**Examining Laboratory Notebook Practices in Introductory Physics Courses**

Abstract: Laboratory notebooks are significant records of research to show what a researcher did, how they did it, and what data were collected from the experiment. The *AAPT Laboratory Recommendations* is one example of a group who wants teachers to emphasize the importance of helping students develop their scientific documentations skills throughout the undergraduate curriculum. Learning proper lab notebook practices is important in preparing for graduate school and the STEM workforce. Laboratory notebooks are also important for instructors when assessing students understanding of the lab activity. This study tracks students’ progression through introductory physics lab courses in developing the necessary notebook practices for success. This research was conducted through a series of student surveys given in undergraduate physics classes. A pre-survey and a post-survey were given covering topics of how students use lab notebooks, how they learned those practices, and their attitudes toward doing those practices. This paper will discuss the changes in laboratory notebook beliefs and practices of students through three semesters of introductory lab work. Results on what methods of training are most beneficial to students’ will also be shared.

**Introduction**

Laboratory notebooks at every level are vital to success during that experiment. The notebooks used for documentation during experiments from researchers are a record of everything done, all of the observations, and results made during an experiment. That laboratory notebook can be shared with other researchers to repeat the experiment and confirm of refute the results. The notebook entries can also be shared with the public to spread the wealth of knowledge researchers are growing every day. Proper scientific documentation is the key to this communication between researchers and from researchers to the public. The skill of scientific documentation begins to develop the minute a young science student steps into their first laboratory class. It is the instructor’s responsibility to guide those students to proper lab notebook practices. \\

Recently there has been a growing interest on the use and practices of notebooks in undergraduate physics labs. A handful of organizations have published recommendations for lab reform and included how to get the most out of using lab notebooks. Some of these organizations do not limit the importance of lab notebooks to intro physics labs but recommend for all science labs, like chemistry\cite{NSF1998}. Another group laid out specific standards for physics students in introductory lab courses. The \textit{AAPT Lab Recommendation} specifically call for an increased focus on teaching the proper notebook techniques, specifically in the introductory lab. This group identifies using lab notebooks as a technical and practical laboratory skill and an integral part in communicating physics \cite{AAPT2014}. This document lists standards for the introductory students to meet in order to build on and reach a level expected for industry or graduate school.\\

Lab notebook's importance in the introductory laboratory is not a new idea. In 1962 a paper was published about value such a notebook can play in the introductory laboratory. The author discusses how the focusing a lab on the notebook will have a positive effect on students understanding of physics. He also mentions that replacing formal lab reports with a focus on the notebooks gives the instructor a better understanding of what the students know\cite{Dayton1962}. There are recent studies that show that lab notebooks are still an effective assessment tool \cite{Ruiz-Primo2004,Adler2006,Stanley2017}. Each section of the lab notebook as an opportunity for the students to show the instructor what they know. The background/introduction of the lab show how much of the theory the students grasped. The methods and procedure sections can show what students understand about the equipment they are using. The results and conclusion section is perhaps the most telling section. It is the time students can relate the theory they stated in the intro with the observations they saw during the experiment. Each section demonstrates and important aspect of understanding for the students.\\

Lab notebook skills are not only important for the classroom but proper lab notebook practices are vital for students pursuing careers in research. Whether that research is performed at an educational institution, government facility, or private industry, proper lab notebook practices are universal. A recent study shows that many incoming physics graduate students do not have the scientific documentation skills needed for graduate level research \cite{Stanley2016}. Two common themes were reported from these students when surveyed about their experience with their lab notebook practices. One, that their undergraduate courses did not use their notebooks as assessment tools. And, two, that the practices they used to maintain their graduate research notebook were learned though hands on practice or what they call, "authentic lab experience." Students with exposure to this type of lab or research gain practice in many important skills. Some organizations propose all introductory laboratory courses shift from standards based to hands on, discovery style labs for the students \cite{Holdren2010}. \\

Discovery style labs give students an opportunity to practice many important lab skills including scientific documentation. It also gives students and opportunity to develop bad habits if not instructed and assessed properly. Researchers at the University of Colorado-Boulder have published a paper explaining the most important features in an authentic notebook and recommendation of how to include them into a classroom \cite{Stanley2018}. These recommendations were formed by interviews with current graduate students. These main features include how to organize the notebook and what type of information is important to include. The recommendations are for an upper-division physics lab but can be adapted to introductory students. Introductory physics students are often using lab notebooks for the first time. In this study we explore the practices, beliefs, and attitudes of these introductory students and how they develop over three semesters of introductory physics labs.

**Methods:**

Student's were analyzed through a series of surveys. Each student received a pre-survey at the beginning of each introductory physics lab course and a post-survey after their last class meeting of the semester. The pre-survey included questions regarding demographic information. Students were asked to provide information about their gender, ethnicity, major, and experience with laboratory notebooks. Each student used a unique PIN on each survey that would allow us to track their progress over the semester. Both surveys consisted of 31 Likert style questions. Each question was answered on a scale of 1 to 5 (strongly disagree to strongly agree). The questions that were asked pertained to the students students beliefs, practices, or attitudes toward lab notebooks. Both surveys also asked the students who have previously used a lab notebook what kind of training they had received during that time. \\

\begin{figure}[h!]

\centering

\includegraphics[scale=0.25]{survey.png}

\caption{Here is a sample of the survey given to the student to begin their lab course and at the end.}

\label{survey sample}

\end{figure}

The post-survey contained 5 extra Likert style questions and 7 short answer questions. The extra Likert-style questions pertained to the lab notebooks particularly during that semester. For example, the questions asked if the students felt their notebooks were graded fairly and if they were given sufficient feedback to improve their practices throughout the semester. The short answer questions on the post survey asked students which lab notebook training method was most helpful and what they would have liked more of. The short answer questions also pertained to the feedback the students received and how the lab notebooks in this introductory physics course related to lab notebooks they kept in their chemistry courses. This series of surveys covered many topics and provided us with a great sum of data on how the students improved and what helped them most improve over this time. \\

During this time the data was being collected the physics department has been gradually updating their introductory physics lab curriculum. For example, each of the three introductory labs is that each contained at least 1 student designed lab. The goal of the student designed lab is to give the students an authentic lab experience. In most of these labs there is more than one way to do solve the given problem so the students are given a plethora of materials to design an experiment and solve the problem. This type of lab is usually done toward the end of the semester when the students are familiar with the equipment and theories needed for the lab. At the end of the lab, the students create a presentation based on what they did and the results they found. Students lab notebooks are put to the test because their presentations require the details of the lab a student would forget if they are not documenting properly. \\

All of the introductory physics lab instructors agreed to increase the focus on lab notebooks during the data collection period. Each instructor varied in their approach to teaching lab notebook practices. Some instructors provided rubrics and handouts. Other instructors gave a lecture during their first class describing the proper lab notebook techniques. Some did both. Grading and feedback also varied by the course instructor. This variation of teaching methods paired with the short answer questions on the post survey allows us to find which instructional methods students found most beneficial.

**Analysis**

Likert data is ordinal and not interval, a normal distribution cannot be assumed, and the pre-post survey pairing gives us a paired set of data. For this paired and ordinal data we used the Wilcoxon signed rank test to analyze. The hypothesis being tested with this statistical method is that the median difference is zero \cite{McCrum-Gardner2008}. That is to say, there was no shift in the students belief between the pre and the post survey. This method of data analysis has been used recently in other physics education research as well \cite{McPadden2017}. \\

For the short answer responses we used grouping to categorize the responses and compare growth to reported training. The grouping of responses allows us to see what the most students think is the best method of teaching for them to learn the proper lab notebook practices. It also will tell us what students really want to see more off. \\

The signed rank test was completed for many different sets of student data. Over the last 3 semesters as the data was making its way in we looked as groups of students with similar experiences. We looked at how students grew during general physics 1 and again how they grew during general physics two. We looked at the growth of students after two full semesters of training. Now, with three full semesters of data we can analyze the growth of students over that entire span. We also look back and update some of the older groups we looked at with more data. We compare the post surveys from the first semester to the pre survey to the second semester to see if there is a significant sift due to the students forgetting what they learned. All of these different grouping of students can give educators a strong insight on how students learn lab notebook practices in introductory physics labs.