Undergraduate Review

Volume 15

Article 13

2020

# Comparing the Overall Effectiveness of Pre- Laboratory Data Activities and Scaffolded Laboratory Procedures in Calculus-Based Physics I

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**Abstract**

Laboratory courses expose students to the important skills of thinking and working scientifically; this may mean looking for correlational variables, testing a hypothesis, or confirming a theory. In the Calculus-Based Physics I course at Bridgewater State University, students are introduced to the idea of using an experimental setup to confirm fundamental physical principles studied in class. Students often struggle to master this idea of making a connection between theory and experiment, so we tested two different methods of improving the laboratory experience: pre-laboratory data activities and scaffolded laboratory procedures. By tracking student progress through laboratory journals and conceptual tests, normalizing grades recorded for different groups, and calculating the gains made in each semester involved in the project, we can begin to see the effect of these different curriculum designs. Results of this project support methods which emphasize laboratory process over course content: semesters where pre-laboratory data activities were used showed a negligible laboratory gain of +0.0625, while the semester where scaffolded laboratory procedures were used showed a high positive gain of +3.69. These findings will be used during curriculum development of future Calculus-Based Physics I semesters to provide students with more opportunities for growth.

**Introduction**

The most important discoveries in physics have been models which expand our understanding while containing what we already know as a foundation, accomplished with the collective minds of great theorists and experimentalists. The connection between theory and experiment is an important theme for students beginning scientific careers to understand; it is the distinction between solving textbook problems with memorized formula and becoming deep, scientific thinkers. Physics education research allows us to work towards creating stronger curricula which emphasize this.

This project serves as a small-scale physics education research project, targeting students' ability to compare physical theory to experiment. It began as a way of addressing Calculus-Based Physics I students' confusion about what to do with data taken during a lab; or, how to connect experimental data to an established theory. We decided to reorganize the course curriculum in place through two different methods, tested separately. First, in the Fall 2018 and Spring 2019 semesters, we implemented pre-laboratory data activities which asked students to analyze sample data in worksheet problems before performing the formal laboratories which have always been present in the course. Second, in the Summer 2019 session, we rewrote the preexisting laboratory procedures so they were scaffolded and focused on laboratory journal organization; scaffolding in an educational setting refers to a curriculum organization where instruction is gradually removed to guide students towards understanding and independence (3). These two methods were compared to the previous structure of the course, and we were looking to see any significant increase in student performance and growth.

Current research into physics laboratory curricula proposes a change in preconceived thought: that physics labs done by students should primarily emphasize scientific thinking and processes rather than content taught in class (2). In a 2018 study done by physics educators Natasha Holmes and Carl Wieman, they found "the only thinking the students said they did in structured and content-focused labs was in analyzing the data and checking whether it was feasible to finish the lab in time" (2). Laboratories designed to reinforce class content are often too formulaic and "cookbook" in style to allow students to learn processes on their own. The pre-laboratory data activities given during the Fall 2018 and Spring 2019 semesters fell more into the category of content-based laboratory curriculum and did not produce the desirable outcomes we were aiming for; the scaffolded laboratory procedures from the Summer 2019 session, however, emphasized more of the laboratory process with more desirable outcomes. This means less confusion from students about comparing theory to experiment and increased student performance.

Data analysis from the project thus far confirms Holmes and Weiman's research and indicates that the scaffolded laboratory procedures produce better results in the Calculus-Based Physics I class. Because only one class was given the scaffolded procedures, we will be collecting additional data this Fall 2019 semester to see if the same results are seen. Confirmation of the positive impact of scaffolded procedures and therefore process-based laboratory curricula will inform future decisions about Calculus-Based Physics I course organization at Bridgewater State University.

**Methods**

We determined that the assignments which would be most indicative of student performance and growth were the first and final laboratory journals completed by students and the pre- and post- Force Concept Inventory (FCI) tests. Each semester of Calculus-Based Physics I begins with students taking the FCI test, a nationally-normed exam focused on conceptual physics (1). This test allows us to evaluate students' baseline physics knowledge and does not affect their grade in the class. Over the course of the semester, students complete three formal laboratories, each of which requiring them to keep a laboratory journal. The semester ends with students taking the same FCI test they took at the beginning of the year to again test their knowledge.

Because this project spans multiple semesters and involves sections of Calculus-Based Physics I taught by different professors, we needed to normalize the laboratory journal grades recorded before analyzing data; the FCI test scores did not need to be normalized as it is a standardized test given under the same conditions each semester. Normalization is a process which works to remove the effects of differing conditions (6). First, each semester is looked at separately; students within each semester are given a z-score. This serves as an indicator of relative performance based on the standard deviation of the group and is found by using $z = \frac{x - m}{SD}$, where z represents the z-score, $x$ represents the individual student's score on a given assignment, and $m$ and $SD$ represents the group mean and standard deviation for the assignment (6).

Once each student within each semester has a z-score assigned to them, we can begin to look at the entire group, or all students involved in the project over the various semesters. Using the z-scores, we can apply the students of each semester to a common platform on which to compare everyone evenly and calculate a T-score ($T$) for each student. A T-score represents the normalized, recalculated score on the given assignment on the common platform for each individual and is equal to $T = m_t + SD_t z$, where $m_t$ and $SD_t$ represent the target mean and target standard deviation respectively (6). The target mean and target standard deviation establish the common platform; for this project, we chose these values to be the average of all the semesters' means and standard deviations on a given assignment to create a fair, realistic platform on which to compare. This process of calculating z- and T-scores was done for each assignment we examined: this includes pre-assessments and post-assessments.

Using the normalized scores, we wanted to quantify student growth. Student growth can be measured by calculating either average normalized gain or the average of gains (4). Average normalized gain is a measurement of the relative growth or improvement a group of students on average and is defined as $\langle g \rangle_{NG} = \frac{\langle T_{post} \rangle - \langle T_{pre} \rangle}{100 - \langle T_{pre} \rangle}$ , where brackets indicate average values of the T-scores on post- or pre-assessments. Similar to average normalized gain, the average of gains also measures relative performance, but does so for each individual student before taking the average of the final result. It is found by calculating $\langle g \rangle_{AG} = \left\langle \frac{T_{post} - T_{pre}}{100 - T_{pre}} \right\rangle$ , where the different placement of the brackets indicate that an average is not taken until each student's individual gain is found (4). The average of gains is helpful as it can be used to see individual student growth as well as whole class growth, while normalized gain is helpful when post- and pre- assessments cannot be matched to one student.

To calculate the growth between pre- and post- FCI tests for each semester of this project, we used the average normalized gain ($\langle g \rangle_{NG}$), as some students did not provide names on their tests or were absent for either the pre- or post- test. For calculating the growth between first and third laboratory journals, we used the average of gains ($\langle g \rangle_{AG}$) to only consider students who completed the course. This data allows us to see the growth of students in course material in general as well as growth of students in laboratories: we first looked at laboratory growth, which encompassed the targeted skill, and then checked if there was a connection between laboratory growth and conceptual growth in course material as indicated from the FCI tests.

**Results**

**Table 1** outlines the gains made by each individual semester involved in the project.

| | Fall 2016 | Fall 2017 | Fall 2018 | Spring 2019 | Summer 2019 |
|---|---|---|---|---|---|
| FCI Gains ($\langle g \rangle_{NG}$) | N/A | N/A | +0.309 | +0.0957 | +0.374 |
| Lab Gains ($\langle g \rangle_{AG}$) | -0.290 | -0.316 | -0.428 | +0.553 | +3.69 |

*Table 1: Summary of statistics for individual semesters.*

FCI Gains are calculated using the average normalized gain and indicate growth made by students on the conceptual course content introduced in class. Lab Gains are calculated using the average of gains and indicate growth on laboratory assignments; this corresponds to student growth on the targeted skill of comparing theory to experiment. We can also look at the three separate groups, the control group, the pre-laboratory data activities group, and the scaffolded procedures group, to further analyze the data (see Table 2):

**Table 2**

| | Control | Pre-Laboratory Data Activities | Scaffolded Procedures |
|---|---|---|---|
| FCI Gains ($\langle g \rangle_{NG}$) | N/A[1] | +0.202 | +0.374 |
| Lab Gains ($\langle g \rangle_{AG}$) | -0.303 | +0.0625 | +3.69 |

*Table 2: Summary of statistics for groups, found by averaging respective semester statistics.*

Here we can better see the outcomes from the separate methods we implemented in the Calculus-Based Physics I class.

**Discussion**

Gains indicate a percentage of improvement or decline from an initial to a final assessment; for example, a gain of +0.260 indicates a 26% increase from the initial to the final assessment and corresponds to an increase in normalized letter grade of a sign (such as a B to a B+) when the numerical results are applied to Bridgewater State University's grading policy. Negative gains work similarly, only indicating a decline rather than an improvement.

The gains calculated in Tables 1 and 2 can be analyzed using the following standard indicators of gain values (Table 3):

**Table 3**

| Gain Value | Qualification |
|---|---|
| $g > 0.7$ | High Gain or Growth |
| $0.3 < g < 0.7$ | Medium Gain or Growth |
| $g < 0.3$ | Little Gain or Growth |

*Table 3: Interpretation of gain values (5).*

Looking first at the laboratory gains in Table 2, the control group displays negative gain, meaning that student performance decreased from the first and third laboratory journal. But we must also consider the common grading style of professors, which is to grade students more harshly on the final laboratory journal than on the first laboratory journal because of increased expectations.

If we consider this negative laboratory gain recorded for the control group as our baseline and compare to both the pre-laboratory data activity (PLDA) group and the scaffolded procedures (SP) group, we see that both methods created a net positive gain; however, the PLDA group has very little, negligible growth when examined with the standards indicators from Table 3, while the SP group shows extremely high growth by the same standard indicators. While this does indicate that the scaffolded laboratory procedures had a more positive influence on student lab performance, we must also consider that the SP group only consists of the summer 2019 semester, which is a condensed course, and this may be an outlier.

It is also beneficial to examine and compare the FCI Gains made by the PLDA group and the SP group. Student performance on the FCI test is related to content area mastery of topics discussed in class and is not directly related to laboratory skills, though there are connections. Table 2 shows that the SP group presented high gain when examined with the standards indicators from Table 3 on the FCI test and therefore their conceptual physics knowledge while the PLDA group presented medium gain. This can be connected to the similar results in Lab Gain, where the SP group showed higher results than the PLDA group: laboratory curricula which focus on process rather than content correspond to higher gains in both laboratory skills and conceptual learning for students (2). The pre-laboratory data activities were content-focused as they did not have a hands-on element and were presented only with other textbook problems in a worksheet format, while the scaffolded procedures re-created the preexisting laboratory curriculum to focus on the process of completing a laboratory journal and thinking scientifically. This is an unexpected benefit to making laboratory curriculum improvements: students do better not only within the laboratory but overall.

The next steps for this project will be to analyze data taken during the upcoming Fall 2019 semester, which will be a part of the SP group. This will give us more data for this group and allow us to begin to confirm or deny the positive results seen in the SP group thus far.

**Conclusion**

After implementing the two different methods- pre-laboratory data activities and scaffolded laboratory procedures- of improving student laboratory performance in Calculus-Based Physics I, we see positive gains. The pre-laboratory data activities resulted in laboratory skill gains of +0.0625 and conceptual, content area gains of +0.202. The scaffolded laboratory procedures resulted in laboratory skill and conceptual, content area gains of +3.69 and +0.374 respectively. These results confirm that methods which emphasize laboratory process and scientific thinking over content material from class have the most positive overall impact on students. Future work will involve gathering more data to confirm these results and to improve the educational experience of students taking Calculus-Based Physics I.

**Notes**

1. FCI data not collected during Fall 2016 or Fall 2017- also seen in Table 1.

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**About the Author**


Zoe Hasham is graduating in May 2020 with a degree in Physics and Secondary Education. Her research in physics education with Dr. Jeffrey Williams (Physics) was made possible by the Adrian Tinsley Program for Undergraduate Research summer grant. Zoe was inspired to do this research after serving as a Peer Leader in the Physics Department, working with the Calculus-Based Physics I and II classes. She plans to teach high school physics after graduation.