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Work In Progress: Adding Additional Methods to Identify Mistakes in an Undergraduate Biomedical Instrumentation Laboratory Course

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Introduction

In his 2013 book, John Hattie stated "the most powerful single influence enhancing achievement is feedback." [1] The feedback students receive on their achievement of learning outcomes can take many forms: self-evaluation checkpoints, the grade on a summative exam, or the comments left on a lab report. By their nature, assessments inherently include an element of feedback [2], but formative assessments guide students toward self-evaluation during the learning process rather than after the fact. Qadir et al. identified six key aspects of beneficial feedback, including being timely, actionable, and aligned with learning goals [3]. However, they also noted that feedback is not sufficient if it does not also prompt self-evaluation within the student. Encouraging the mindset of self-assessment is one way to give students more autonomy and confidence in their learning ability. In a lab course, students must take the initiative to interpret the protocol, troubleshoot unexpected errors, and ensure that they have achieved the learning outcomes in the process of data collection. This process helps students to begin to develop engineering intuition [4].

However, feedback runs both ways. Successful professors should reflect and evaluate the courses they teach to iterate on past successes and learn from shortcomings. One way to ensure the reflection process is representative of student experience is to gather feedback from those who are currently taking the class, a process we refer to here as "Course Consultants." According to Schmidt et al., these are based on the principle of making decisions in collaboration with those who will be affected by those decisions [5]. The goal is to create a group that students may voluntarily join and provide a space for constructive dialogue on course policies or proposed changes. In Nambiar et al., "Quality Circles" in a microbiology course were used as a means of gathering feedback from a subset of students throughout the semester, resulting in suggestions for course improvement and a greater sense of student agency [6].

Autograding uses a system that can evaluate a student's work automatically and assign a grade, with the potential to provide feedback to students [7]. As class sizes increase, there has been increased interest in autograding student assignments to lessen the grading load on instructors and increasing feedback to students, made easier by the increasing integration of these tools into established Learning Management Systems (LMS) [8]. The implementation of autograders has shown many benefits for both students and instructors, including greater consistency, reduced workload for instructors, more immediate feedback for students, and improved student performance. In manual grading, there is the inherent risk of unintentional variability and bias in grading, both between instructors and within a single instructor's load [7], [9], [10], [11], [12]. Autograding removes the risk of these biases by applying a consistent grading and feedback policy across all submissions [9], [11], [13]. Additionally, autograding enables instructors to spend less time on low-impact teaching work, like grading, and focus more on high-impact teaching work like tutoring and content renewal [14]. With increasing class sizes, instructors face a mountain of student submissions, and this can lead to delayed feedback to students as well as decreased quality of teaching and student interactions [7], [12], [13], [15]. Autograding can help reduce this burden and aid in the faster identification of gaps in understanding and at-risk students [13], [14].

For students, autograding enables immediate feedback that is more helpful to students to engage with and learn from their mistakes [10], [11], [16]. However, the content and depth of this feedback are critical to helping students learn and must be carefully crafted by instructors to be useful [7], [13], [17]. Students may struggle with applying feedback if it is not properly designed, as there can be ambiguity in automatically generated feedback, and it can feel impersonal [13], [15]. Another consideration in the implementation of autograding systems is ensuring that the value of the assignments is not compromised to fit the grader [18]. Successful implementation of autograding systems necessitates the engagement of instructors to complement and help interpret the generated feedback [13], [14], [15].

Based on student feedback and staff reflections, it was noted that the speed and consistency of feedback on laboratory assignments led to confusion and uncertainty during the course. Several new ways of identifying mistakes earlier in the process were added to the course. The goal of this paper is to share how feedback was modified and additional evaluation data from the initial implementation. The flow of the course, assignments, and feedback is illustrated in Figure 1.

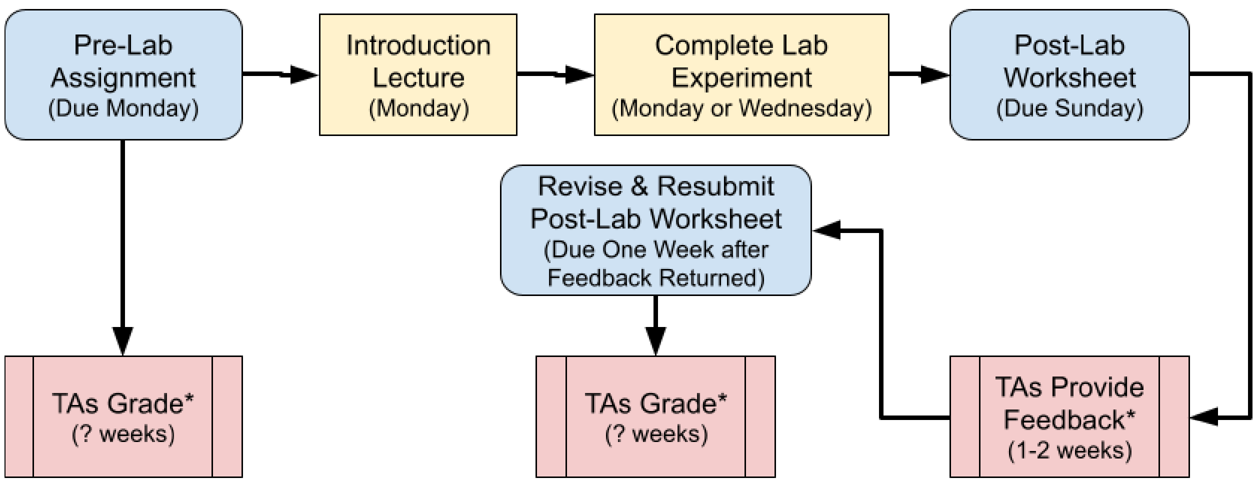

*Figure 1 - Course flow chart. The blue round-corner boxes depict assignments, yellow rectangles are scheduled course meetings, and red boxes with vertical lines are manual points of feedback from TAs. *Duration of time to return feedback varies significantly based on TA experience and enrollment.*

Methods

This section outlines the context of the course and the methodologies used to gather and analyze feedback to improve its structure and delivery.

Course Context

The course is a two-credit-hour undergraduate laboratory in biomedical instrumentation, offered at a large public university in the Midwestern United States. It spans a full semester and is taken alongside a three-credit-hour lecture course, taught by a separate instructor, which covers the theoretical foundations. Both courses are required for all third-year bioengineering undergraduates and are also commonly chosen as technical electives by students across various engineering disciplines.

Students attend a one-hour introductory lecture each Monday, led by the course professor, to review concepts and prepare for the week's laboratory experiments. Later in the week, they work in pairs during scheduled three-hour lab sessions. Prior to each lecture, students complete a pre-lab assignment where they are asked to review key concepts, identify parameters of key components, complete circuit designs, and lay out a circuit on a breadboard in TinkerCAD. In Fall 2024, there were 40 students, forming 20 groups of two. Each lab section is supervised by a graduate teaching assistant (TA), with support from an undergraduate course assistant (CA), who has previously completed the course. The professor is available during lab sessions and periodically checks on student progress.

The laboratory consists of 12 fully equipped stations, each containing a function generator, oscilloscope, DC power supply, digital multimeter, data acquisition system (DAQ), pack of resistors with other electrical components, required cables, and a desktop computer running Windows 11 with required software. Students receive all components necessary to construct circuits and for each experiment, students complete an individual pre-lab assignment, a group post-lab worksheet, and an individual reflection.

Sources of Feedback

This study utilized participatory action research to assess and improve the effectiveness of feedback mechanisms in the course. The research team included the professor, a former teaching assistant, a former student, a current teaching assistant, a current undergraduate laboratory student, and a former student who is a current course assistant. Additionally, feedback was taken directly from students actively enrolled in the course during the Fall 2024 semester. This ensured multiple perspectives informed the research process, from those involved in instruction to those experiencing the course firsthand. Multiple forms of feedback were introduced or updated in the Fall 2024 semester, including course consultants, directed course staff reflections, end-of-semester surveys, autograded pre-labs, and checkpoints.

Select student volunteers, referred to as "Course Consultants," participated in structured feedback sessions throughout the semester. These sessions provided valuable, real-time insights into the clarity, pacing, and effectiveness of instructional materials and assignments. Feedback from these sessions helped identify specific areas for improvement and adjustments to the course. For this semester, two feedback sessions were held, one about half way through the semester and one at the start of the following semester.

The course staff including the professor, TAs and CAs provided feedback during weekly meetings. These discussions focused on challenges faced during the lecture, lab sessions, and opportunities to improve pre-lab assignments, lab protocols, and grading practices. TAs developed a repository of "standard" comments for common issues encountered in lab reports and TinkerCAD submissions. These comments were designed to provide detailed, actionable feedback and reduce variability between graders.

At the end of the semester, enrolled students completed a survey and anonymous end-of-semester evaluations. This survey aimed to assess the effectiveness of feedback mechanisms, the clarity of assignments, and overall satisfaction with the course structure. The end-of-semester evaluations are standardized and administered by the university. Both covered different aspects of the course and structure.

Autograded pre-lab quizzes were introduced to reduce grading time and provide timely feedback on certain questions. Solutions and general feedback were released for most questions after the due date and before the lab started. To encourage self-assessments, TinkerCAD solutions were covered in class and students were encouraged to compare their TinkerCAD designs to the provided solution during class for the first three circuit design labs.

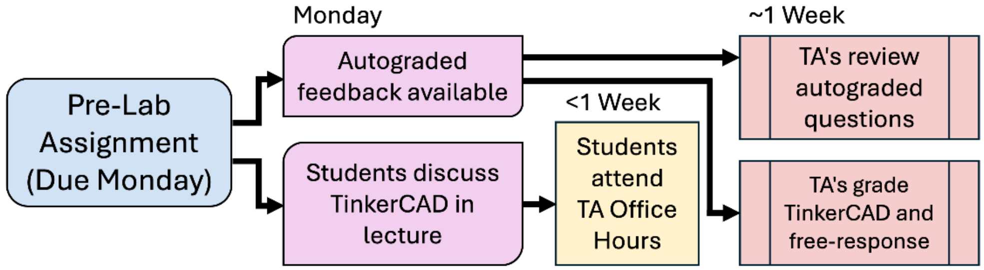

Figure 2 - Updated Pre-Lab flow chart. The blue round-corner boxes depict assignments, pink rectangles are new implementations of feedback mechanisms, yellow rectangles are scheduled course meetings, and red boxes with vertical lines are manual points of feedback from TAs.

Lab protocols were revised to include self-assessment and peer checkpoints. These checkpoints prompted students to verify their results, compare them with theoretical expectations, and identify discrepancies.

Table 1 - Summary of feedback mechanisms

Type	Source	Recipient	Purpose
Autograded Pre-lab Quizzes	Computer	Student	Provide general feedback and correct values for pre-lab exercises prior to the start of the lab
TinkerCAD Self-Assessment	Small peer groups	Student	While reviewing an accepted TinkerCAD solution provided by the instructor, students were also asked to compare their pre-lab solution with the accepted solution and ask questions
In-lab Check Points	Lab partners, peers	Lab partners	Steps were added into the laboratory procedures that had students compare their measured results to expected results from the pre-lab or previous lab steps. The goal was to ensure they had usable data before leaving the laboratory session.
Course Consultants	Students	Instructor and research team	A focus group of current students to provide feedback on the course during the semester.

Type	Source	Recipient	Purpose
Staff Reflections	Graduate teaching assistants, undergraduate course aids	Instructor	Feedback from staff about how each lab went and common questions or problems.
End-of-semester Surveys	Students	Instructor and research team	There were two end-of-semester surveys, one end-of-semester evaluation administered by the university, and an additional survey created by the research team to get more specific evaluation data.

Results

The autograded pre-lab quizzes were implemented in Canvas (the LMS available through the university). These quizzes had the intended effect of reducing the total time spent manually evaluating student responses, with an average time savings of approximately 4 minutes per student on each pre-lab. This was assessed through a report from the grading TA who estimated the time saved with the autograding implementation for each assignment individually, with a range of estimates from 30 seconds per student for one assignment and 8.5 minutes per student for another. The autograded pre-lab quizzes also provided a greater standardization of feedback, but the format also required some adjustment through the semester. In particular, splitting the original quizzes' multi-part questions into separate autogradable entries in the LMS made the quizzes appear far longer. In this format, students did not always recognize which questions were meant to directly build on each other. The solution to this problem was to provide a hard copy of each quiz in its original format; not only could students see the intended flow and grouping of questions more easily, but they could start work on the week's quiz even if the autograded version was not ready to be rolled out for student submissions. Examples of autograded pre-lab questions and general feedback are provided in Table 2, below.

Table 2 - Example pre-lab quiz questions and general feedback provided.

Example Pre-Lab Quiz Question	General Feedback
The typical input resistance of the LM741C is (value) (units) . Note: The first blank is the value as a number and the second blank is for units.	From the Electrical Characteristics table on page 2 of the LM741 specification sheet. This is an automatically graded question.
What is the gain of the non-inverting op-amp circuit if R_1 = 12 KΩ and R_2 = 22 KΩ?	Plug the values into the equation in the previous problem and simplify. This question is automatically graded.

While quantitative questions were largely graded effectively by the autograding system, there were a few pitfalls the course staff encountered. Students who used commas to indicate decimal separations could be flagged as incorrect and would need to be manually awarded points. Additionally, there were some short answer questions that could only have one answer listed as correct, even if there were many possibilities (i.e. different units or combinations). In general, any question marked as incorrect was assessed by a dedicated TA to ensure that it was truly wrong, and that it could not be explained by a propagation of error from a previous part of the same question, something that would have been easier to determine in the old quiz format. One part of the quizzes that could not be autograded was the TinkerCAD schematics students submitted for each circuit. An example circuit is included in Figure 3 and the corresponding TinkerCAD solution is in Figure 4. The grading process for these was the same as previous semesters; a list of standardized criteria for common errors and associated point values were compiled and applied to each circuit by copying and pasting into the feedback box, with some room for TA interpretation.

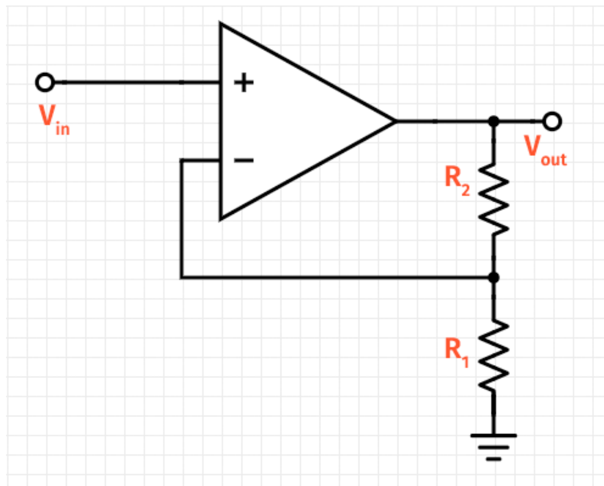

Figure 23 - A non-inverting op-amp schematic provided in one pre-lab quiz.

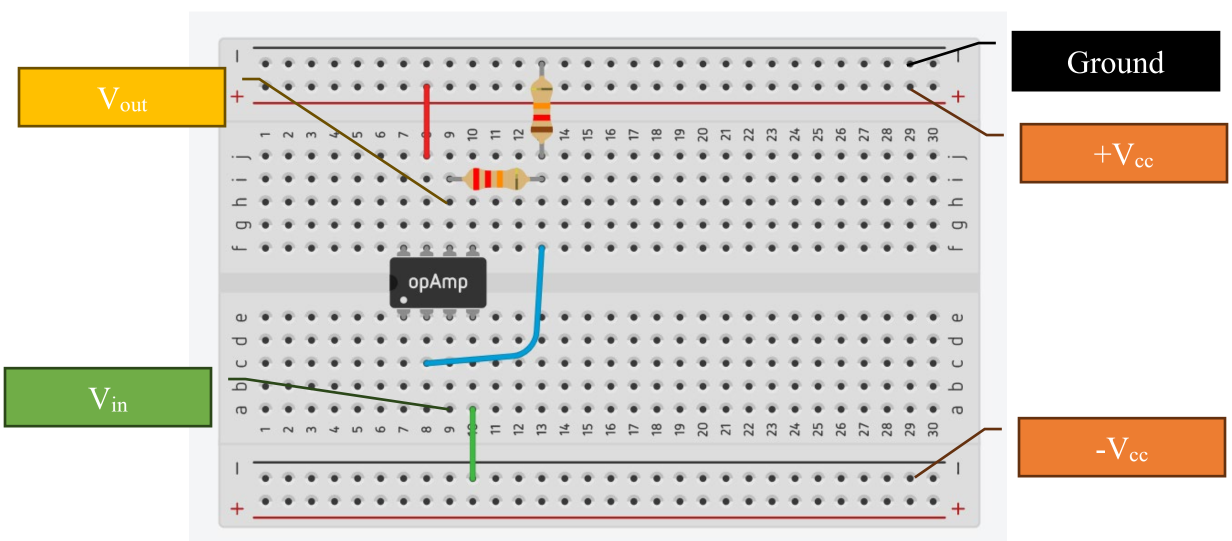

Figure 34 - Example TinkerCAD solution for the schematic in Figure 3.

To streamline this process, after reviewing common points of confusion on lab reports from the previous two semesters, a list of "standard" comments for each assignment were stored in the shared TA resources folder. Not only does this result in more thorough explanations, but it gives future TAs an idea of topics to address during the lab period before students begin writing their report. Similarly, providing personalized feedback on TinkerCAD schematics (something that was new to many students without a background in electronics) allowed the TA to suggest that students seek individual help during office hours if creating the schematics was something they needed more guidance on.

Through a conversation with course consultants, we were able to identify the benefits and pitfalls of the automated feedback from the perspective of students enrolled in the class. The students said they admired how well thought out and structured pre-lab assignments were but wished that the association of questions were clearer. They were unclear about how to view the comments and grades post-submission, as the submission in the grading system reads “not yet graded” until inspected by the TA, and the students were unaware of this reason. Similarly, the students sought more specific feedback from the autograded questions, as well as an indication of what questions were going to be personally reviewed by the TA and would therefore not receive immediate right/wrong feedback. From this conversation, the team worked on incorporating their feedback into the remainder of the class. A video was created by a CA to help students navigate the submission to find the comments and the process of TA review was explained to the students to ensure that they understood why some questions were not automatically marked as right or wrong in the system, and that some responses marked as wrong could later be manually updated by the TA. Drop-down selection boxes were added to questions with many possible units to ensure that the students could choose the appropriate units without typos taking away their points. The answer explanation text in later pre-labs was adapted to include more specific feedback, namely listing the location in the E-text or class notes where the answer could be found.

To encourage engineering intuition and self-assessment, the team implemented several checkpoints within lab protocols that encouraged students to stop and check to make sure that their values make sense. These checkpoints prompted the students to review their pre-lab assignments and class notes to ensure that their values were consistent with their calculations. Through these checkpoints, students could evaluate their results for themselves and identify problems that they needed help with while still in class where teaching staff could aid in their troubleshooting. Additionally, these checkpoints served as a checklist for both students and course staff to ensure that students had all the correct data necessary for the post-lab analysis to reduce the need for benchtop work in office hours. The implementation of in-class review of the TinkerCAD design after pre-lab submission enabled students to immediately evaluate their designs and remedy their circuits without waiting for the TAs to grade their submissions. This encouraged student reflection and self-assessment to set all students up for success in their lab class.

About 20% of the students completed each end-of-semester survey. Unfortunately, the data from the surveys did not provide significant insight into the effectiveness of the feedback changes that were implemented throughout the semester. Additional data will be collected in future semesters.

Discussion

This project indicates substantial progress toward developing an engaging educational environment in STEM fields. The project’s approach of improving assessment feedback and enhancing organization presents a comprehensive model for addressing clarity within laboratory settings. These approaches assessed and enhanced classroom relationships and transparency between the professor and the students.

With the implementation of more structured feedback on assignments, training videos on finding pre-lab feedback, and peer-check systems, the quality of feedback and assessment in laboratory settings greatly increased. By supplying consistent and detailed feedback, instructors and course assistants were able to effectively guide students toward a more profound understanding of the material. In addition, training videos designated students to independently access and interpret feedback, encouraging self-directed learning. The peer-check system further enhanced the learning experience by promoting collaboration, critical thinking, and constructive feedback among students.

Regularly assessing student progress through checkpoints and improving the structure and clarity of pre-lab assignments significantly enhanced organization and accountability in the laboratory setting. These strategies enabled students to stay on track, identify areas of weakness, and develop a deeper comprehension of the underlying concepts. Instructors could foster a more organized and efficient learning environment by delivering a clear and structured framework for pre-lab work. Additionally, instructors can monitor students' understanding of the concepts and see if the material is applied.

The lack of standardization in instructor feedback can lead to variations in quality and clarity, hindering student learning. Additionally, challenges in monitoring student improvement over time and inefficient methods for comparing pre-lab responses to post-lab results can limit the effectiveness of feedback. Time constraints for instructors and student workload can further impede the provision and incorporation of detailed feedback. Finally, limited opportunities for peer interaction and constructive criticism can reduce student engagement and motivation, negatively impacting the overall learning experience.

Conclusions and Future Work

Overall, the additional feedback mechanisms provided insights for both students and course staff throughout the semester. Student course staff and the course consultants provided valuable insights into the professor may not have been aware of due to the structure of the course. Additionally, the conversational nature of the team meetings and course consultant meetings allowed for deeper understanding than a survey, since there was an opportunity for follow-up questions and open discussions. While anecdotal evidence suggests that the autograding and checkpoints were a positive addition to the course, further analysis of the grading mechanisms, survey data, and additional conversations with the course consultants are needed to fully understand the impact. From discussions with the course staff, the checkpoints did encourage students to check their work and ask questions during the lab. However, there is room for improvement in the process, such as adding more checkpoints and more clearly identifying the purpose of the checkpoints. Each of these forms of feedback will be updated and continued in the next semester.

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