Measurement of the Effect of Interactive Questions in Lab Manuals on Student Learning

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Abstract -- This research paper will describe the results of an experiment in which two groups of students in a laboratory class received different web-based lab manuals featuring interactive questions, the treatment with many more interactive questions than the control. The hypothesis was that asking students more questions would cause the students to reflect on the task at hand, which would in turn increase learning. This study was motivated by work on experiential learning, particularly Kolb's Experiential Learning Cycle, which suggests that moving from concrete experiences into reflective observation is essential for learning.

This learning was assessed by direct assessment of students' performance on an in-lab exam that assessed both theoretical and experimental skills, surveys of self-efficacy administered before and after the treatment, coding student answers to reflection questions in the lab manuals, and counting the number of answers to interactive questions to determine compliance.

Significant results from the experiment indicated that students in the treatment group took longer to complete the lab, felt greater time pressure, performed more poorly on the in-class evaluation, and had fewer metacognitive gains than the control group. The treatment appears to have increased the cognitive load of the laboratory experience and thereby reduced learning.

1 Introduction

Kolb's experiential learning theory [1] suggests that students learn from experience by cycling between states of concrete experience, reflective observation, active experimentation and abstract conceptualization. This theory has been applied successfully to the design of engineering laboratory courses [2], and inquiry-based interventions that specifically attempt to invoke the transition from concrete experience to reflective observation have shown some success [3]. This work tried to build on Kolb-based examples by examining another method of inspiring reflection: interactive questions in web-based laboratory manuals.

Interactive questions in this context refer to questions embedded in a laboratory manual website that respond dynamically to student mouse movement or clicks. For instance, a question that relates laboratory learning to classroom topics might appear between steps of a task in a lab manual, and hovering the mouse over it will reveal the answer. Literature on web-based laboratory manuals is sparse ([4] is an exception), as is literature on the effect of lab manuals on learning in general [5], though some attention has been paid to the effect of laboratory manuals on student satisfaction [6]. Incorporating modern, dynamic web design into laboratory manuals is an unexplored field.

This work examines the hypothesis that interactive questions encourage students to reflect on the purpose of the steps in the lab manual, and thereby gain both learning benefits (by cycling further around Kolb's learning cycle) and metacognitive benefits (by reflecting on the context of the laboratory task). This hypothesis was tested in a controlled experiment at Harvey-Mudd College, a small, STEM-focused liberal arts college. The introductory engineering course at the college teaches discipline-agnostic, mathematical modeling of engineering systems using a flipped classroom with tightly coupled laboratory sessions. Approximately half of the students in the laboratory sections received treatment lab manuals with many interactive questions, while the other half received control lab manuals that contained fewer questions. The groups were assessed in various ways, including surveys, open response reflection questions on their weekly lab deliverables, and an in-laboratory midterm examination that required both laboratory skills and theoretical understanding.

The results did not confirm the hypothesis, and in fact treatment students appeared to have reduced learning compared to the control. The additional cognitive load imposed by the interactive questions appears to have interfered with the learning process, which is an effect reported before in literature on electrical engineering instructional manuals [7].

Section 2 of this document discusses the implementation of the experiment in detail, Section 3 presents the results of the assessment, and Section 4 concludes the work and proposes future directions for research.

2 Methods

2.1 The Host Course

The introductory engineering course that hosted this study is a requirement for all sophomores regardless of major. It is intended to give students an introduction to a variety of engineering disciplines using a unified mathematical framework and to let students experience the work of engineering by fusing analytical and experimental efforts in a laboratory section. The choice to focus on many disciplines and on experimental practice is intended to help students choose majors by presenting a wide and representative cross-section of engineering.

The course consists of tutorials, which occur twice a week, and practicums, which occur once a week. Tutorials are flipped classrooms, so students are required to watch videos to introduce them to the theory for the week before the start of tutorials. In-tutorial time is devoted to practicing the concepts covered in videos using group quizzes and in-class assignments. Practicums are separate 150 minute laboratory sessions that occur once a week, and they are intended to supplement theoretical learning with hands-on practice. Students complete practicums in self-selected pairs.

The laboratory setups for the practicum are in two adjacent rooms, and students work in both rooms while one instructor and four lab assistants move back and forth between them. The instructional staff is different for each lab section; four instructors split up the eight practicum sections, and each section had a different set of lab assistants.

The course has a midterm exam that features an in-lab examination, which provided an organic opportunity to assess practicum-related learning goals. Though the practicums were completed in pairs, students took the midterm alone.

2.2 Study Design

This study was designed to interrogate the effects of lab manuals on student learning, so the assessed learning had to be selected carefully. Two learning targets were selected: use of the oscilloscope, which was taught solely in practicum and not in tutorial, and making a mathematical model of oscilloscope data, which required combining learning from both practicum and tutorial.

The treatment in this study was applied to four consecutive practicums -- called 2B, 2C, 2D and 3A -- by providing different lab manuals to the two practicum rooms. The treatment is discussed in greater detail in Section 2.3. These practicums were selected for a reason: Practicums 2B and 2C focus on teaching students how to use oscilloscopes. Practicums 2D and 3A have students use the artifacts developed in practicums 2B and 2C to collect data, which means students are not required to use oscilloscopes in these two practicums. However, these last two practicums have particularly tight coupling to material being taught in tutorials, so it was hypothesized that treatments applied during these weeks could particularly enhance students' modeling skills.

Students were asked for informed consent to participate in the study during the second practicum of the year, three weeks before practicum 2B. Because students register for a practicum time slot and not a particular room, it was necessary to randomize the room assignment of each pair of students to ensure the control and treatment groups were homogeneous. Pairs of students were assigned randomly to control and treatment rooms during the first practicum section.

Assessment data was gathered in a variety of ways: an in-lab examination, reflection questions in laboratory manuals, and surveys of students. The in-lab examination is discussed in greater detail in Section 2.4, and other assessment tools are discussed in Section 2.5.

2.3 Treatment Details

Figure 1 shows two examples of interactive questions in the treatment manual from the treatment manual. Figure 1a shows a question where students could hover their mouse cursor over the question text to see the answer. In Figure 1b, students were invited to click on multiple choice answers until they found the correct one, receiving immediate feedback on each click. Students were asked to record these responses in the submission sheet required for each practicum.

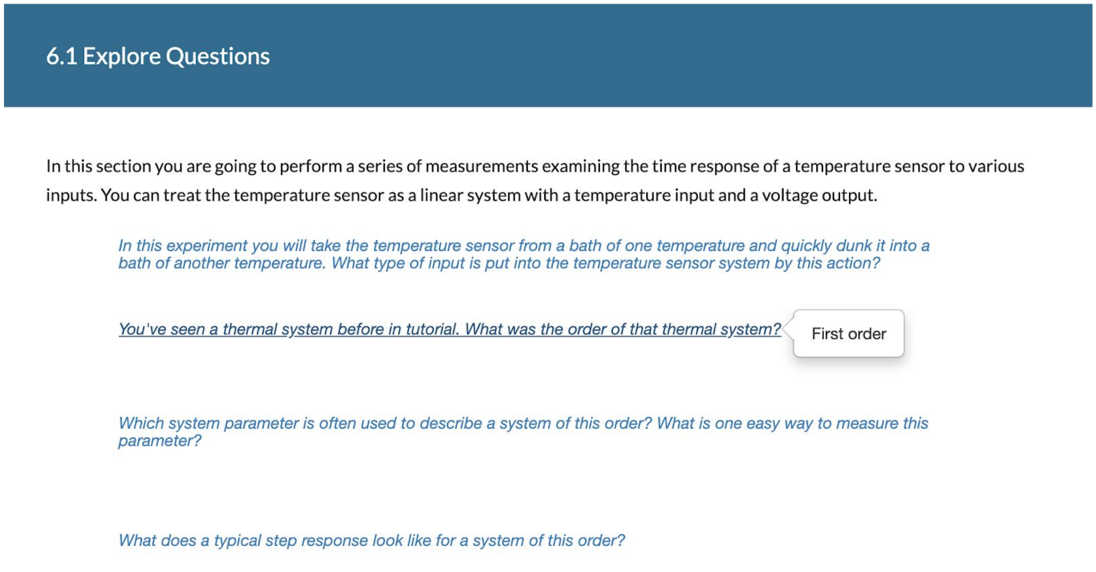
The treatment group received a lab manual with more interactive questions than the control group. The control group received a manual that was similar to those used in previous years: it contained instructions with a few basic interactive questions. The number of additional interactive questions was different in each lab: practicum 2B included 13 more questions in the treatment manual, Practicum 2C included 4 more questions, Practicum 2D included 7 more questions, and Practicum 3A included 5 more questions.

2.4 In-Lab Midterm Examination

The midterm described below provided quantified evidence of student learning in two ways: the total score on the in-lab exam, which combined measurements and students ability to apply theoretical understanding to those measurements, and images of students oscilloscope measurements. The images of oscilloscope measurements revealed how well students used their oscilloscopes, which was a learning outcome from practicum that was not taught in tutorials. The in-lab exam required students to use concepts taught in tutorial to analyze data measured on their oscilloscopes, so their total score represented students' ability to connect concepts taught in practicum to those taught in tutorial.

The practicum midterm asked students to interact with the apparatus pictured in Figure 2. Given a "mystery box", students were tasked with determining a mathematical representation of its behavior. Doing so required connecting a power supply to the 6V and 0V terminals, generating the proper signal for the input, and connecting an oscilloscope to the output signal to measure the system's output. The output signal captured from the oscilloscope was required to answer the final few questions on the exam, which were related to the in-class topic of extracting parameters from step responses.

Students' measured output signals were submitted along with the exam, and these images were coded for specific features (proper scaling, saved with scope interface vs. cell phone, etc.) to create categorical data that represented student facility with the instrument. Examples of uploaded oscilloscope data can be found in Figure 6 and descriptions of the coding and results can be found in Section 3.2. Students were allowed to ask instructors to set up parts of their hardware in exchange for a penalty on their final score. These requests were tracked as another means of assessing the competence of the treatment and control group.



6.1 Explore Questions

In this section you are going to perform a series of measurements examining the time response of a temperature sensor to various inputs. You can treat the temperature sensor as a linear system with a temperature input and a voltage output.

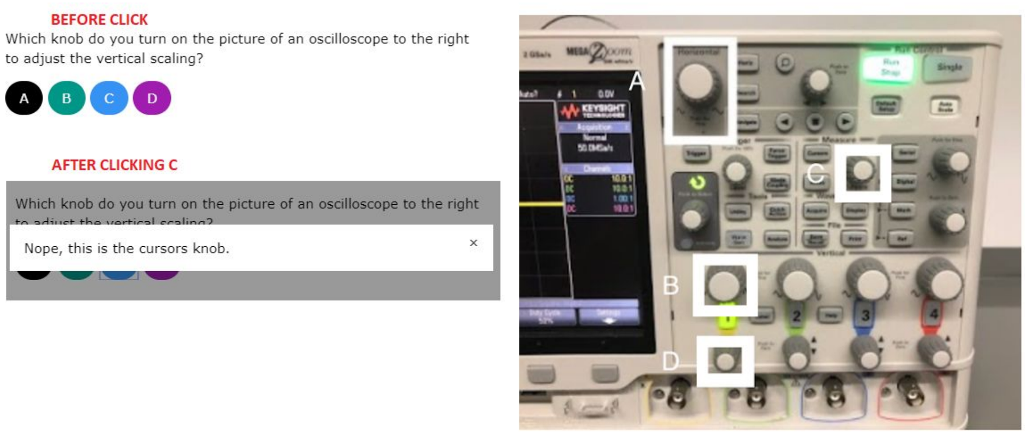
In this experiment you will take the temperature sensor from a bath of one temperature and quickly dunk it into a bath of another temperature. What type of input is put into the temperature sensor system by this action?

You've seen a thermal system before in tutorial. What was the order of that thermal system? First order

Which system parameter is often used to describe a system of this order? What is one easy way to measure this parameter?

What does a typical step response look like for a system of this order?

(a)



(b)

Figure 1. Example interactive questions listed in Practicum 2B.

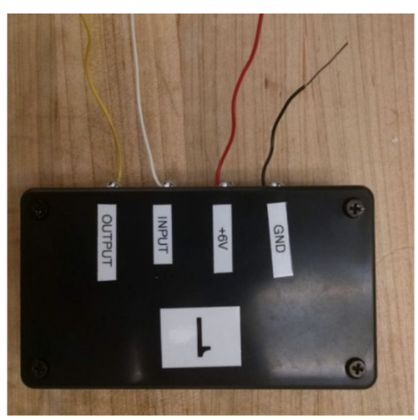


Figure 2: Experimental apparatus for in-lab assessment.

2.5 Other Data Collection Instruments
Data for this study came from three major sources: the midterm exam, student responses on weekly worksheets required in practicum, and surveys of students. The midterm is described in Section 2.4 above, and the other two data sources are discussed in this section.

The weekly practicum worksheets required students to submit answers to the questions “What was the main take away from this practicum?” and “What is one thing in this practicum that you still need to understand better?”. The responses were coded with codes that indicated key themes like “Want to Understand Oscilloscope Better” or “Time Management is Important” as described in Section 3.1. In addition, the worksheets required students to record answers to interactive questions and the times at which parts of the practicum were completed, which helped assess the student compliance with answering questions and the time cost of incorporating the questions into practicums.

Surveys were conducted at the beginning of the course and after practicum 2C, which was the last practicum that taught oscilloscope skills. These survey questions can be found in Table 1, and responses to them were on a 5 point Likert scale. The table indicates if the question was asked in both the pre-course survey and the post-2C survey, or only in the post-2C survey.

Asked On	*Question: Rate your agreement with the following statements (5 point Likert Scale)*
Pre, 2C	I can use an oscilloscope to measure an electrical signal.
Pre, 2C	I can generate a waveform on a function generator.
Pre, 2C	I can use a power supply to supply a voltage.
Pre, 2C	I can solder through hole components to a PCB.
Pre, 2C	I can use a breadboard.
Pre, 2C	I understand why engineers and scientists use benchtop test equipment like oscilloscopes or function generators.
2C	Over the last 2 weeks, the questions in our practicum manual helped me understand the concepts in the practicum.
2C	Over the last 2 weeks, the questions in our practicum manual helped me see the link between practicum and tutorial.
2C	Practicum 2C stimulated my interest in using oscilloscopes in the future.
2C	Practicum 2B stimulated my interest in using oscilloscopes in the future.

Table 1: Questions in surveys. Some questions not used in the study omitted from the table

The survey questions were designed to probe students' self-efficacy (the first six questions), student metacognitive gains caused by the intervention (the next two questions) and student attitudes towards oscilloscopes (the final two questions).

2.6 Summary

In summary, students were split into treatment and control groups randomly. The treatment group received a practicum manual with more interactive questions than the control group, but that was otherwise identical to the control. The treatment was applied during four practicums, during which students learned how to use oscilloscopes and saw physical realizations of concepts that were critical on the midterm examination.

Students worked in pairs during every practicum, and they produced data by answering open response questions (which were later coded), writing down their answers to the interactive questions and recording the time at which they finished particular parts of the practicum. Individual students completed the surveys to assess sentiment and confidence with lab equipment before and after the practicums that focused on oscilloscope skills (practicums 2B and 2C). Students also individually completed their practicum midterm, which provided a total score that indicated their ability to combine lab and theoretical learning, and images of oscilloscope outputs, which indicated their learning of practicum-only skills.

3 Results and Analysis

3.1 Population Statistics

249 students were enrolled in the host course, and 233 gave consent to participate in the experiment. 123 students were in the treatment group and 110 were in the control group. The Respondents who answered the pre-survey question "I can use an oscilloscope to measure an electrical signal" with "strongly agree" were excluded from the study. 9 students were excluded on this basis, which resulted in 118 students in the treatment group and 106 students in the control group. Overall course enrollment was 49.8% female and 29.8% underrepresented minority. Demographic information was stripped from the dataset, so compositions of control and treatment groups are unavailable.

3.2 Results from Practicums

The interactive questions seem likely to have little effect if students didn't answer them, so a first step in analyzing results was checking whether students complied with instructions to answer them. The answers that students copied into the weekly practicum worksheets were reviewed to determine if students answered all of the questions. Students in the control group answered at least 97% of the questions asked of them in each practicum. Students in the treatment group answered at least 90% of the (larger number of) questions asked of them in practicums 2B, 2D and 3A. Treatment students only answered 79% of the questions asked in practicum 2C, though was probably a result of students running out of time to complete practicum 2C. Response rates increased in practicums 2D and 3A, and the large peak at 150 minutes in Figure 3 shows that practicum 2C was the longest of the practicums.

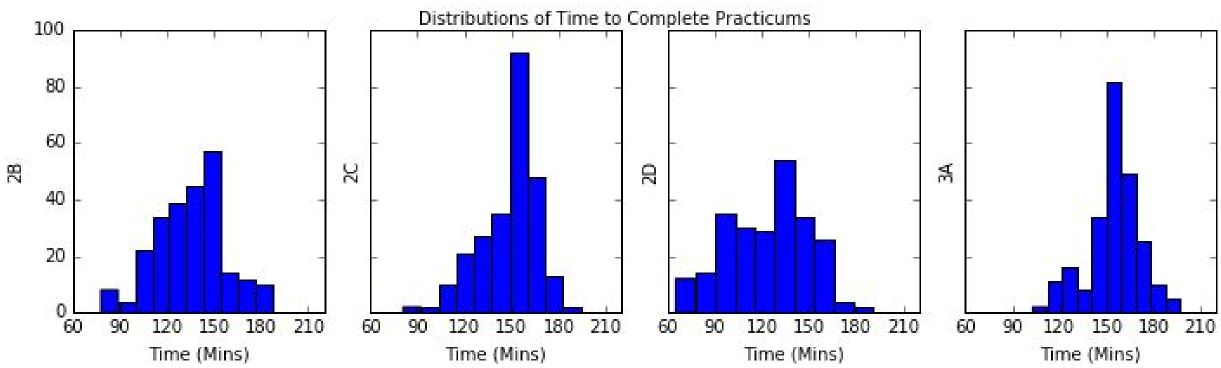


Figure 3: Histograms of total time to complete each practicum.

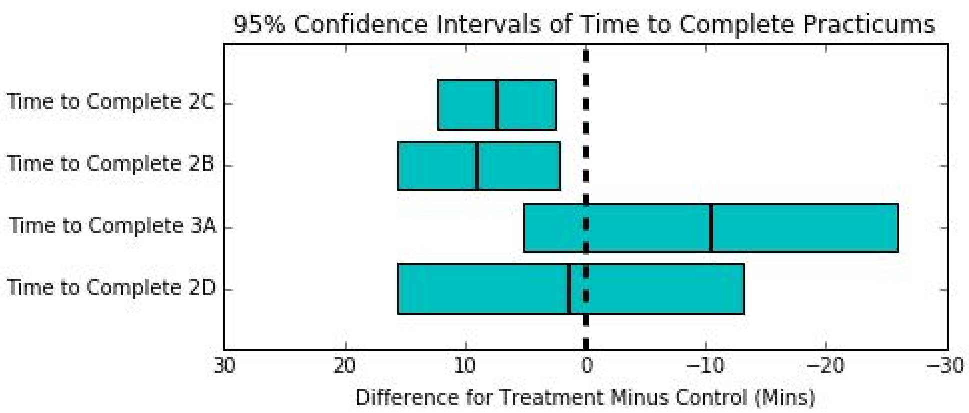


Figure 4: Confidence intervals for time to complete practicums 2B, 2C, 2D, and 3A.

The times reported on student's practicum worksheets were used to calculate how long it took students to finish each practicum. Figure 4 shows the difference in completion times between the treatment and control groups. Practicums 2B and 2C took a significantly longer time for the treatment group to complete than the control group, while practicums 2D and 3A show no significant difference in completion times between the groups. Note that practicum 2C took the most additional time for the treatment group when it was already the longest practicum.

The amount of time per extra question varies between practicums. The practicum 2B treatment manual had 13 more questions than the control, which suggests 0.6 ± 0.4 minutes per extra question. Practicum 2C, on the other hand, had 4 extra questions, which implies treatment students took 2.2 ± 1.7 minutes per extra question. Though there are 7 and 5 extra questions in

2D and 3A respectively, there are no significant differences in the time taken on these practicum between the control and treatment groups, which suggests the treatment students finished each question faster than the control students.

The difference in time-per-question suggests that not all interactive questions were created equal. Some required students to struggle and caused time pressure, notably in Practicum 2C where the total time required was long, while others seem to have had little effect, as in Practicums 2D and 3A. The treatment student's faster pace on questions in later practicums could have been caused by student fatigue: teaching staff reported anecdotes of students expressing frustration with the questions in later practicums. However, the extra time required per question in practicums 2B and 2C suggests that the questions were a real burden for students.

Figure 5 shows the results from coding the two open ended questions on the submission sheet, which asked students what they would like to understand better and to state a key takeaway from the lab. Three raters coded the responses separately, awarding the codes listed in Figure 4 to each comment. The raters then came together to resolve disputed codes to generate a final dataset. Only codes with an inter-rater reliability of >66% were retained for the final codebook, and those codes appear on the y-axis of Figure 4. The three raters' average inter-rater reliability was 75% before resolving their answers and 100% after resolving them.

The time management code for practicum 2B was the only significant result from coding these responses. Again, this shows that treatment students were aware that the practicum (particularly 2B) took longer to complete, as more students in the treatment group indicated they needed to improve their time management skills than the control group.

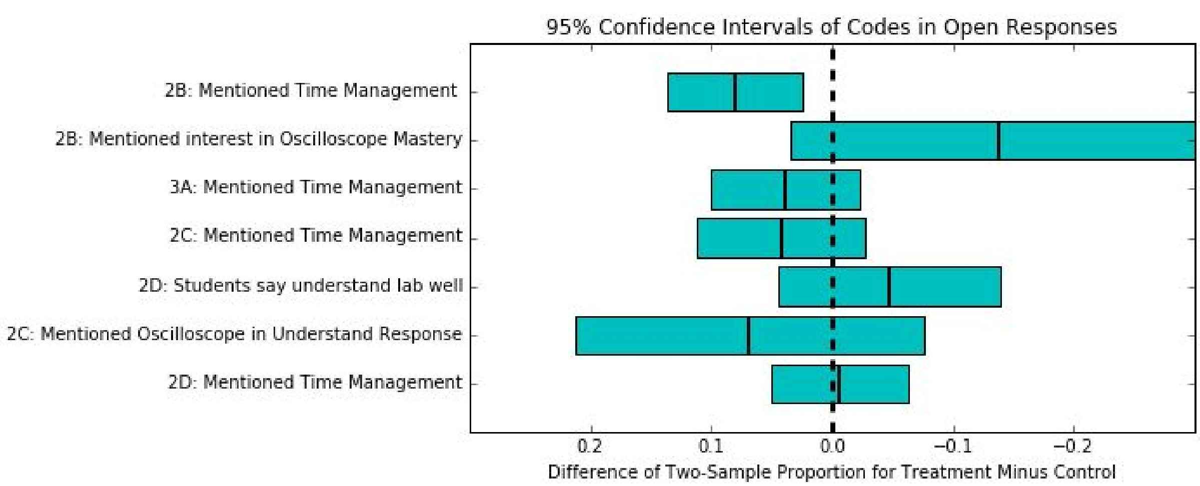


Figure 5: Confidence intervals for difference in proportion of comments receiving listed codes between control and treatment groups.

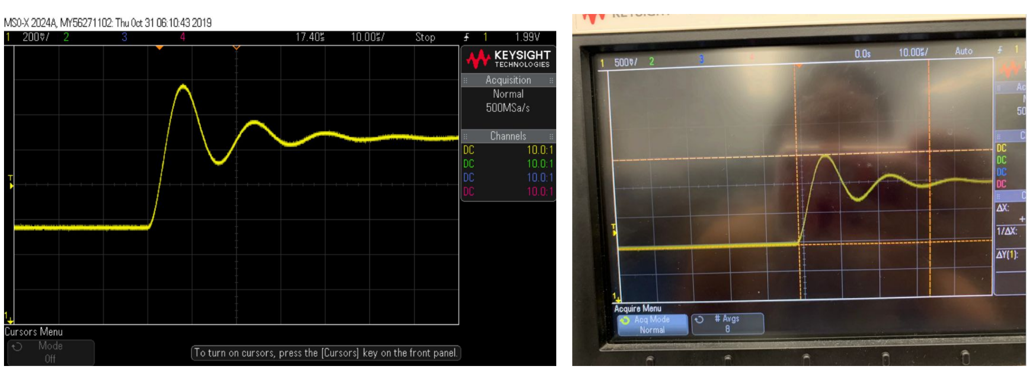
3.3 Results from Midterm

Oscilloscope images that students submitted during the midterm exam were coded based on the following codebook:

- Was the oscilloscope trace scaled properly such that it spans four divisions both vertically and horizontally as requested in the exam manual? Correctly scaled oscilloscope traces suggest a student has basic competence with the oscilloscope.
- Was the horizontal delay used to align the signal to the left side of the screen? Using this feature represents an advanced understanding of the oscilloscope.
- Was the image recorded using the built-in save/recall feature of the oscilloscope? This is more desirable than taking a cell phone picture, and is another proxy for basic competence in using the oscilloscope.
- Did the student request that an instructor help to set up their oscilloscope during the exam? This represents a lack of mastery of the oscilloscope or a failure of recall.

For reference, Figure 6a shows an example of a good oscilloscope trace: it is properly scaled, it uses the horizontal delay and it was exported using the built-in save/recall feature. Figure 6b shows a bad oscilloscope trace, which is not properly scaled, does not use the horizontal delay, and which was captured using a cell phone.

Figure 7 shows the difference of proportions of control and treatment groups awarded these codes. The only significant result is that the control group requested help less often than the treatment group, which suggests the control group had learned about how to use oscilloscopes more effectively. This suggests the treatment harmed learning, perhaps by increasing the cognitive load on students in the treatment practicums.



(a) (b)

Figure 6: A comparison of good and bad oscilloscope submissions.

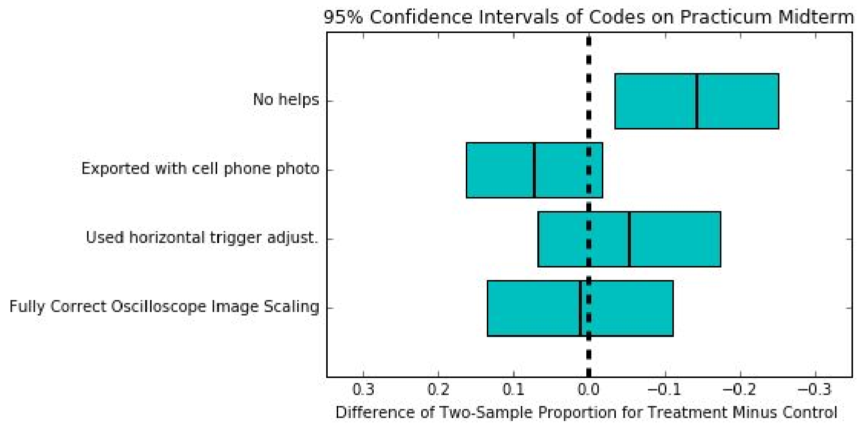


Figure 7: Confidence intervals of the difference of proportions of students receiving specific codes on practicum midterm.

3.4 Results from Survey

The difference between the control and treatment responses between before the course to after practicum teaching oscilloscope skills (2B and 2C) to the Likert questions shown in Table 1 were analyzed by calculating the 95% confidence intervals of the difference. The confidence intervals of questions related to self-efficacy are shown in Figure 8, which shows no significant differences between treatment and control. The results from the questions about affect toward oscilloscopes and metacognitive benefits of the intervention, also listed in Table 1, are shown in Figure 10. There is one significant result: the control group agreed with the statement "Over the last 2 weeks, the questions in our practicum manual helped me see the link between practicum and tutorial" significantly more than the treatment. This suggests that the control students had better metacognitive gains than treatment students in addition to learning gains.

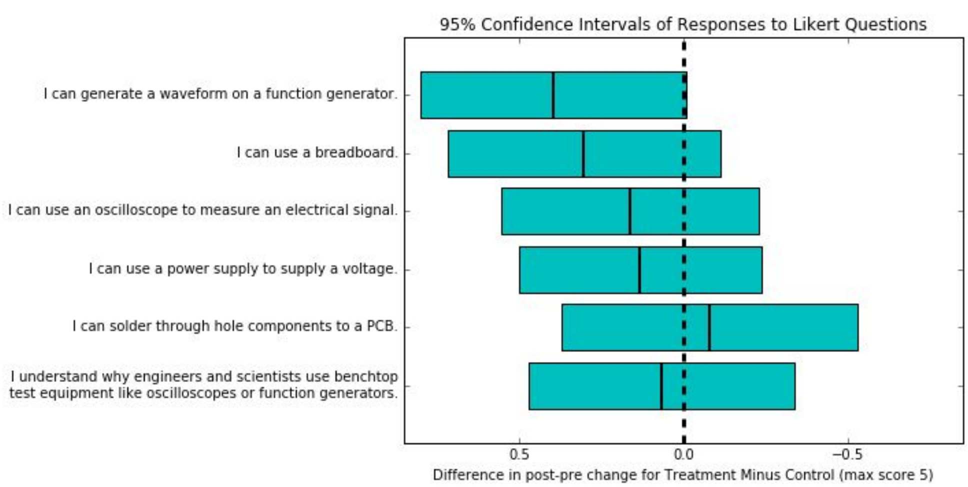


Figure 9: Confidence intervals of difference in responses to Likert scale survey questions between control and treatment groups before course versus after Practicum 2C.

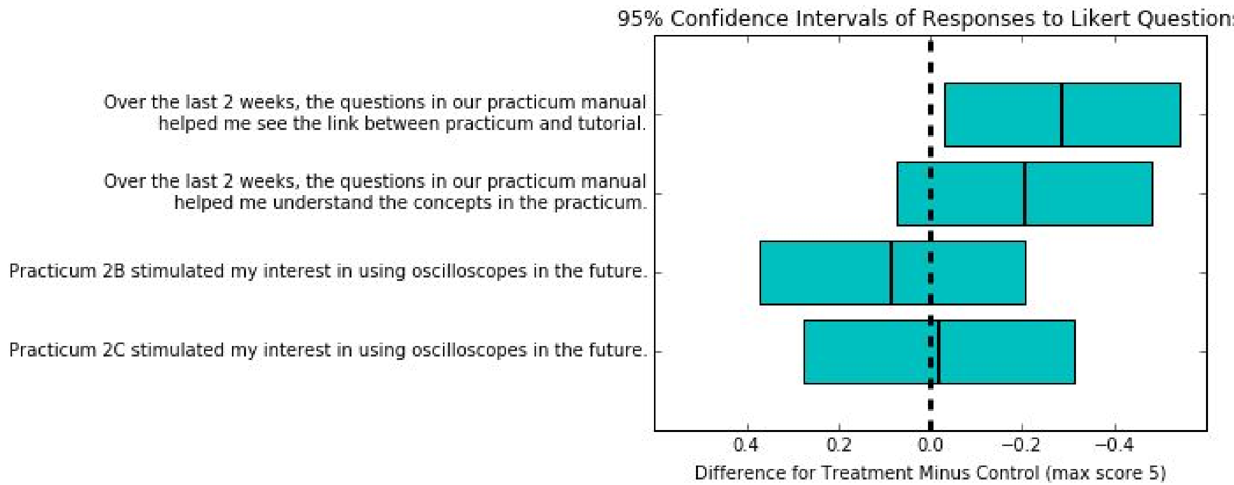


Figure 10: Confidence intervals of difference in responses to Likert scale survey questions between control and treatment groups.

4 Conclusion

This work was designed to improve student learning by including interactive questions in a lab manual to spur reflection and move students through Kolb's experiential learning cycle. However, results from the study indicate that adding questions actually harmed student learning and metacognition, which can be explained with a cognitive load model. Instead of causing students to reflect on the concepts presented by the laboratory manual, the interactive questions presented competing tasks that increased cognitive load and time pressure on the students, so students did not learn as well. The treatment had no effect on affect or self-efficacy, as evidenced by the surveys and open answer questions.

One failed implementation shouldn't doom interactive, web-based lab manuals: there is a rich space for other versions of this study to exist. For instance, this study required students to copy and paste the answers to their questions into weekly worksheets, but that activity is a textbook source of cognitive load. Eliminating that requirement could render this intervention more effective. Time pressure was also a factor in students' experience of this study, and adding the interactive questions to less time-strapped labs could also have better results. Finally, web technologies offer many ways to make dynamic laboratory manuals, and some types of questions may work better than others; Studies of laboratory materials and of their relation to modern media are a rich avenue for creative scholarship on teaching and learning.

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