DELIVERING PRE-CLASS ACTIVITIES VIA WEBWORK TO IMPACT STUDENT LEARNING

Abstract: This paper documents the results of a quantitative and qualitative study to determine the effects on direct and indirect measures of student learning of pre-class online homework in Calculus I courses in a small liberal arts university in the Midwest United States. No differences were noted in course grades for students in the online condition compared to the pencil-and-paper control; however, statistically significant gains were noticed for students in the treatment their perception of "meaningful feedback" ($t(121) = -2.40$, $p = .018$) and "amount of homework" ($t(121) = 2.84$, $p = .006$). The research was funded by IDEA's 2017 Impact Grants program.

Keywords: active learning, web-based learning, calculus

1 INTRODUCTION

The educational landscape is changing as higher education seeks to harness innovative pedagogies, educational research, and technological developments to improve student learning. Active learning is a proven pedagogy in mathematics that continues to receive attention from instructors and researchers [FEM+14]. One challenge to meaningful in-class active learning tasks is that it assumes students have a basic level of familiarity with the content prior to class. To counteract this challenge, many active learning courses have a 'flipped' component in which students first encounter new content prior to the class meeting. Often the pre-class contact for the student is passive in the form of a video or reading. In this work, we combine the pedagogy of active learning with technology to ask, "Do structured pre-class activities delivered via the web in a first calculus course result in improvement in both direct and indirect measures of student learning?"

2 BACKGROUND

In this section, we introduce the two strands which, when woven together, form the basis for our line of inquiry.

2.1 ACTIVE LEARNING

Active learning is a buzz word in educational circles and is increasingly advocated by educational researchers [EJ16, LS16]. "Active learning" is defined as a pedagogy that "engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work" [FEM+14]. The positive impact of active learning in STEM classrooms is the focus of a recent study published in the Proceedings of the National Academy of Sciences [FEM+14]. This meta-analysis of 225 studies on the effectiveness of active learning found that students in lecture-based classes were 1.5 times more likely to fail as those in active learning classes. However, the higher-order active learning tasks undertaken during a class meeting need to be supported by work done before the class meeting.

2.2 WEB-BASED HOMEWORK

Over the past 10-15 years, a growing movement in first-year mathematics courses has replaced traditional pencil-and-paper homework with homework delivered via web-based software. The type of homework assigned in such courses (e.g., calculus, pre-calculus, college algebra) generally results in an answer which is numerical or a mathematical function, the correctness of which can be determined by software. These web-based assignments usually replace the role of pencil-and-paper homework and are intended to assess student learning of content which has already been covered in class. WeBWorK is an example of an online homework system which is used by over 1300 high schools, colleges and universities worldwide [MAA]. Developed by the University of Rochester, the WeBWorK Open Problem Library (OPL) is freely available and is textbook-independent. Currently, the OPL contains over 35,000 problems from a wide range of mathematical and scientific subjects.

A natural question is whether web-based homework is as effective as the traditional pencil-and-paper model. A study of web-based homework which implemented WeBWorK in Calculus II courses suggested that the systems do no harm and may improve final exam scores [LaR10]. Another encouraging finding was a 10-15% increase in the pass rates in freshman math courses when WeBWorK was implemented along with other STEM initiatives at one historically black college/university [PDT10]. It should be noted that while much of the research regarding online homework has been positive, there have also been negative findings including Carpenter and Camp's finding that better-prepared students who used WeBWorK had lower course grades than students in the control setting [CC08].

In an effort to bring these two strands of inquiry together, we wish to study the impact of pre-class activities delivered via WeBWorK in an active learning-focused classroom. Typical pre-class work, especially in mathematics courses, seeks to solidify recent content gains and activate the prior knowledge necessary for new work. In traditional pencil-and-paper activities, students will generally not know if they have completed the problems correctly, and so we seek to determine the effects of delivering pre-class activities via an open-source online homework system that gives immediate feedback to most student responses.

2.3 SIGNIFICANCE OF THE STUDY

It is our belief that the formative feedback students will obtain from completing the pre-class activities delivered through WeBWorK will significantly enhance student understanding and consequently improve both direct and indirect measures of student learning. The next section will explore the methods implemented in this research.

3 METHODS

This study is a quasi-experimental, ex post facto, comparison study of the direct and indirect measures of student learning when structured, online, pre-class activities are administered in Calculus I. The research was set at Dordt University, a small, faith-based, liberal arts university in the Midwest. Students who enrolled in this course represented a variety of majors including mathematics, engineering, and actuarial science. The Mathematics and Statistics Department faculty teach a typical, early transcendentals Calculus I course which is four-credit hours. The department strives to use research-based pedagogy and as a result has made multiple adjustments to the course including adopting active learning and specifications-based (mastery) grading. The class uses mastery exams consisting of problems that assess clear learning targets (see Appendix for an example); these exams remained stable across both the control and treatment groups. It is in this setting that we arrived at the research question, "Do structured pre-class activities delivered via the web in a first calculus course result in improvement in both direct and indirect measures of student learning?"

3.1 SAMPLE

The sample for this study was all students who completed the first-semester calculus course at Dordt University during the Fall 2017 through Fall 2018. This included 153 students with 27 females (17.6%) and 126 males (82.4%). The student majors represented in the course included engineering (35.3%), business administration (19.3%), computer science (7.4%) and mathematics (4.6%). To maintain consistency, the same experienced faculty member taught all students. For direct measures, the sample was all students who completed Calculus I. Final course grades were obtained for all students. Not all students completed the IDEA Student Response to Instruction (SRI) which was used for indirect measures of student learning, producing a 79.1% response rate for the study, or 121 students in the sample.

3.2 INSTRUMENTATION

Both direct and indirect measures of student learning were gathered to examine differences between pre-class online homework for Calculus students compared to pre-class pencil-and-paper homework.

3.2.1 Direct Measure

End of course grades were used as the direct measure of student learning. Dordt University uses a plus and minus four-point scale with no A+. The researchers transformed letter grades to equivalent numbers. For example, a B+ was translated to a 3.333 and a B- translated to a 2.667. The researchers hypothesized that students in the treatment condition receiving the online pre-class homework would have higher end-of-course grades.

3.2.2 Indirect Measures

The instrument employed to assess indirect measures of student learning, the IDEA Student Response to Instruction (SRI), has demonstrated validity and reliability [BCK, BC14]. All IDEA SRIs were administered online. The university's high averages response rate of 90% made it a good choice for indirect measures of student learning.

The four items on the end-of-semester IDEA SRI in Table 1 were selected to examine indirect measures of student learning.

The researchers hypothesized that students in the treatment course would be: more likely to say that they received meaningful feedback (given WeBWorK's immediate feedback); more likely to say that they have made significant progress in a basic understanding of the subject (given that misconceptions on foundational content are corrected immediately by WeBWorK); less likely to say that the subject is difficult (given our hypothesis that the online pre-class activities will better prepare them for the in-class work); less likely to say that there is a large amount of coursework (due to a what we hope to be a clearer understanding of foundational course content).

3.3 TREATMENT

The control course was a typical Calculus I course (early transcendentals) using a combination of a traditional calculus text [Ste15] and a text geared to support active learning [BAS17]. Students were tasked with completing pre-class activities on paper and were graded solely on completion. In-class work was driven by the activities in *Active Calculus* [BAS17] and major assessments (exams) were graded based on student mastery of learning targets (see Appendix).

The treatment course was an early transcendentals Calculus I course using only *Active Calculus*. The same professor taught both the con-

Item	**Response scale**
The instructor provided meaningful feedback on students' academic performance	Integer from 1 to 5, with 1 meaning "Hardly ever" and 5 meaning "Almost always"
Describe your progress on gaining a basic understanding of the subject (e.g., factual knowledge, methods, principles, generalizations, theories)	Integer from 1 to 5, with 1 meaning "No apparent progress" and 5 meaning "Exceptional progress"
Difficulty of subject matter	Integer from 1 to 5, with 1 meaning "Much less than most courses" and 5 meaning "Much more than most courses"
Amount of coursework	Integer from 1 to 5, with 1 meaning "Much less than most courses" and 5 meaning "Much more than most courses"

Table 1. The four IDEA SRI items under analysis.

trol and treatment courses. Similar to the control class, students were assigned pre-class activities graded on effort and completeness. In the treatment class, the preview activities were online adaptations of the paper-based preview activities from *Active Calculus* and administered via WeBWorK. Students were given unlimited attempts to answer the questions correctly, and so could change their answers based on the immediate feedback provided by WeBWorK. Again, in-class work was driven by the activities in *Active Calculus*, and major assessments were graded based on student mastery of learning targets.

3.4 DATA COLLECTION AND ANALYSIS

End of term grades were collected from the Institutional Research Office of Dordt University. The IDEA SRI was administered to the students online during the last two weeks of the semester. Robust data analysis procedures were used throughout this research which combined both direct and indirect measures of student learning. An exploratory significance level of 0.05 was used with two-sided tests for all analyses. SPSS was used for data analysis along with a software application called G*Power to calculate power [FEBL09]. Prior to analysis the data was screened for outliers. All observations were within the three standard deviation threshold set to remove univariate outliers.

For each statistical evaluation the independent variable was each students' treatment condition: control (pencil-and-paper, pre-class homework) or treatment (WeBWorK's pre-class homework). The dependent variable for each test was the measure of direct or indirect student learning under evaluation. Each measure of direct or indirect student learning used a t-test to assess if differences in student learning existed between the groups.

4 RESULTS

4.1 DIRECT MEASURE

End of course grades were used as the direct measure of student learning. An end of course grade was obtained for all 155 students enrolled in the course over the study. The average grade for all students in the study was 3.23 with a standard deviation of 1.14. Table 2 shares descriptive statistics by treatment condition as well as the average Math ACT score for each class which demonstrates a similar academic profile.

	N	M_G	SD_G	M_A	SD_A
Control	92	3.21	1.22	26.44	3.39
Treatment	61	3.28	1.02	26.03	4.49

Table 2. End of course grades and Math ACT score by treatment group. Note that M_G and SD_G represent mean and standard deviation for course grade, while M_A and SD_A represent the mean and standard deviation for the math ACT score.

An independent samples t-test was used to assess statistical significance of the final course grade by treatment group. No statistically significant difference was found between the control and treatment group. A post hoc examination of power indicated adequate power ($d = .5$, $1 - \beta = .85$, $NC = 92$, $NT = 61$) to detect medium effects for the t-test [FEBL09].

4.2 INDIRECT MEASURES

The IDEA SRI was used to obtain four indirect measures of student learning in this research. The courses under examination had 155 students enrolled, of which 79.1% completed the SRI giving a sample of 121

	Control ($n = 92$)	Treatment ($n = 61$)	t value	Probability
Course grade	3.21	3.28	0.438	0.662

Table 3. Mean course grade by treatment group

students. A post hoc examination of power indicated adequate power ($d = .5$, $1 - \beta = .77$, $NC = 69$, $NT = 52$) to detect medium effects for the t test [FEBL09]. The section will examine four responses on the SRI: meaningful feedback, basic understanding of the subject, difficulty of subject matter, and amount of coursework.

4.2.1 Meaningful Feedback

An encouraging finding in this research was student responses to the statement "The instructor provided meaningful feedback on the students' academic performance" as seen in Table 4.

	N	M	SD
Control	69	3.81	1.13
Treatment	52	4.28	1.04

Table 4. Response to *Meaningful Feedback* item by treatment group

The difference between students in the control and those in the treatment who received pre-class, online homework was statistically significant ($t(121) = -2.40$, $p = 0.18$) as seen in Table 5.

	Control ($n = 69$)	Treatment ($n = 52$)	t value	Probability
Meaningful Feedback	3.81	4.28	-2.40	0.018*

Table 5. *Meaningful Feedback* by treatment group.

* denotes significance at 0.05.

4.2.2 Basic Understanding of the Subject

Student responses to the statement "Describe your progress on gaining a basic understanding of the subject (e.g., factual knowledge, methods, principles, generalizations, theories)" were also analyzed as seen in Table 6.

	N	M	SD
Control	69	4.09	0.90
Treatment	52	3.96	0.78

Table 6. Response to *Basic Understanding* item by treatment group

The difference between students in the control and the treatment condition who received pre-class, online homework was not statistically significant as seen in Table 7.

4.2.3 Difficulty of Subject Matter

Student perceptions of the difficulty of the subject matter was also analyzed. Student response to the statement "Difficulty of subject matter" with responses ranging from 1: "Much less than most courses" to 5:

	Control ($n = 69$)	Treatment ($n = 52$)	t value	Probability
Basic Understanding	4.09	3.96	0.81	0.42

Table 7. *Basic Understanding* by treatment group.

"Much more than most courses" were analyzed as shown in Table 8.

	N	M	SD
Control	69	3.49	0.89
Treatment	52	3.44	0.96

Table 8. Response to *Difficulty* item by treatment group

The difference between students in the control who used pencil-and-paper, pre-class homework and students in the treatment who used on-line, pre-class homework was not statistically significant. The results are shared in Table 9

	Control ($n = 69$)	Treatment ($n = 52$)	t value	Probability
Difficulty of Subject Matter	3.49	3.44	0.30	0.77

Table 9. *Difficulty* by treatment group.

4.2.4 Amount of Coursework

An encouraging finding was the student response to the item comparing the amount of coursework in the class to other classes as seen in Table 10. It should be noted that the actual amount of coursework was essentially the same.

	N	M	SD
Control	69	3.33	0.60
Treatment	52	2.96	0.78

Table 10. Response to *Amount of Coursework* item by treatment group

A statistically significant difference was noted demonstrating a decrease in the perceived amount of coursework for students who received the pre-class online homework as shown in Table 11.

	Control ($n = 69$)	Treatment ($n = 52$)	t value	Probability
Amount of Coursework	3.33	2.96	2.84	0.006*

Table 11. *Amount of Coursework* by treatment group.

* denotes significance at 0.05.

4.3 QUALITATIVE FEEDBACK

Written responses to items on the IDEA SRI were also examined yielding two relevant responses to the prompt "Which course assignments, activities, and/or teaching methods were most helpful for your learning?" One student simply identified "the online assignments" as an assignment that was helpful for learning, while another elaborated that the online assignments were helpful because "they made you think about the content and prepared you [for] the next class: the concepts didn't seem as new or scary."

The professor of the control and treatment classes was also asked for her perceptions of the differences between the online and pencil-and-paper classes. She noted two items to consider. The first was her perception that students were more likely to complete the pencil-and-paper pre-class homework to avoid the physical accountability in class of not having a paper to turn in. She also noted that the learning curve for students to be proficient with the WeBWoRK's platform was fairly steep and required both her students and herself to spend time mastering the technology to complete the homework.

5 DISCUSSION

This research provides compelling evidence of improved outcomes for indirect measures. While direct measures showed no statistically significant differences, the indirect measures demonstrated an improved experience for students in Calculus I courses. The perception of more meaningful instructor feedback and a decrease in the amount of necessary coursework are powerful indicators of an improved student experience. They are also a part of the narrative that surrounds a course and is communicated to classmates who consider taking the course.

While the focus of this project is on a Calculus I course, it is anticipated that these positive results could be expanded to other mathematics and STEM classes for follow-up research. Active learning pedagogies have been successfully implemented in a variety of courses including physics, statistics, and engineering. The use of structured, pre-class activities have the potential to be an important pedagogical tool for instructors across the sciences.

5.1 LIMITATIONS

While we are pleased with the significant results we obtained, there are several limitations and opportunities for future work. One limitation is in the use of mastery grading. Anecdotally, mastery grading often inflates grades beyond those attained in a traditional points-based system (e.g., a student who would likely earn a B in a points-based system may use the additional opportunities afforded for mastery in a mastery-based system to earn some form of A). It may be that the differences in the direct measures of course grades would have been larger in a traditional grading system.

Another limitation is the small sample size for two groups. We had anticipated completing a similar study for students in linear algebra classes; however, the sample size was not large enough to give adequate power. Similarly, we had desired analyzing results for specific demographics including minorities and females; however, the sample sizes were too small to give adequate power.

5.2 AVENUES FOR FUTURE WORK

A final limitation (and a first opportunity for future work) is that this course was taken by primarily first-year students. To get a fuller picture of the impact of delivering pre-class activities via an online homework system, replication studies should be done. While we anticipated completing a similar study for a second-year linear algebra course, small sample sizes prohibited us from drawing any conclusions. Thus, further investigations into the efficacy of administering pre-class work via online homework systems should be undertaken, both at the first-year (calculus) level and beyond. Ideally, replication would also take place in other STEM courses. One goal of replication studies would also be to increase the sample size allowing for analyses by specific demographics, particularly females and minority students.

5.3 FUNDING STATEMENT

This research was partially funded by an IDEA Impact Grant to "positively impact teaching and learning and student well-being"[1].

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APPENDIX A: SAMPLE LEARNING TARGETS

The course discussed in this work had major assessments that used mastery-based testing (see [BCHH+19]). Students were given a list of clear learning targets, such as:

1. Use a tangent line approximation to estimate the value of a function at a given point.
2. Find the critical numbers of a function.
3. Solve a related rates problem.
4. Use the fundamental theorem of calculus to evaluate definite integrals.
5. Use substitution to evaluate an indefinite integral.

Students who did not demonstrate mastery the first time a learning target was available received multiple subsequent opportunities to demonstrate mastery, with their best eventual performance counting toward their final grade.

APPENDIX B: PREVIEW ACTIVITY FROM ACTIVE CALCULUS

Below, see a sample Preview Activity from Active Calculus, both in pencil-and-paper (Fig. 1) and WeBWorK (Fig. 2) forms. Note that in the online homework system, questions are frequently modified from the textbook to require multiple choice or numerical answers which can be graded by the computer.

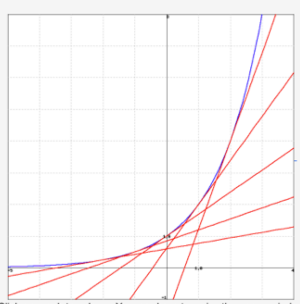
Preview Activity 2.2.1. Consider the function $g(x) = 2^x$, which is graphed in Figure 2.2.1.

a. At each of $x = -2, -1, 0, 1, 2$, use a straightedge to sketch an accurate tangent line to $y = g(x)$.

b. Use the provided grid to estimate the slope of the tangent line you drew at each point in (a).

Figure 1. A pencil-and-paper *Active Calculus* preview activity.

Consider the function $g(x) = 2^x$, which is graphed below, along with the tangent lines to the graph at $x = -2, -1, 0, 1, 2$.



(Click on graph to enlarge. You may have to resize the popup window.)

Use the provided grid to estimate the slope of each tangent line. Your estimates need to be within 10% of the correct answer.

$g'(-2) =$

$g'(-1) =$

$g'(0) =$

$g'(1) =$

$g'(2) =$

Figure 2. The same preview activity implemented in WeBWorK.

BIOGRAPHICAL SKETCHES

Dr. Mike Janssen is an associate professor of mathematics at Dordt University. He is a member of the Gold '14 Project NExT cohort. His research interests lie at the intersection of commutative algebra, algebraic geometry, and discrete mathematics, and he has enjoyed sharing those interests with undergraduate students. He is also interested in the use of mastery grading in the undergraduate mathematics classroom, and enjoys exploring games and puzzles with students.

Dr. Valorie Zonnefeld is an associate professor of mathematics at Dordt University. She is the principal investigator on a National Science Foundation Grant to increase the number of STEM teachers and recipient of Dordt University's 2015 Teaching Excellence Award. Her research interests include educational psychology, STEM outreach and the pedagogy of teaching mathematics from the kindergarten through undergraduate levels. She loves interacting with students of all ages and helping them see a career in mathematics as a possibility.