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Guided Modules Emphasizing Process-Based Troubleshooting Techniques Help Below-Average Performing Students Improve Instrumentation Skills

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Abstract

Instrumentation laboratory courses commonly focus on the design and development of novel technologies. Students work to develop the technical skills necessary to design and build circuit systems and their associated software, but often lack practice in troubleshooting skills and device testing and optimization. While the design of new devices is often more attractive to students, understanding how devices fail and learning structured ways to test and repair failure points is an important aspect of engineering design.

To address this limitation, seven self-contained modules were developed to reinforce troubleshooting skills in a junior level bioinstrumentation course. These modules were not part of the course requirements but were presented as an additional tool to help students develop a logical, structured process for troubleshooting basic electronic circuits. Troubleshooting modules consisted of a hardware component (built using National Instruments prototyping boards and a variety of basic electronic components and transducers) and the associated software (National Instruments ELVIS and LabVIEW) necessary to test and identify the failure point of the electronic circuit. A step-by-step instruction manual was also included with each module to provide the technical specifications of the circuit and guide the students through a structured troubleshooting process.

Final individual course grades and GPA scores from instrumentation-related core courses were both used to categorize below-average and above-average students in an effort to understand the effect of the course performance as well as the effect of their overall instrumentation skills on the observed response. Students that accessed the troubleshooting modules between the midterm and final laboratory exams were identified by the completion of a survey and served as the experimental group. Students that did not use the modules throughout the course served as the control group.

Laboratory exams evaluate the students' ability to design and troubleshoot electronic circuits and associated software and therefore were used to assess the impact of these changes. Midterm and final exam grades were compared between experimental and control groups for above and below average students using a two-way ANOVA. Due to the small class size, the impact of these modules was assessed over three semesters (fall 2015, fall 2016, fall 2017).

The interaction effect between the use of modules and student performance was found to be statistically significant when below and above average students were categorized based on the final individual course grade ($p=0.044$) and when they were categorized based on the GPA scores in instrumentation-related courses ($p=0.006$). These results indicate that the effect on laboratory exam grades observed after using the troubleshooting modules will differ for below-average and above-average students.

Our data suggests that using guided modules is an effective tool to improve hands-on troubleshooting skills, and that the observed response is greater for below-average students.

Troubleshooting Skills in the Bioinstrumentation Laboratory Course

Laboratory courses play an important role in engineering education, providing the students with opportunities to develop proficiency in experimental design, data analysis, the use of relevant equipment and tools, team work, communication skills and other practical skills relevant to the engineering practice[1-3]. As design instruction has become more prevalent, engineering programs have incorporated design courses and embedded design projects at several stages of the undergraduate curriculum[4], including instructional laboratories. However, most of these courses focus on the early stages of the design process (i.e. problem identification, design criteria, research and brainstorming), with only some including a prototyping component and very few emphasizing the testing and iteration steps of the engineering design process. As a result, students rarely develop a structured process to test, debug and optimize equipment, components or prototypes.

The Bioinstrumentation Laboratory (BIOE 385) is a required junior-level course that uses open-ended instruction to equip students with technical skills in electronic circuits and software. The course focuses on designing, building and testing two different devices: and optical immunoassay and an electromyogram-reflex device. The project-based structure of this lab provides students with the opportunity to apply some aspects of the engineering design process to solve problems in instrumentation. Students work on fabrication and optimization of discrete project components before they begin testing of the completed device.

Because the course focuses on the development of biomedical technology, students practice the technical skills necessary to design and build circuit systems and their associated software, but rarely acquire significant experience in troubleshooting skills and device testing. While the students are gaining in-depth knowledge of the instrumentation topics covered in the lab, they often lack the ability to apply a structured troubleshooting process to repair or optimize an unfamiliar device or electronic circuit. Students become proficient in working with their specific devices, but when presented with new devices they are not able to extrapolate the process knowledge, even when failure points are similar to the ones they encounter in lab. Learning and practicing a structured process to test and repair failure points that can applied to any device is an important skill in the engineering practice[5].

The Bioinstrumentation laboratory course has been modified in previous years to emphasize the troubleshooting process by:

- including course materials that describe common steps used when working with electronic circuits,
- providing additional testing tools and equipment for students to practice these skills outside of class,
- including a troubleshooting section as part of the final project report, and
- asking procedural questions in class to help students familiarize themselves with the troubleshooting process[6,7].

Although some of these efforts have resulted in allocating more in-class time to device testing and optimization, most of these initiatives did not focus on troubleshooting techniques using a structured process (but rather on specific technical content), resulting in students using a trial-and-error approach when troubleshooting their devices.

Intervention and Assessment

To address the observed limitations, seven self-contained modules were developed to reinforce troubleshooting skills in the bioinstrumentation course. These modules were not part of the course requirements but were presented as an additional tool to help students develop a logical, structured process for troubleshooting basic electronic circuits. Troubleshooting modules consisted of simple electronic circuits: a hardware component (built using the National Instruments ELVIS II engineering workstation and prototyping board and a variety of basic electronic components and transducers), and the associated software (National Instruments ELVIS and LabVIEW) necessary to test and identify the failure point of the modules. A step-by-step instruction manual was also included with each module to provide the technical specifications of the circuit and to guide students through the steps of the structured troubleshooting process.

The impact of the troubleshooting modules was assessed using hands-on laboratory exam grades. Laboratory exams are designed to evaluate the students' ability to build and troubleshoot electronic circuits and associated software and therefore represent a valid tool to assess the impact of these changes. Midterm and final exam grades were compared between experimental and control groups. Due to the small class size (34-41 students per year), the impact of these modules was assessed over three semesters (fall 2015, fall 2016, fall 2017).

Students that did not use the modules during the semester served as the control group. Students that accessed the troubleshooting modules between the midterm and final laboratory exams were identified by the completion of a survey and used as the experimental group. Students in the experimental group were also asked to evaluate the effectiveness of the modules in terms of complexity, effectiveness as a learning tool, and the ease of use of the step-by-step manual associated with each module.

To assess if the use of modules affected the measured response differently based on student performance, students were classified into low and high performing students. Final individual course grades in the bioinstrumentation laboratory course and GPA scores from all instrumentation-related core courses in the bioengineering undergraduate curriculum were both used to categorize below-average and above-average students. These two categories were used independently to analyze our results in an effort to understand the effect of the course performance as well as the effect of their overall instrumentation skills on the measured response.

Changes in grades between midterm and final laboratory exams for students in the control and the experimental group were compared using an unpaired, 2-tailed t-test. A two way unbalanced analysis of variance (ANOVA) was conducted to evaluate the interaction between the use of troubleshooting modules and student performance (below-average vs. above-average students) on the laboratory exam grades, using both classifications as described above.

Results

The increase in grades from midterm to final exams was statistically higher (p=0.035) for students that used troubleshooting modules (n=33) when compared to students that did not use the modules as an instructional tool (n=79). These results indicate that the use of the modules positively impacts the students' ability to troubleshoot electronic circuits (Figure 1).

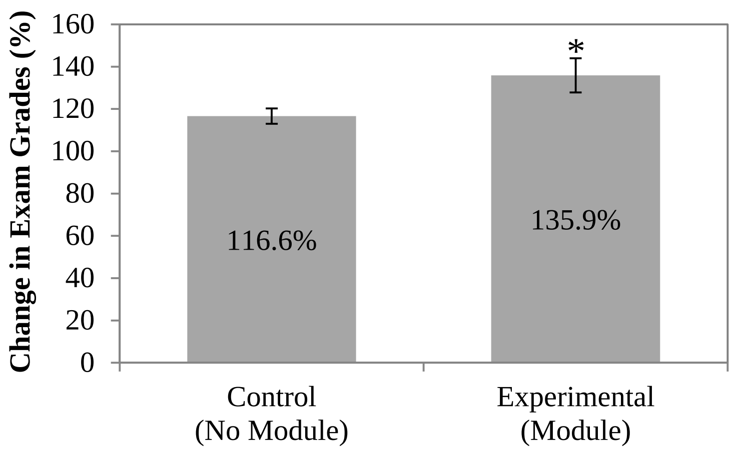
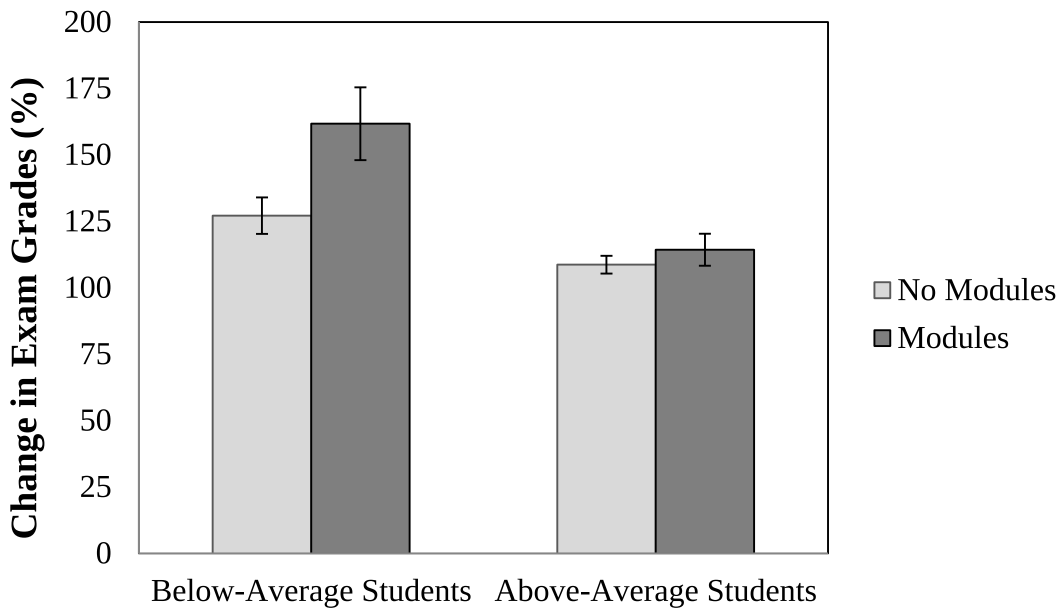


Figure 1. Effect of using troubleshooting modules on laboratory exam grades. Data represents mean ± standard error for the control (n=79) and experimental (n=33) groups (*p<0.05).

Since high-performing students are more likely to use optional studying tools such as the troubleshooting modules, the results were further analyzed taking into consideration student performance. To understand if the observed increase in grades associated with the use of modules differently affects high and low performing students, the control and experimental groups were further divided based on final individual course grades and instrumentation-related GPA.

Using the individual final course grade (average score = 74.5%) to categorize above-average and below-average students, the effect of using troubleshooting modules on student performance was evaluated. A two-way ANOVA was conducted to explore the interaction between the use of modules and the student course performance on the laboratory exam grades. Students were divided into two groups according to the use of modules, and divided again according to their final individual overall grade in the course as above-average and below-average performers. The interaction effect between the use of modules and the final individual course grade was found to be statistically significant (Figure 2), F (1, 108) =4.15, (p=0.044). *These results indicate that the observed increase in laboratory grades as a result of using troubleshooting modules was even more significant for students that performed below average in the course.*

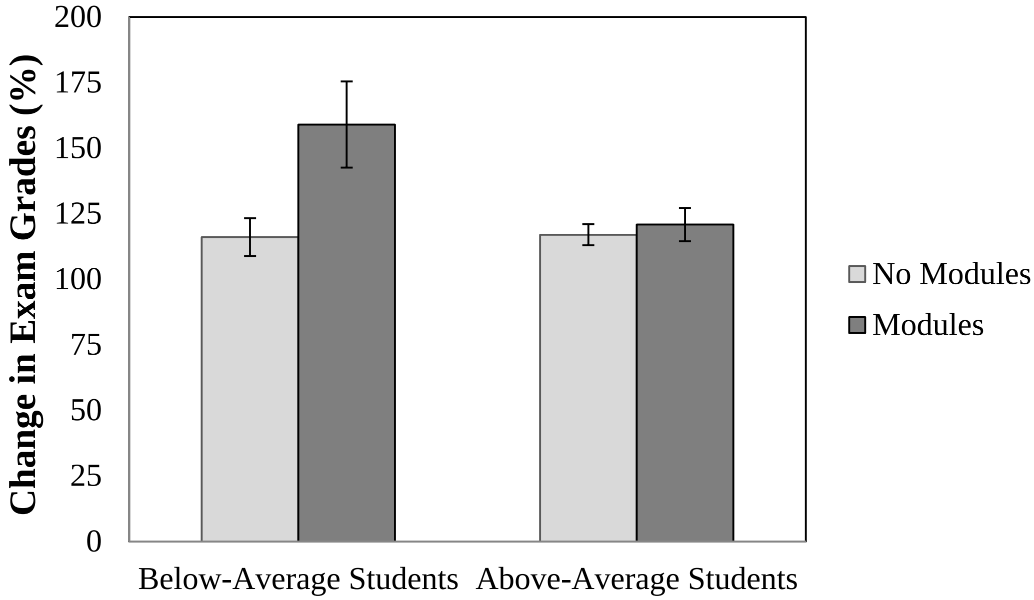


	Below-Average Students	Above-Average Students
No Modules	127.1 ± 6.9%, n=34	108.7 ± 3.4%, n=45
Modules	161.8 ± 13.7%, n=15	114.3 ± 6.0%, n=18

Figure 2. Effect of using troubleshooting modules on student performance for below- and above-average students, as identified by final course grades (p=0.044). Data represents mean ± standard error of the percent increase in laboratory exam grades.

To evaluate the effect of using troubleshooting modules on student performance based on electronics skill level, the individual GPA scores for all the instrumentation-related core courses required to complete the Bioengineering major were used to categorize students (Figure 3). A two-way ANOVA was conducted to explore the interaction of the use of modules and the student performance on instrumentation-related courses on the laboratory exam grades. Students GPAs for 4 instrumentation-related courses (two pre-requisite and one co-requisite for the bioinstrumentation laboratory course) were calculated and used to categorize students as above-average and below-average performers.

Using the instrumentation-related GPA provides an independent metric of above-average and below-average student performance. These results are independent from the scores obtained in laboratory exam grades and provide a fair measurement of the effects of using troubleshooting modules. The interaction effect between the use of modules and the instrumentation-related GPA scores was found to be statistically significant (Figure 3), $F(1, 104) = 7.74$, ($p=0.006$). *These results show that the increased performance observed in students that used the troubleshooting modules is even more significant for students with a GPA below average in instrumentation-related courses.*



	Below Average Students	Above Average Students
No Modules	116.0 ± 7.2%, n=29	117.0 ± 4.0%, n=50
Modules	159.0 ± 16.4%, n=13	120.9 ± 6.4%, n=20

Figure 3. Effect of using troubleshooting modules on student performance for below- and above-average students, as identified by instrumentation-related GPA scores (p=0.006). Data represents mean ± standard error of the percent increase in laboratory exam grades.

Survey Results

To understand the students' perception on the usefulness of the intervention, students in the experimental group were asked to reflect on the modules in terms of their complexity, their effectiveness as a learning tool and the ease of use of the step-by-step manual associated with each module. A five-point Likert scale was used to measure the student responses on the three dimensions (Figure 4, n=103).

When asked if the modules displayed an appropriate level of *complexity*, 62% of the students agreed or strongly agreed, 22% of the students responded in a neutral manner and 16% of the students disagreed or strongly disagreed. While these results suggest that complexity could be increased in the available modules, it is important to note that the modules were intentionally designed with a low complexity level to allow the students to focus on the process rather than the technical skills.

The students also evaluated the effectiveness of the modules as a *learning tool*, with 78% agreeing or strongly agreeing that the modules provided a useful tool to practice their troubleshooting skills and study for the hands-on laboratory exams. 18% of the respondents were neutral and only 4% disagreed of strongly disagreed.

The ability to use the step-by-step *instruction manual* was critical to help the students follow and develop a structured process when troubleshooting the modules. In addition to providing technical specifications and relevant diagrams, the manual indicated the steps commonly used to troubleshoot electronic circuits, including testing steps and expected results. The majority of the students completing the survey agreed or strongly agreed that the manual provided was easy to follow (92%). Only 5% of the students disagreed with this statement and 3% reported a neutral opinion.

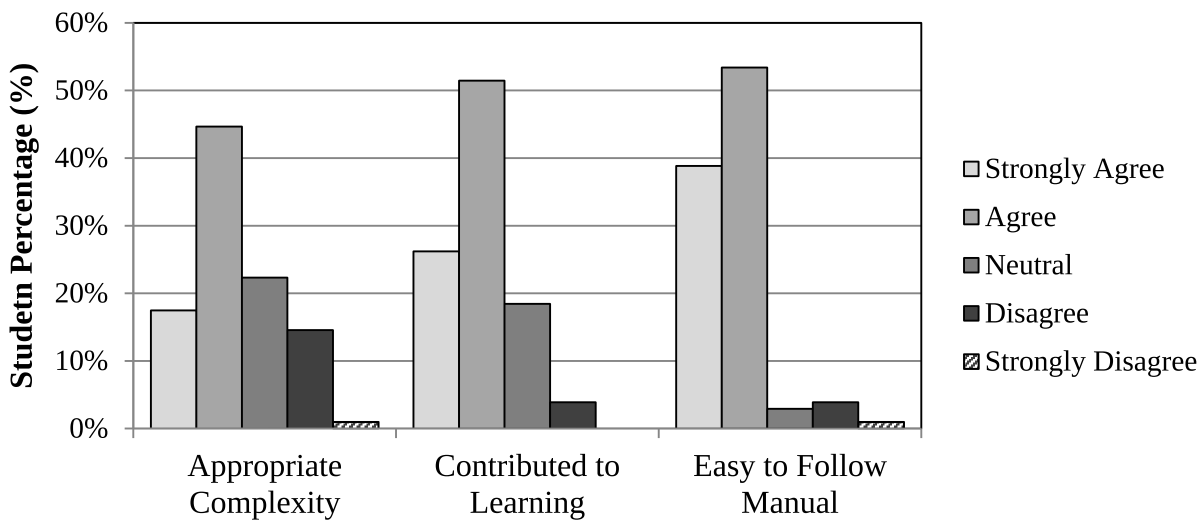


Figure 4. Student responses to post-module survey were measured using a 5-point Likert.

Instructor Observations and Student Comments

While the addition of these modules proved to be an effective tool to develop the students' ability to troubleshoot electronic circuits, the implementation of this tool has considerable challenges. Since electronic circuits need to be probed and modified while troubleshooting, the students often fail to return the modules to their original "broken" state. As a result, students can get frustrated when they try to troubleshoot a working circuit or when the modules do not align with the instruction manual descriptions. For the modules to be an effective tool, they need to be checked and modified frequently, which represents a considerable amount of work for the instructor.

When students were asked to comment on some of the areas of improvement, the most common categories were:

- *Module Design*: some modules were too simple or did not add any new technical concepts.
- *Implementation issues*: the modules were not always in their original "broken" state.
- *Instruction Manual*: the answers were not written at the end of the manual.

While these comments should be taken into consideration for future work, the simplicity of the modules and the absence of solutions in the manual were designed intentionally to encourage students to focus on the process, rather than just reading the correct answer or spending all the time learning new technical skills.

Students also commented on the strengths of the modules:

- *Module Design*: technical concepts learned in lab were reinforced.
- *Instruction Manual*: troubleshooting steps were clear and easy to follow.

Select Student Comments:

"I liked the way the steps were laid out in a logical progression. Instead of just trying random things to see if you can get it to work, like we sometimes do on our projects, there was a very clear process to follow"

"The modules helped me think systematically, going element by element or section by section through the circuit to find the problem"

Discussion

The ability to follow a structured process when testing and troubleshooting electronic circuits and devices is an important skill in instrumentation. Because of the broad nature of the field and the rapid development of new technology, biomedical engineers are often exposed to new devices and equipment that they are not familiar with. Developing a process to identify and repair failure points in a structured manner is an important skill for bioengineering students.

The troubleshooting modules were created based on common failure points that students encounter regularly in the lab. However, instead of expecting the students to identify and repair the failure point (which typically results in a trial-and-error approach), these modules provide examples of how to follow a structured process during troubleshooting. Before the introduction of these troubleshooting modules, prototyping boards and electronic components were provided to help students study for the laboratory exams. Even though the time spent studying for exams was not measured in this work, the author expects that students' studying habits did not change drastically and that the observed changes were not just a result of students spending more time in lab, but rather the development of an ability to follow a troubleshooting process to test and repair different electronic components.

While this study presents some limitations associated with the self-selection of students into the experimental group, the use of instrumentation-related GPA as a way to classify students into low and high performing suggests that the change is not only a result of student overall motivation or interest in the subject.

The results presented in this paper suggest that using guided modules is an effective tool to improve hands-on troubleshooting skills, as can be seen when comparing laboratory exam grades in control and experimental groups. This response is further increased in low performing students, identified based on GPA and course grades.

Acknowledgments

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References

1. Ernst, EW. (1983) A New Role for the Undergraduate Engineering Laboratory. IEEE Transactions on Education. E-26 (2), pp. 49-51

2. Feisel LD, Rosa, AJ. (2005) The Role of the Laboratory in Undergraduate Engineering Education. Journal of Engineering Education, pp. 121-130

3. National Research Council (1986). Engineering Undergraduate Education. Washington, DC: National Academy Press.

4. Dym CL, Agogino AM, Eris O, Frey DD, Leifer LJ. (2005) Engineering Design Thinking, Teaching, and Learning. Journal of Engineering Education. 94(1), pp. 103–120

5. Prince MJ, Felder RM (2006). Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. Journal of Engineering Education. 95(2), pp. 123-138

6. Anderson LW, Krathwohl DR, Airasian PW, et al. (2001) Taxonomy of Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives, 2nd ed. Boston, MA: Pearson Allyn & Bacon

7. Tofade T, Jamie Elsner J, Haines ST. (2013) Best Practice Strategies for Effective Use of Questions as a Teaching Tool. Am J Pharm Education. 77(7), 155