# An Online Approach to the Analog Electronics Laboratory

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## Abstract

Demand for science, technology, engineering, and mathematics (STEM) courses continue to rise. Given personnel and budgetary constraints, we explored an approach that provides more individual assistance to students, while simultaneously allotting the individual student more time to practice essential course competencies independently. In the Fall of 2016, the undergraduate 300 level Analog Electronics Laboratory at the West Virginia University Lane Department of Computer Science and Electrical Engineering, set up one of its four sections offered in an online fashion as a "lab in a box." This approach is a set of hands-on exercises where students design, build, and test circuits at home using an inexpensive all-in-one electronics kit, digital multimeter, and a USB oscilloscope. With this "lab in a box," the students, at their own convenience, conduct several multi-week laboratory experiments such as basic amplifier design, LED four channel color organs, and frequency response of circuits. Each week, students use online tools such as discussion boards and blogs through a web-based course management system, built into the campus Learning Management System. This method allows the Teaching Assistant to provide feedback and allows other students to engage and work with each other to solve the problem. Different online tools were used during different lab experiments. The students' understanding of the material was evaluated through the assessment of their lab reports. In this paper, we describe the setup of the "lab in a box" method, the use of TA tools, the effects this method has had on learning outcomes, and present qualitative student responses to this online approach to learning.


## Introduction

Teaching students in the 21st Century present major challenges in which one must adapt to overcome. The generation of students enrolled in undergraduate degrees has been raised with an instant fulfillment mentality that is no longer met by traditional passive teaching approaches. The students crave new strategies which encompass authentic exploration and learning, visual stimulation and community-based practices [1].

Several pedagogical paradigms have been proposed to help better engineering education; Constructivist, constructionist, and action-based learning theories help lay the pedagogical foundation needed to adapt instruction in higher education to meet this need [2]. The foundation from these theories provides instructional methods that help promote critical-thinking, experimental inquiry and collaboration while the use of technology plays a vital role in contributing to access and manipulation of information along with knowledge retention [3]–[5].

With the increase of current K-12 hands-on constructivist learning, students are entering STEM degree fields expecting to learn via hands-on technology support learning [6]. This mentality along with the increase of STEM enrollment poses a problem for current educators. Engineering enrollment is on the rise due to an increase in emphasis on STEM exposure and STEM-related careers. From 2007 to 2015, an average annual increase of 5.4% in bachelor's degrees were in engineering [7]. To increase access and to meet this growing demand, developing an online hands-on strategy is essential. By creating such an approach, this may help relieve the amount of space and personnel needed for such a demand.

*Lab-in-a-Box*

Within the world of engineering education, several constructivist models of hands-on discovery learning have been successfully developed [8]–[10]. The University of Washington shared their Lab-in-a-Box (LiaB) concept with Virginia Tech. In 2004, it was integrated into the curriculum to improve student learning by allowing students to make their own observations on concrete examples of fundamental concepts in electrical engineering [11]. The LiaB was initially used in their first electronics course to help the students gain hands-on experience with basic DC circuits utilizing the LiaB with homework experiments. The LiaB allowed the students to perform these experiments without dedicated lab space and on their own time.

A 2011 approach that further developed the idea of the LiaB, the Mobile Studio, was developed to replace traditional laboratory equipment with the use of portable technology that can be used with a laptop anytime, anywhere. This concept has been shown to assist active learning with the increase of real life, hands-on student experiences and paired with discovery learning helps stimulate content acquisition, problem-solving, and transfer of information for content related to electrical engineering and physics [12], [13].

13 Historically Black Colleges and Universities utilized the first Analog Discovery Board to support their experimental student-centered learning. Faculty and students reported an increase in intrinsic motivation, interest in content, and confidence in their ability to learn with 88% of students mentioning that the Analog Discovery Board helped them learn. An increase of students expressing interest in graduate programs and research was also noted [6].

Expanding on the LiaB and Mobile Studio concept, we wanted to investigate the feasibility of implementing a similar structure at West Virginia University. What difficulties must be overcome with integrating into existing infrastructure? What resources are best situated for the use of the TA? What effects does this method have on student learning outcomes? How do students' respond to this approach?

**WVU LiaB Setup**

The setup chosen for this pilot investigation included: Digilent Analog Discovery 2 Board, BNC Adapter Board, BNC Oscilloscope x1/x10 Probes (Pair), Shielded USB cable, and WaveForms 2015 software [14]. The Analog Discovery 2 Board is an all-in-one box that fits in the palm of your hand and performs various functions such as measuring, validating, testing, debugging and generating. Its multi-functional use allows students to plug the device into their computer or laptop, and start working with a two-channel oscilloscope, two-channel arbitrary function generator, two programmable power supply, and a single channel voltmeter. Minimal space and money are required for this setup when compared to typical benchtop equipment. Students could easily add the equipment in their lab kit bags due to the size and weight of the Analog Discovery 2 Board. Any components needed for experiments were stored on campus and students had access via their student ID. The difference between the traditional laboratory setup vs the minimal portable setup of the LiaB can be seen in Figure 1.

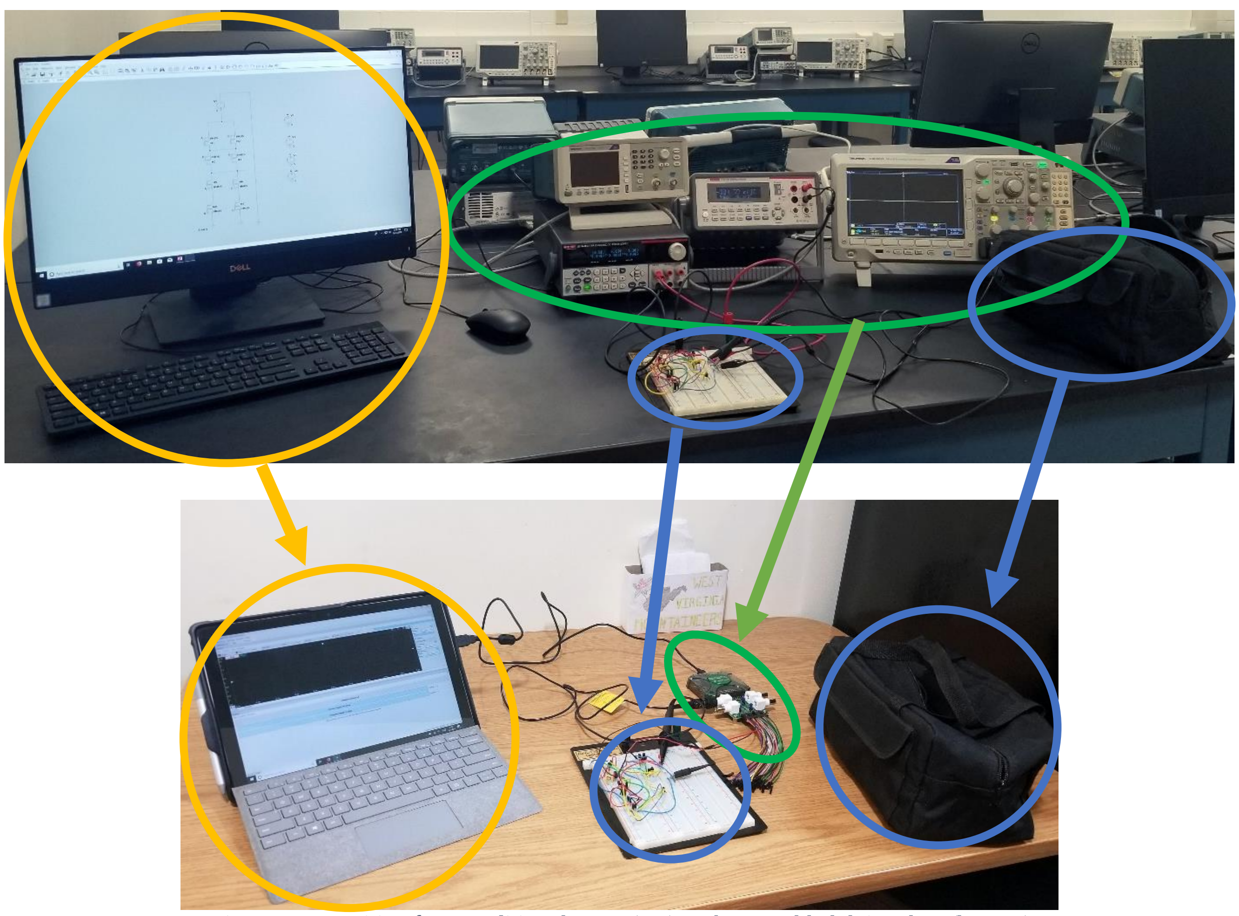

*Figure 1: Transition from traditional setup (top) to the portable lab in a box (bottom)*

## Course Context

A one-credit hour analog electronics laboratory course, EE 356, designed for third-year electrical and computer engineering students, typically taken with the lecture, EE 355 Analog Electronics, was chosen as the test bed for this approach. The course covers topics including frequency responses, operational and power amplifiers, and small signal analysis of BJT and FET circuits. By the end of the semester, students should demonstrate the ability to characterize, understand, and troubleshoot the operation of electrical components and circuits, operate technical equipment, and comprehend and analyze data results.

The lab consisted of an introduction and six labs, several being a multi-week setup. The introductory lab did not have a lab report but was used to help refresh the basics of FETs and BJTs and equipment functionality. The online section used this introductory lab to meet the TA, receive their equipment, and learn the fundamentals with the basic labs. The topics that each lab covered follow the lecture and are listed in Table 1.

*Table 1: Laboratory Topics*

| Lab # | Topics Covered |
|---|---|
| Intro | BJT/MOSFET as a Switch |
| 1 | Photodiodes: Maximum Detectable Frequency and Distance |
| 2 | Half and Full-Wave Rectifiers |
| 3 | Curve Tracer Usage/Design, MOSFET Amplifiers Design/Build: Common Source, Common Source with Source Degeneration, Common Drain |
| 4 | Effects of Width and Length of a MOSFET on a Common Source Amplifier |
| 5 | Low, High and Band Pass Filter Design/Build with MOSFET Amplifiers |
| 6 | CMOS Op-Amp Design and Frequency Response |
| Final | Four Channel LED Color Organ |

## Methods

Four sections of EE 356 were offered in the Fall of 2016, enrollment ranging from 11-20 students each with one section randomly selected to be the “online” section of the lab, where students would receive the lab in a box setup. The other three sections were held as a constant utilizing traditional “face-to-face” techniques. All sections were covered by the same Teaching Assistant (TA) for the course.

### *Description of Participants*

Among the 60 students enrolled in the Analog Electronics course, 54 students consented to participate in the study (90% participation) with 18 enrolled in the online section. Among the 54 students, 10 were female and 44 were male. Most of the students were junior and senior students.

*Online Section Structure*

In order to help normalize the approach across the University and minimize the amount of new software/hardware the students had to learn, the current online learning management system, eCampus, a custom version of BlackBoard Learn v.9.1, was used for document distribution, submitting assignments and exploration of intervention strategies for the online section. eCampus can be accessed using a laptop, desktop, or any other mobile device. This tool enables the collaboration between students and faculty across the university within individual classes and disciplines.

The online section was broken into two groups, A and B, with two different intervention strategies used to assist students. During the face-to-face sections, each student had access to the TA to seek help, such as asking questions pertaining to performing the lab. Group A and Group B rotated their TA intervention methods every two weeks. Table 2 lays out which interventions were used during which labs.

*Table 2: Intervention Layout*

| **Lab** | **Online Section** | |
|---|---|---|
| | ***Group A*** | ***Group B*** |
| Intro | Face to Face | |
| 1<br>2 | Discussion Board | Blog |
| 3<br>4 | Blog | Discussion Board |
| 5<br>6<br>Final | None | None |

Students logged onto eCampus to post questions, concerns, or comments pertaining to the lab assignments either on a discussion board or blog. Students would create a thread through a discussion board if they encountered problems, other students could post solutions or comments. Others that experience a similar problem would use the thread as a reference. In the blog, some students posted their work about how they approached the lab, asked questions, and made comments on the blog as well. The interventions were meant for students; the TA would occasionally post a solution or comment on either posting methods.

*Data Collection*

Lab reports were one of the main student products used in grading and assessment of the course, a corresponding learning objective within the current infrastructure, and consequently a primary data source for the study. The same reviewer, who was not associated with the course or laboratory, was used in assessing the lab reports via the rubric in Appendix A.

Along with the lab reports, students were asked at the end of the semester to rank the difficulty of each lab using a 10-point Likert scale and to turn in a one-page summary answering these questions:

1. What did you learn in the lab?
2. Any ways to improve the lab experience?
3. Which labs were your favorite and why?
4. Which ones did you hate and why?
5. Any improvements that can be made by myself, lab equipment, lab handouts, etc.
6. Anything else you would like the TA to know?

**Results**

*Exercise Difficulty*

Table 3 highlights the descriptive statistics for laboratory exercise difficulty. Sections 2 and 5 are two of the three traditional sections. Because one of the traditional sections, 4, had no responses on the laboratory exercise difficulty question, that section is not represented in the above table. Section 3A and 3B represent the online sections Group A and Group B. There was no section 1 offered. Labs 3, 5 and 6 were by far the most difficult labs.

*Table 3: Difficulty Descriptive Statistics by Section*

| Section | N | Lab 1 | | Lab 2 | | Lab 3 | | Lab 4 | | Lab 5 | | Lab 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 2 | 6 | 2.50 | 1.38 | 3.50 | 1.05 | 8.83 | 0.75 | 5.17 | 1.94 | 6.67 | 1.63 | 6.67 | 1.37 |
| 5 | 6 | 2.50 | 1.87 | 3.00 | 2.28 | 5.67 | 2.16 | 4.33 | 2.07 | 6.33 | 1.21 | 6.50 | 1.05 |
| 3A | 3 | 2.33 | 0.58 | 3.67 | 2.08 | 7.67 | 3.21 | 2.67 | 1.53 | 6.67 | 1.53 | 5.67 | 1.15 |
| 3B | 6 | 3.17 | 1.83 | 2.83 | 1.60 | 8.00 | 2.76 | 2.67 | 1.51 | 6.50 | 1.87 | 7.00 | 1.67 |
| Total | 21 | 2.67 | 1.53 | 3.19 | 1.66 | 7.52 | 2.42 | 3.86 | 2.01 | 6.52 | 1.47 | 6.57 | 1.33 |

*Interventions Usage*

The online eCampus resources, discussion board, and blog, were not heavily used. Group B appeared to have utilized the discussion board more than Group A, but both groups had similar blog usage. A breakdown of usage is presented in Table 4.

*Table 4: Intervention Usage*

| Lab # | Group A | Group B |
|---|---|---|
| 1 | 1 thread, 2 posts | 2 posts, 1 comment |
| 2 | 1 thread, 3 posts | 1 post |
| 3 | 2 posts, 3 comments | 4 threads, 8 posts |
| 4 | 1 post, 0 comments | 0 threads |

*Lab Reports*

*Table 5: Lab Report Descriptive Statistics by Section*

| | Section 2 | | | Section 3A | | | Section 3B | | | Section 4 | | | Section 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lab | *N* | *Mean* | *SD* | *N* | *Mean* | *SD* | *N* | *Mean* | *SD* | *N* | *Mean* | *SD* | *N* | *Mean* | *SD* |
| 1 | 12 | 77.83 | 12.21 | 10 | 71.60 | 11.15 | 10 | 68.00 | 14.37 | 11 | 69.55 | 12.53 | 15 | 74.87 | 11.81 |
| 2 | 13 | 83.54 | 10.95 | 10 | 82.40 | 7.23 | 9 | 86.22 | 6.67 | 11 | 78.73 | 11.19 | 16 | 78.69 | 7.80 |
| 3 | 12 | 81.25 | 14.44 | 8 | 70.25 | 17.87 | 7 | 82.43 | 12.71 | 10 | 80.50 | 11.36 | 16 | 79.13 | 14.96 |
| 4 | 13 | 85.54 | 3.93 | 10 | 75.80 | 12.02 | 9 | 78.00 | 15.12 | 11 | 79.36 | 6.69 | 16 | 82.94 | 7.39 |
| 5 | 13 | 77.00 | 10.72 | 10 | 71.70 | 13.03 | 8 | 78.88 | 10.30 | 10 | 79.70 | 9.07 | 16 | 78.94 | 8.31 |
| 6 | 13 | 78.00 | 12.39 | 9 | 75.11 | 6.97 | 8 | 71.13 | 18.05 | 8 | 73.75 | 12.45 | 13 | 77.92 | 12.72 |
| Avg | | 80.53 | 10.77 | | 74.48 | 11.38 | | 77.44 | 12.87 | | 76.93 | 10.55 | | 78.75 | 10.50 |

Notice in the following figure the scores for the lab reports were clustered in the band from 60 to the upper 90’s.

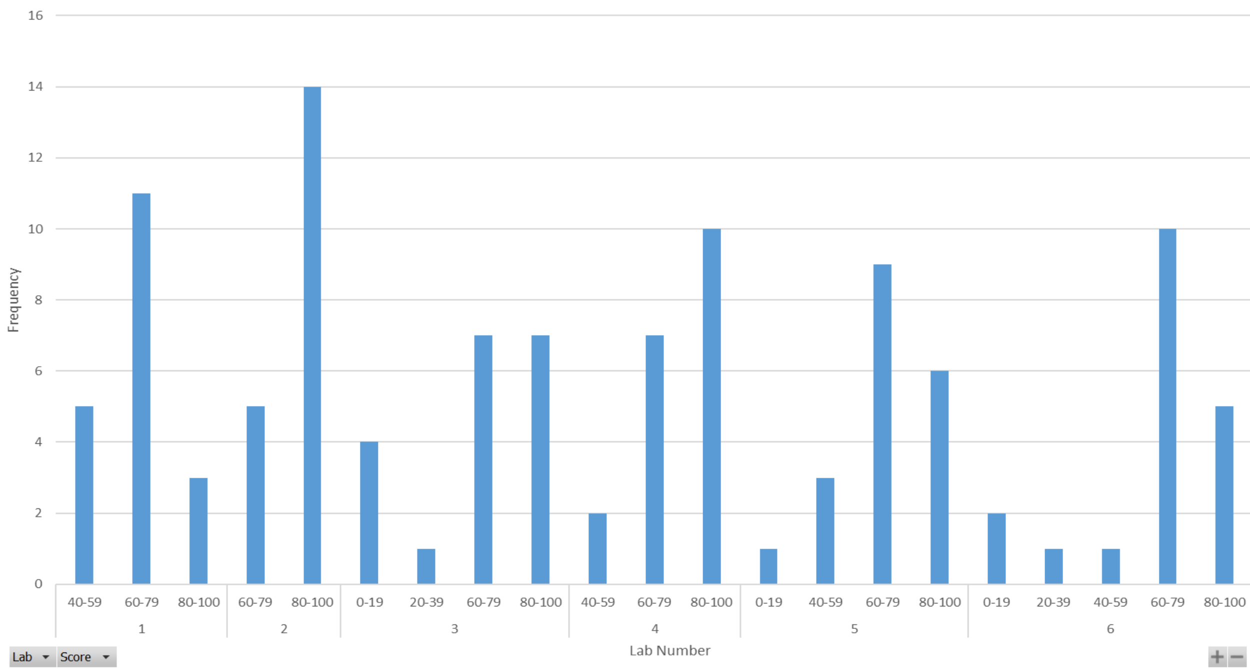


*Figure 2: Distribution of Lab Report Scores by Lab*

*Regression Analysis*

Multiple regression analysis was used to test if the type of available help or the difficulty of the lab significantly predicted participants' scores. The results of the regression as shown in Table 6 and Table 7 show that the two predictors were not statically significant.

*Table 6: Regression Statistics*

| | |
|---|---|
| Multiple R | 0.18 |
| R Square | 0.03 |
| Adjusted R Square | 0.02 |
| Standard Error | 23.06 |
| Observations | 114 |

*Table 7: ANOVA Summary Results*

| | df | SS | **MS** | **F** | **Sig. F** |
|---|---|---|---|---|---|
| Regression | 2 | 2057.69 | 1028.84 | 1.93 | 0.15 |
| Residual | 111 | 59047.55 | 531.96 | | |
| Total | 113 | 61105.24 | | | |

The results show that the type of help (threaded discussion, blog or none) and the difficulty of the lab did not impact the students from completing the lab successfully. It appeared that there seemed to be other factors, such as the type of instruction that contributed to the success of the online sections. This bodes well for the continued development of an online approach to lab designs.

*Student Reactions*

The one-page summaries showed that 93% of the responses had an overall positive experience with the take home lab with a positive learning experience and strengthening of skillsets. This seemed largely because most students had to spend extra time to overcome some of the challenges with the lab setup. These challenges seemed to provide a slight hinderance to the experience without affecting the overall experience. Of the fifteen (15) responses, some of the common themes of hinderance were:

- Need for an optional in-person time with TA or method of instant feedback (N=10)
- Lab handout ambiguity and need for adaptation for equipment (N=6)
- Equipment struggles (N=5)
- Need for more in-depth equipment tutorials (N=3)
- Finding time outside of class to work with partners (N=2)

*Discussion*

The results demonstrate that the lab can be successfully completed using a totally asynchronous online environment. The biggest issue from the students' perspective was the lack of instant feedback from the TA which required them to investigate the problem on their own. Some students stated that they spent in upwards of 20+ hours some weeks to overcome the problems faced. These comments are very intriguing as the online help provided was underutilized. It seems students opted for no or little "instant help" from the TA and self-explore the solution rather than utilizing the "delayed" response used with the different TA interventions explored. Consequently, the results specify the availability of help was inconsequential to students' performance. What was interesting is that the difficulty of the lab did not stimulate the students to use the available help.

Reasons for the lack of use stem from the nature of the online use of the help system. The students noted that the response was slow. They desired a more immediate response to the question at hand. The students in the online section performed consistently even though they did not use the available help. Notice in Table 5 and Figure 2. The most difficult labs (3, 5 & 6) had the widest distribution of scores.

## Conclusions and future work

With the students performing similarly with the different TA interventions, one of the questions that come up is whether the lab report is an appropriate measure of the students' lab performance and understanding of the material. These sections may provide more insight into students' comprehension instead of total lab report grades:

- Abstract
- Observations, Data, Findings, and Results
- Data Discussion
- Conclusion and Suggestions

Reproducing this study with a different assessment method, such as using Synopsis reports, may be a more appropriate method to analyze the students' effects of the LiaB method and TA interventions [15]–[17].

One must also take into consideration all the feedback given by the students and take the following steps before continuing with online help, specifically for WVU:

1. Rework any experiments to verify the scope of the lab is met the abilities of the LiaB equipment.
2. Stronger introduction lab and more specific equipment tutorials
3. A solution for "instant" TA. This could range from the utilization of a Frequently Asked Questions section or a dedicated time period in which the TA is available online via Blackboard Collaborate.
4. Encourage students to better utilize the University's online learning management system.
5. Consider new assessment methods for laboratory learning outcomes to better gauge the success of future implementation.

**Acknowledgment**

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Appendix A

# Lab Report Grading Rubric

| ***Section*** | ***Beginning*** | ***Developing*** | ***Accomplished*** | ***Exemplary*** | ***Points*** |
|---|---|---|---|---|---|
| Abstract | Several major aspects of the experiment are missing, student displays a lack of understanding about how to write an abstract | Abstract misses one or more major aspects of carrying out the experiment or the results | Abstract references most of the major aspects of the experiment, some minor details are missing | Abstract contains reference to all major aspects of carrying out the experiment and the results, well-written | /25 |
| Introduction | Very little background information provided or information is incorrect | Some introductory information, but still missing some major points | Introduction is nearly complete, missing some minor points | Introduction complete and well-written; provides all necessary background principles for the experiment | /15 |
| Equipment Used | Listed little of the equipment used with no details | Listed some of the equipment used including make and model | Listed majority of the equipment used including some detail | Listed all equipment used including make and model | /5 |
| Experimental Method | Missing several important experimental details or not written in paragraph format | Written in paragraph format, still missing some important experimental details | Written in paragraph format, important experimental details are covered, some minor details missing | Well-written in paragraph format, all experimental details are covered | /5 |
| Observations, Data, Findings, and Results | Figures, graphs, tables contain errors or are poorly constructed, have missing titles, captions or numbers, units missing or incorrect, etc | Most figures, graphs, tables OK, some still missing some important or required features | All figures, graphs, tables are correctly drawn, but some have minor problems or could still be improved | All figures, graphs, tables are correctly drawn, are numbered and contain titles/captions | /10 |
| Data Discussion | Very incomplete or incorrect interpretation of trends and comparison of data indicating a lack of understanding of results | Some of the results have been correctly interpreted and discussed; partial but incomplete understanding of results is still evident | Almost all of the results have been correctly interpreted and discussed, only minor improvements are needed | All important trends and data comparisons have been interpreted correctly and discussed, good understanding of results is conveyed | /15 |
| Conclusion and Suggestions | Conclusions missing or missing the important points | Conclusions regarding major points are drawn, but many are misstated, indicating a lack of understanding | All important conclusions have been drawn, could be better stated | All important conclusions have been clearly made, student shows good understanding | /20 |
| Format | Sections out of order, too much handwritten copy, sloppy formatting | Sections in order, contains the minimum allowable amount of handwritten copy, formatting is rough but readable | All sections in order, formatting generally good but could still be improved | All sections in order, well-formatted, very readable | /5 |
| Spelling, grammar, sentence structure | Frequent grammar and/or spelling errors, writing style is rough and immature | Occasional grammar/spelling errors, generally readable with some rough spots in writing style | Less than 3 grammar/spelling errors, mature, readable style | All grammar/spelling correct and very well-written | /5 |
| | | | | Deductions | |
| | | | | Total | /105 |