short-term performance (i.e., grades on homework and quizzes). However, spending more time in the textbook throughout the term was not significantly related to long-term performance described by

average exam grade and final course grade. Somewhat unexpectedly, the results show that time spent on instructional text and worked example pages is negatively related, though not significantly, to all measures of performance. Similarly, the number of visits to worked example pages is negatively and significantly related to the long-term measures of performance. These findings reveal that those students who visited worked example pages more often, tended to perform more poorly in the course overall. It is possible that reading this type of material is detrimental to performance. However, it is more likely that this is a result of otherwise low-performing students using the example problems to help supplement their understanding. But no definitive conclusion can be drawn, as correlations cannot prove causal relationships.

Finally, when relative viewing times for each content type are considered, the results indicate that students who spend a larger portion of their textbook viewing time on pages containing the homework problems tend to have higher short-term and long-term performance. Relative viewing time for homework problem pages were significantly and positively related to all measures of performance. I hypothesized that employing the self-testing learning strategy would be positively related to course performance. Our results support this hypothesis as relative time spent on homework – which indicates how much of the study effort was focused on homework, which is a form of self-testing – correlates positively and significantly with all measures of performance.

The results presented in Chapter 3 illuminate how students use the textbook in an introductory engineering course and how this use impacts performance. The technology-

enhanced data collection techniques developed to measure students' use of the textbook allows for a more detailed picture of student study habits and can provide insight into students' learning strategies. Further, it allows for a more in-depth evaluation of the differential importance of the content provided to students in relation to their performance and learning outcomes.

Research Inquiry 2

In the second line of inquiry, I examined whether students are able to accurately judge their time spent using the provided course materials – textbook, homework solutions, lecture slides, and graded work – and if discrepancies between a student's judgment of their study time and their actual study time was related to course performance. While the study in Chapter 3 considered only textbook use, this work considers four types of materials. Additionally, I measure the discrepancy between students' self-reports of time spent with the materials, and their actual time spent, to identify if students are able to accurately judge their study time. Errors in judgments of study time and their relationship to course performance were also examined, assessing whether students who are more aware of the time they spend in study are able to perform better.

I hypothesized that students would be unable to accurately judge their actual time spent with the provided materials. On average, students reported significantly more time spent per week with each material type investigated. Between 76% and 92% of students over-reported their usage, depending on the material type considered. In fact, only moderate correlations were observed between students self-reported time and actual time

with *r* values ranging from .231 (textbook, *p* = .021) to .395 (homework solutions, *p*

<.001). Therefore, my hypothesis was supported by these findings. If students were

accurate in their judgments of study time, these correlations should be approaching 1.

These findings are consistent with previous research comparing students' self-reports and

actual time spent completing homework problems (Rawson, Stahovich, and Mayer,

2017). This work highlights the idea that there may be a fundamental difference between

self-reported measures of study and actual time spent in study, though much of previous

research on student study habits assumes they are comparable. A self-report represents an

individual's perception of something and is therefore subject to errors in reporting or

even intentional misreporting. This is not to say that a student's perception of their study

is unimportant when considering the relationships with learning outcomes, but that both

self-reported measures and actual measures of study may have unique contributions to the

relationship.

When investigating the relationship between students' errors in judgment and

course performance, I hypothesized that any discrepancies between these two measures

would be negatively related to learning outcomes. Errors in judgment for the textbook,

homework solutions, and lecture slides were found to be significantly and negatively

related to final course grade. These findings suggest that students who are less aware of

their actual study habits perform more poorly in the course, which supports the

hypotheses laid out for this line of inquiry. Additionally, as judgments of study time can

be considered an indicator of metacognitive awareness, a skill shown to be related to

academic success (Schraw & Dennison, 1994; Wang, Haertel, & Walberg, 1990; Young

& Fry, 2008), these findings are in line with previous research suggesting that students who are less aware will be less able to inform appropriate study decisions in future and will ultimately perform more poorly.

The work presented in Chapter 4 provides a means to effectively analyze the reliability of students' self-reports of study behaviors, which are a common measure in educational research. In doing so, it illuminates the importance of awareness of one's own study habits as errors in judgments of study time are significantly negatively related to performance. This work begins to identify the technology-enhanced data collection techniques, utilized throughout this dissertation, as an effective tool in investigating long-held theories involving student behaviors in educational research.

Research Inquiry 3

In the third and final research inquiry addressed in this dissertation, I investigated if student's reading behavior could be influenced by adding targeted preparatory assignments to the course curriculum, and if this would correspond to a change in course performance. Chapter 5 details an intervention study that aims to answer these questions. Similar to Chapter 3, I examined students' use of each type of content in the textbook separately. Additionally, I investigated measurements of time spent on assigned pages of each of the content types separately. Finally, I explore students' patterns of daily reading and a novel measure that identifies the centroid of reading distribution within windows of time prior to homework deadlines. Observed changes in reading behaviors between the

control quarter, and a quarter with preparatory assignment added to the course structure, were evaluated as predictors of course performance.

The aggregate findings suggest that when the preparatory assignments were added to the course structure, students visited the textbook significantly more often but did not spend significantly more time reading overall. Additionally, with the preparatory assignments, students visited 10% more of assigned textbook pages. The significant increase in visits to the textbook was predominately spent on pages containing explanatory text – the content that was necessary if one wanted to perform well on the graded preparatory assignments. A more detailed analysis demonstrated that students did in fact spend more time using the assigned explanatory text pages in the days leading up to homework assignment deadlines. However, in weeks where exams were scheduled, and a preparatory assignment was not given in the treatment quarter, no significant increases in use occurred. These findings demonstrate the power of the preparatory assignments to encourage students to visit more of the important sections of the textbook while preparing for homework assignments throughout the term.

Investigations into the patterns of daily reading identified cramming periods prior to homework assignment deadlines and exams in both the control quarter and quarter with treatment. I hypothesized that the preparatory assignments would encourage students to visit the textbook earlier, relative to the homework assignment deadlines. The findings suggest that students used the explanatory text and worked examples pages earlier, with respect to homework assignment deadlines, when the preparatory assignments were added to the course structure. However, patterns in students' use of

homework problem pages did not change. These findings support the hypothesis for this research inquiry. What is encouraging is that the preparatory assignments did have a significant effect on students' study behaviors regarding the explanatory text, but that behavior change did not translate to viewing homework problem pages earlier. These findings are in line with a recent investigation of students' behavior regarding homework assignment completion (Rawson, Stahovich, & Mayer 2017).

I also investigated the impact of the preparatory assignments on students' course performance and hypothesized that in the quarter with preparatory assignments, students would demonstrate increased performance on quizzes, exams, and final course grade. The findings show that, while controlling for students' incoming prior knowledge, in the quarter with preparatory assignments, students performed significantly better on short-term performance (i.e., quizzes). However, there was no significant increase observed on long-term performance (i.e., exam grades nor overall final course grade. My hypothesis regarding this line of inquiry was partially supported by these findings.

The novel reading measure identifying when explanatory text reading activity occurred with respect to homework assignment deadlines was investigated as a moderator of the association between course structure and course performance. Correlational analyses revealed that the relationship between short-term course performance and this measure of study habits was positive and significant. That is, students who engaged with any content in the textbook earlier and more often, performed significantly better on the in-class quizzes administered throughout the term. However, these relationships were

stronger in the quarter without the preparatory assignments. Similar differential strengths of association were also observed between this measure of study habits and final exams as well as final course grades. A possible explanation for this finding is that in quarters without preparatory assignments students were not explicitly encouraged to read earlier and more often, however those students who displayed these study habits independently and had higher performance drove this strong positive relationship.

Further, I hypothesized that engagement in the activity of reading earlier and more often will promote a deeper understanding of the core concepts and moderate the effect of preparatory assignments on overall course performance. Therefore, moderation analyses were conducted using multiple regression to predict final course grade and a significant interaction was observed between preparatory treatment and the measure of how early students used the explanatory text. This interaction supports my hypothesis and demonstrates that the effect of preparatory assignments on final course grade was significantly moderated by this study behavior.

Limitations and Future Directions

These studies rely on an instrumented document viewing application to measure students use of course materials. It is possible that students could gain access to the course materials outside the document viewer, which would reduce the accuracy of measurement. For example, the textbook might be available to students outside of the instrumented software, via physical copy, downloaded pdf, etc. As a remedy, in the studies presented in this dissertation, all materials, including the textbook, were provided

to students free of charge. Additionally, survey questions administered to the students at the end of each term were designed to identify if students had access to, and viewed, the textbook outside of the provided document viewing application. An additional survey question was designed to inquire what percentage of the time students viewed the textbook material with the provided application as opposed to a secondary copy. Responses to these questions were used to exclude data from students who reported a high degree of usage outside of the instrumented software. In some cases, further checks were done to ensure the measured usage of the textbook was a complete picture of students' usage. For example, it is assumed that those students who viewed a majority of their homework assignment problems with the instrumented software also used it for most other interactions with the textbook. It is important to note that this issue is limited to the textbook material type only; all other materials were available exclusively from within the instrumented software.

The best possible solution to this limitation is to use a custom textbook. Several online course management systems contain a library of custom material that is often sold to students as content for a course [e.g., CourseSmart Analytics (https://www.vitalsource.com), LON-CAPA (Kashy et al., 1993), zyBooks (https://zybooks.zyante.com), etc.]. The benefit of this approach is that the material is not available elsewhere so that all usage can be measured. However, the information presented to instructors/researchers is often not as detailed, customizable, or even accessible with these types of systems. The custom instrumented software presented in this dissertation was designed to be compatible with any material available in electronic

pdf format, including commercially available electronic textbooks and custom content developed by the instructor, thus making it more universally compatible.

One of the brightest future directions of this work is real-time analytics that could drive, for example, automated feedback systems, instructor interventions, or dashboarding and visualization of study statistics for students. Currently, the ever growing body of educational data is being used almost exclusively by educational researchers. The findings surrounding student behaviors, course structures, assessment tools, etc., may not be effectively reaching those who could use it. With recent advancements of novel technologies being used in the classroom, there is an opportunity to not only collect useful quantitative information on student habits and behaviors, but also an opportunity to use that data to inform instructional decisions in real-time.

With a real-time analysis of students' usage of course materials, determinations could be made about the students engagement levels, study behaviors, etc. These determinations could be used to automatically identify students who are at risk of performing poorly or who are simply demonstrating poor study behaviors. In a time when student to teacher ratios are ever increasing, the need for automated feedback systems are increasing accordingly. Imagine an instructor being provided regular reports identifying students who may require extra guidance, or identifying content in the textbook that was re-visited often. These instructors would be able to use the aggregated information to inform their lecture decisions and student interactions. In addition to traditional educational settings, automated feedback should be an integral part of the recently

mounting massive online open course (MOOC) movement. There is a distinct difference between being presented novel material and studying it on your own versus with feedback. MOOCs have a unique opportunity to provide feedback to a student body that could benefit greatly from it while increasing the efficacy of online open course environments.

Instructors are not the only ones who can benefit from real-time analyses of student data. The students themselves, assuming they want to learn the material and perform well in school, can potentially benefit from aggregate data on their own behaviors. If students were able to receive similar reports identifying where their study behaviors rank with regards to a standard or the class average, they might be more aware of their behaviors. Further, they could be better able to identify deficiencies in their study skills, which may encourage changes in study behaviors or inform their decision to seek help. As such, a potential area for future work is simply presenting a student's own study statistics to them in a simple useful manner. For example, data can be analyzed in real-time and used to update a dashboard presenting statistics, and any changes in student study habits, directly to the student themselves.

Conclusions

The work presented in this dissertation provides examples of how a technology-enhanced data collection approach to educational data can be a means of objectively collecting detailed information on student study habits and behaviors. The work highlights the importance of not only how much time is spent in study, but also what

types of content are being used and when they are used. This work begins to identify the

types of detailed information required to gain a better understanding of what makes a

student successful. The study habits and behaviors investigated in this dissertation can

inform future decisions regarding content delivery, course structure, and instructional

design.

References

Azevedo, R. (2005). Using Hypermedia as a Metacognitive Tool for Enhancing Student Learning? The Role of Self-Regulated Learning. *Educational Psychologist*, *40*(4), 199–209. https://doi.org/10.1207/s15326985ep4004_2

Azevedo, R. (2007). Understanding the Complex Nature of Self-regulatory Processes in Learning with Computer-based Learning Environments: An Introduction. *Metacognition and Learning*, *2*(2–3), 57–65. https://doi.org/10.1007/s11409-007-9018-5

Bash, K. L., & Kreiner, D. S. (2014). Student Perceptions of Study Time. *Psi Chi Journal of Psychological Research*, *19*(1), 3–9.

Bishop, J. L., & Verleger, M. A. (2013). The Flipped Classroom: A Survey of the Research. *In ASEE National Conference Proceedings, Atlanta, GA* (Vol. 30, No. 9, pp. 1-18).

Bloom, B. S. (1976). Human Characteristics and School Learning. New York: McGraw-Hill.

Carroll, J. B. (1963). A model of school learning. Teachers College Record, 64(8), 723-733.

Dobson, J. L. (2008). The use of formative online quizzes to enhance class preparation and scores on summative exams. *Advances in Physiology Education*, *32*(4), 297–302. https://doi.org/10.1152/advan.90162.2008

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving Students' Learning with Effective Learning Techniques Promising Directions from Cognitive and Educational Psychology. *Psychological Science in the Public Interest*, *14*(1), 4–58. https://doi.org/10.1177/1529100612453266

Ebbinghaus, H. (1885/1964). *Memory*. New York: Dover.

Eddy, S. L., & Hogan, K. A. (2014). Getting Under the Hood: How and for Whom Does Increasing Course Structure Work? *CBE-Life Sciences Education*, *13*(3), 453–468. https://doi.org/10.1187/cbe.14-03-0050

Fiorella, L., & Mayer, R. E. (2015). Learning as a Generative Activity. New York: Cambridge University Press.

Fouh, E., Breakiron, D. A., Hamouda, S., Farghally, M. F., & Shaffer, C. A. (2014). Exploring students learning behavior with an interactive etextbook in computer

science courses. *Computers in Human Behavior*, *41*, 478–485. https://doi.org/10.1016/j.chb.2014.09.061

Gates, A. I. (1922). Recitation as a Factor in Memorizing (No. 40). Science Press.

Glover, J. A. (1989). The "Testing" Phenomenon: Not Gone but Nearly Forgotten. *Journal of Educational Psychology*, *81*(3), 392-399.

Guzdial, M. (1994). Software-Realized Scaffolding to Facilitate Programming for Science Learning. *Interactive Learning Environments*, *4*(1), 001-044. https://doi.org/10.1080/1049482940040101

Junco, R., & Clem, C. (2015). Predicting course outcomes with digital textbook usage data. *The Internet and Higher Education*, *27*, 54–63. https://doi.org/10.1016/j.iheduc.2015.06.001

Karpicke, J. D., & Aue, W. R. (2015). The Testing Effect is Alive and Well with Complex Materials. *Educational Psychology Review, 27,* 317-326.

Karweit, N. (1982). *Time on Task: A Research Review. Report No. 332*. Retrieved from https://eric.ed.gov/?id=ED228236

Karweit, N. (1984). Time-on-Task Reconsidered: Synthesis of Research on Time and Learning. *Educational Leadership*, 41(8), 32.

Koriat, A. (1997). Monitoring One's Own Knowledge During Study : A Cue-utilization Approach to Judgments of Learning. *Journal of Experimental Psychology. General*, *126*(4), 349–370.

Kornell, N., & Son, L. K. (2009). Learners' Choices and Beliefs about Self-testing. *Memory*, *17*(5), 493–501. https://doi.org/10.1080/09658210902832915

Kortemeyer, G., Kashy, E., Benenson, W., & Bauer, W. (2008). Experiences using the open-source learning content management and assessment system LON-CAPA in introductory physics courses. *American Journal of Physics*, *76*(4), 438–444. https://doi.org/10.1119/1.2835046

Kuncel, N. R., Credé, M., & Thomas, L. L. (2005). The Validity of Self-Reported Grade Point Averages, Class Ranks, and Test Scores: A Meta-Analysis and Review of the Literature. *Review of Educational Research*, *75*(1), 63–82. https://doi.org/10.3102/00346543075001063

Laverty, J. T., Bauer, W., Kortemeyer, G., & Westfall, G. (2012). Want to Reduce Guessing and Cheating While Making Students Happier? Give More Exams! *The Physics Teacher*, *50*(9), 540–543. https://doi.org/10.1119/1.4767487

Macfadyen, L. P., & Dawson, S. (2010). Mining LMS Data to Develop an "Early Warning System" for Educators: A Proof of Concept. *Computers & Education*, *54*(2), 588–599. https://doi.org/10.1016/j.compedu.2009.09.008

Masui. (2014). Do Diligent Students Perform Better? Complex Relations Between Student and Course Characteristics, Study Time, and Academic Performance in Higher Education. *Studies in Higher Education*, *39*(4), 621–643. https://doi.org/10.1080/03075079.2012.721350

Mayer, R. E., Stull, A. T., Campbell, J., Almeroth, K., Bimber, B., Chun, D., & Knight, A. (2007). Overestimation Bias in Self-reported SAT Scores. *Educational Psychology Review*, *19*(4), 443–454. https://doi.org/10.1007/s10648-006-9034-z

McDaniel, M. A., Wildman, K. M., & Anderson, J. L. (2012). Using Quizzes to Enhance Summative-assessment Performance in a Web-based Class: An Experimental Study. *Journal of Applied Research in Memory and Cognition*, 1(1), 18-26.

Phillips, B. J., & Phillips, F. (2007). Sink or Skim: Textbook Reading Behaviors of Introductory Accounting Students. *Issues in Accounting Education*, *22*(1), 21–44. https://doi.org/10.2308/iace.2007.22.1.21

Pilegard, C., & Mayer, R. E. (2015). Adding Judgments of Understanding to the Metacognitive Toolbox. *Learning and Individual Differences*, *41*, 62–72. https://doi.org/10.1016/j.lindif.2015.07.002

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*, *93*(3), 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Puntambekar, S., & Hubscher, R. (2005). Tools for Scaffolding Students in a Complex Learning Environment: What Have We Gained and What Have We Missed? *Educational Psychologist*, *40*(1), 1–12. https://doi.org/10.1207/s15326985ep4001_1

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A Scaffolding Design Framework for Software to Support Science Inquiry. *Journal of the Learning Sciences*, *13*(3), 337–386. https://doi.org/10.1207/s15327809jls1303_4

Rawson, K., Stahovich, T. F., & Mayer, R. E. (2017). Homework and achievement: Using Smartpen Technology to Find the Connection. *Journal of Educational Psychology.* http://dx.doi.org/10.1037/edu0000130

Rhodes, M. G., & Tauber, S. K. (2011). The Influence of Delaying Judgments of Learning on Metacognitive Accuracy: A Meta-Analytic Review. *Psychological Bulletin*, *137*(1), 131–148.

Roediger, H. L., & Karpicke, J. D. (2006). The Power of Testing Memory: Basic Research and Implications for Educational Practice. *Perspectives on Psychological Science*, *1*(3), 181–210. https://doi.org/10.1111/j.1745-6916.2006.00012.x

Romero, C., & Ventura, S. (2010). Educational Data Mining: A Review of the State of the Art. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, *40*(6), 601–618. https://doi.org/10.1109/TSMCC.2010.2053532

Runquist, W. N. (1983). Some Effects of remembering on forgetting. *Memory & Cognition*, *11*(6), 641–650. https://doi.org/10.3758/BF03198289

Schraw, G., & Dennison, R. S. (1994). Assessing Metacognitive Awareness. *Contemporary Educational Psychology*, *19*(4), 460–475. https://doi.org/10.1006/ceps.1994.1033

Schraw, G. (2010). Measuring Self-Regulation in Computer-Based Learning Environments. *Educational Psychologist*, *45*(4), 258–266. https://doi.org/10.1080/00461520.2010.515936

Schuman, H., Walsh, E., Olson, C., & Etheridge, B. (1985). Effort and Reward: The Assumption That College Grades are Affected by Quantity of Study. *Social Forces*, *63*(4), 945–966. https://doi.org/10.2307/2578600

Seaton, D. T., Kortemeyer, G., Bergner, Y., Rayyan, S., & Pritchard, D. E. (2014). Analyzing the impact of course structure on electronic textbook use in blended introductory physics courses. *American Journal of Physics*, *82*(12), 1186–1197. https://doi.org/10.1119/1.4901189

Son, L. K., & Metcalfe, J. (2000). Metacognitive and control strategies in study-time allocation. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *26*(1), 204–221. https://doi.org/10.1037//0278-7393.26.1.204

van Gog, T. (2013). Time on task. In J. Hattie & E. M. Anderman (Eds.), *International guide to student achievement* (pp. 432–433). New York: Routledge.

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Harvard university press.

Wang, M. C., Haertel, G. D., & Walberg, H. J. (1990). What Influences Learning? A Content Analysis of Review Literature. *The Journal of Educational Research*, *84*(1), 30–43. https://doi.org/10.1080/00220671.1990.10885988

Wang, A., & H. Newlin, M. (2000). *Characteristics of students who enroll and succeed in psychology Web-based classes* (Vol. 92). https://doi.org/10.1037/0022-0663.92.1.137

Wood, D., Bruner, J. S., & Ross, G. (1976). The Role of Tutoring in Problem Solving*. *Journal of Child Psychology and Psychiatry*, *17*(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Young, A., & Fry, J. D. (2008). Metacognitive Awareness and Academic Achievement in College Students. *Journal of the Scholarship of Teaching and Learning*, *8*(2), 1–10.