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Exploring an Inquiry-based Learning with Peer-teaching Pedagogy in a Physiological Signals Lab Course

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Introduction and Background

Active learning can support meaningful engagement with science concepts and practices, which has been known to improve students' affect toward science [1]. Professors recognize the opportunity for students to engage in such active learning during laboratory courses and have employed successful methods of doing so that foster meaningful engagement [2,3,4]. One method of active learning and enhancing student engagement is using inquiry-based learning in a laboratory environment. This method also helps to develop creativity and critical thinking skills [8,9] which are not easily practiced in cookie-cutter labs [5,6,7]. Collaborative learning including peer-teaching has also been shown to increase student learning [10] in a laboratory environment [3]. Though collaborative, student-led inquiry and peer-teaching has been shown to support multiple learning outcomes, it remains unclear how much support students need in laboratory courses and how such pedagogical methods can influence students' confidence in their learning. In this approach, inquiry-based learning followed by peer-teaching was used in a Quantitative Physiological Signal Analysis Lab course for 4 offerings. An iterative, design-based approach was used to continually analyze and improve the implementation of this pedagogical technique. Continuing from a previously presented Work in Progress detailing the first offering which is not covered here [11], *the goal of this pedagogical approach was to increase confidence and enthusiasm of physiological signal collection and analysis by having students develop "expertise" through guided exploration (inquiry-based learning) and then teaching their peers how to perform and analyze a specific experiment (peer-teaching).* Presented here are findings from a three-year design-based exploration of the course developed including lessons learned regarding inquiry and peer-teaching approaches, the role of such methods on student engagement, and additional factors that influenced student attitudes and confidence.

Course Structure and Assessment

Table 1. Enrollment and participation information.

Year	Year 1: 2015	Year 2: 2016	Year 3: 2017
Enrollment per section and total	19+19+9 = 47	19+18+14 = 51	14+26+9 = 49
Number of responses to the SALG survey	27	11	7
Number of responses to the end of semester evaluation	35	22	30

The Quantitative Physiological Signal Analysis Lab is a required one credit, three hour per week lab in the junior year. The first half of the semester reflected traditional style labs focused on foundational concepts of the nervous system such as diffusion, simulations of ion channels and action potentials, and using circuits to model a membrane and an action potential. The second half of the semester focused on the collection and analysis of physiological electrical signals and is the portion of the semester where the inquiry-based learning followed peer-teaching was implemented as described below. Each offering, once a year, had 3 sections capped at 24 students with the exception of one section in the third year that had 26 students (Table 1). Each section had a different senior undergraduate teaching assistant (TA) who attended the entire lab to help students and answer questions with the additional expectation of grading prelabs and electronic notebooks (ELNs). No graduate students participated in the course. Every section was led by the same instructor.

Table 2. Expectations for student achievement from the lab experiment. The order of the labs shown (top to bottom) is the order that they were performed (weeks 9-13 out of 15).

Earthworm Conduction Velocity	• Record an action potential after stimulating (poking) head
	• Record an action potential after stimulating (poking) tail
	• Calculate action potential velocity
	• Compare velocity for forward and backward travel
	  ○ Does it vary with different worms or other variables?
	  ○ Does it vary with first versus second AP?
	• Elicit varied numbers of action potentials to determine stimulus threshold (how many APs does it take for a muscle response)

Human Conduction Velocity	• Record an action potential after stimulating the ulnar nerve in triplicate at different locations
	  ○ Consider error, standard deviations, propagation of error…
	• Calculate action potential velocity based on three different stimulation locations
	  ○ Account for other factors in the timing by comparing stimulation at different locations

Electromyography (EMG)	• Collect EMG signals using myDAQ with homemade circuit and Labview
	• Analyze signal in order to compare trials using an appropriate measure
	  ○ Can use Labview or MATLAB or other
	• Compare muscle effort for various applied weights and speeds of bicep curls
	  ○ Are there differences in frequencies?
	  ○ Compare using an appropriate signal characteristic (e.g. amplitude, power, intensity…). Explain why it's appropriate.

Electroencephalography (EEG)	• Collect alpha waves under two different conditions (suggested eyes open and closed) • Quantitatively compare the dominant frequencies under the two different conditions ○ This can be done by collecting multiple segments of each condition to determine an average power per time segment

Electrooculography (EOG)	• Convert voltage to approximate angle (calibration dependency for each person and application of electrodes)
	• Describe signal characteristics
	  ○ Determine function for any decay
	  ○ Can you determine the velocity of head movement from signal?
	• Measure reaction time to move eyes only

A brief description of the physiological signal measurement techniques and the objectives to be met is shown in Table 2. These were presented to all of the students before they were asked to complete a survey ranking their preferred topic to study. Groups of two or three students were created by the instructor based primarily on the survey while not regrouping students together. Prior to the Inquiry lab, groups were given critical background information to prepare for lab including references regarding relevant physiology, measurement techniques, and data analysis specific for the acquired signal. The groups were allowed a three hour lab period to troubleshoot and practice the measurement and analysis techniques in order to achieve the instructor provided objectives making them the “experts”. The instructor played an active role to ensure all groups understood and achieved proper data collection. All of the groups presented their techniques and how to achieve the objectives using recorded presentations and providing written procedures. Materials were due the following week when a traditional lab was performed. This was one week prior to the first peer-teaching lab (Worm AP propagation) to allow enough time to post materials from Thursday’s section for Monday’s section to review on the online Learning Management System, commonly known as Blackboard. During the next five lab periods, the experiments were performed. The “experts” acted as additional teaching assistants (TAs) during the lab period to answer questions and assist the students in achieving the instructor provided objectives.

The impact of this pedagogy was assessed using two anonymous surveys: the end of the semester institutional course evaluation and an additional online survey. ‘Student Assessment of their Learning Gains (SALG)’ focused on student-perceived learning gains, confidence in their understanding, and enthusiasm for learning the new material assessed by Likert-style and free response questions [12]. The Likert-style questions ranged from “no gains” or “no help” scoring a 1 to “great gains” or “great help” scoring a 5. Both surveys were administered after the peer-teaching labs and before grades were posted.

Year One Findings

The quantitative values from the SALG survey (Table 3) showed nice results with 19 to 41 percent of respondents reporting “great gains” in their understanding for each experiment. Only one respondent reported “no gain” which was for EOG. These perceived learning results compliment decent actual learning results as shown by grades (Table 4).

Qualitative SALG results showed an overall positive tone with only a couple of respondents (n=27 out of 47 students) answering negatively for multiple questions. When asked to comment on how the way this section of class was taught helps them remember key ideas, most students liked the approach but one respondent replied “I feel the student instruction left me wanting for more guidance towards more specific lab goals.” When asked what they will carry with them into other classes or other aspects of life, responses were almost all positive and included “writing good procedures”, “how to measure a signal”, “it was useful to learn how to effectively teach someone how to conduct an experiment”, “signal processing capabilities, experience, and confidence”, and “how to work with and teach peers.” While many of the responses supported the objective of this technique, some showed a student-perceived dependence on the instructor.

The end of semester institutional course evaluations (n=35 out of 47 students) had two text response questions. The first asked for comments and the second asked for improvements. Most of the comments focused on how "helpful" the instructor was and how "organized" and "interesting" the course was. Some examples that focused on the peer-teaching section of the course specifically were:

- "The teams for the second half of the class worked really well and the labs were very clear and they were all completed successfully."
- "the expert section of the class was really fun. Being the TA really pushes you to understand more about the experiments and troubleshoot problems with different errors seen throughout the class."
- "I liked that she had us all run a lab and be a TA. We learned a lot making our own protocol and teaching others."

In the same evaluation, most of the suggested improvements focused on lab report or experiment expectations being unclear (44% of respondents), unknowledgeable instructor (28% of respondents), and timeliness of grading (20% of respondents). Some examples that focused on the peer-teaching section of the course specifically were:

- "For the expert labs, there was not much feedback on the procedures and presentations made by the students. As a result there were issues with the procedures that the student experts could not have anticipated. More instructor feedback on the student made procedures would have been helpful."
- "While I did like the expert lab experience, I feel like I learned more about the one that I was an expert in rather than all the other ones."
- "The "expert" method of teaching was really frustrating because students who didn't know what they were doing were "teaching" students who didn't know what they were doing."

These results overall were optimistic. The grades and SALG results (Tables 3 and 4) showed a little room for improvement regarding actual learning and self-perceived learning gains and enthusiasm while the feedback in the course evaluation led to a conclusion that focusing on clarifying objectives would benefit the students. The feelings expressed by the students during lab time were positive and collaborative and thus this pedagogical approach continued with some improvements.

Year Two

<u>Year 2 Improvements</u>. Some intentional changes for the second offering included:

1. A few expectations for assessments in the first half of the semester with the traditional style labs were clarified.
2. An early lab using circuits that had been challenging was divided into two weeks.
3. The label for the peers who were teaching was changed to try to create reasonable expectations. The "experts" were changed to "leaders".
4. The order of EEG and EOG was switched. A common misunderstanding was the assumption that the very large and clear signal from moving the eyes (EOG) was brain waves (EEG). The intent was by having the class practice EOG collection first that

students would recognize the signal as EOG even if the "leaders" did not in their teaching materials.

5. Due to non-course related circumstances, the instructor intentionally spent less time in the lab. For the first half of the semester, instructor's attendance and participation in the lab was fairly normal as compared to previous semesters but after the inquiry-based labs and during the peer-teaching part of the course, the instructor spent very little time in the lab. The anticipation of this change was made by preparing the students at the beginning and throughout the semester for a decrease of instructor presence.
6. Updates in lab objectives for the peer-teaching labs were:
    - The addition of the word "quantitatively" was included in the EMG objectives in order to clarify expectations and encourage less discussion focused on the shape of the signal and encourage more rigorous analysis.
    - The addition of the expectation for a statistical comparison was included in the EEG objectives. This was accompanied with discussion with the "leader" groups how that could be achieved.

Year 2 Findings. Based on electronic notebook (ELN) and lab report grades, EMG and EOG learning improved but Human Action Potential scores decreased (Table 4). In all three cases, the same background information was sent to the "experts"/"leaders" in the Year 1 and 2 offerings. The addition of the word "quantitatively" to the EMG objectives pushed students to look beyond a qualitative comparison of the signal shape obtained which had a positive impact on student learning. While the expectation of switching the order of EOG and EEG was intended to help the student's understanding of the EEG signal, it is possible that it negatively impacted EOG. No clear explanation could be found for the decrease in Human Action Potential. In both years the "experts"/"leaders" received good scores for their presentations and procedures.

The quantitative SALG results (n=11 out of 51) showed an interesting trend (Table 3). Every single question showed a decrease in student-perceived learning gains as well as attitudes and confidence in the subject of collection and analysis of signals. EEG and EOG still showed a high percent of respondents reporting "great gains" in their perceived learning which may be a reflection of starting with a lesser understanding of the signals compared to EMG and action potential propagation. The qualitative SALG showed mixed results. General comments were made about moderate learning.

For the end of semester institutional course evaluations (n=22 out of 51), the responses when asked for comments were a smattering of topics with no distinct themes but most were positive. Most of the improvements focused on being available in lab (59% of respondents) and timeliness of grading (36% of respondents). Very few responses to either comments or improvements addressed specifically the peer-teaching part of the course. They were:

- "The leader lab section was the best part of the lab. Instructions provided by peers were easy to understand."
- "I really like the layout of the course where we complete pre-written procedures then switch over to peer-led labs. It really makes you learn the material and WHY you're doing an experiment instead of just coming to class and running through a procedure that's already written out."
- "The Leader Labs were helpful in increasing knowledge about particular subjects."

- “I did enjoy the TA leader lab, but this was also hard to create when everything was open ended.”
- “I don’t like the student teaching. I would rather have a traditional short lecture at the beginning of the lab.”

These results made clear that instructor presence was important, even if the instructor was not active in the class and sat along the side of the room. The student’s self-perceived learning scores, enthusiasm, and confidence were low while their grades were not low. General comments about the course suggested that the students made a connection between instructor presence and the instructor caring about the course and students. This disconnect between perceived learning and actual learning when students do not feel supported has been reported before [13,14,15] and thus was not a surprise but was not the intent. In fact, starting off the semester by clearly explaining the decrease in presence might have been the wrong tactic. The conclusion from this offering was that adjustments including selling the students on the pedagogical technique and tying it to the lack of instructor presence would be made. Overall, the lab activities appeared to be going well.

Year Three

Year 3 Improvements. Some intentional changes for the third offering included:

1. Some early assessments were streamlined in an attempt to reduce instructor grading, increase timeliness of returning grades, and simplify student workload. The weekly post-lab individual discussion paragraphs were removed. The group ELN which had always been completed in Microsoft OneNote by the end of lab was now due one week after lab to allow for a complete recording of data analysis.
2. An instructor change for the signals lecture course that precedes this course resulted in MATLAB instruction and explicit use being removed from that course and leaving the students less prepared for data analysis of real signals. The first couple of labs were restructured to accommodate this change and teach students general signal analysis techniques and tools.
3. A university change in schedule resulted in 1) the Monday section being moved to Tuesday, 2) an additional week of pre-inquiry lab preparation time, 3) the traditional experiment being removed after the inquiry lab and materials being due at the end of the lab period giving students a total of 6 in-lab hours to work on the production of their materials, 4) Thanksgiving falling in the middle of the peer-teaching instead of after, and 5) the removal of a two week final project.
4. In addition to having “leaders” post presentations and procedures, the requirement for analysis assistance such as MATLAB code or Excel template was made formal.

Year 3 Findings. As compared to Year 1, EOG notebook scores significantly increased similar to Year 2 (Table 4) while the perceived learning stands out as particularly low (Table 3). While there appeared to be a dramatic decrease in the EEG lab report scores, a few very low scores brought the average down. As EEG became the last lab of the semester, a few students did not complete the report.

Unfortunately only 14% of students responded to the SALG survey so comparing any one question is problematic but compared to the Year 1 almost all the values decreased (Table 3). Interestingly, the one data point that did not decrease suggests a self-perceived gain overall for the course. Looking closely at the data showed that all respondents answered with at least a self-perceived moderate gain (3 out of 5) in "the main concepts explored in the class" which cannot be stated about the Year 2 class. The EOG score dramatically decreased compared to the rest and may be explained by a lack of "leaders". When assigning groups to their "leader" signal, not many students picked EOG and thus an unintentional lack of "leaders" occurred. Usually 4-6 groups were assigned to a signal but only 2 were assigned so a lack of instructional material was produced. This further suggests that a lack of support can lead to a lack of perceived learning gains even if learning occurred. For the qualitative questions, students complained about the technology, mostly MATLAB and OneNote, but very few focused specifically on the peer-teaching aspect of the course.

For the end of semester institutional course evaluations (n=30 out of 49), most of the comments focused on the clarity of objectives and expectations with a few comments regarding the peer-teaching labs:

- "I really like the leader labs"
- "Allow students to figure out how to teach an experiment with the teaching section at the end of the semester"
- "I especially liked the second portion of the class when the students were the teachers"

Most of the suggestions for improvements focused on technology issues. OneNote was complained about by 24% of the respondents and MATLAB or assistance with digital filtering was also complained about by 24% of respondents. Only 19% mentioned a lack of instructor presence (down from 59% Year 2) but a complaint that occasionally arises came across as a bigger issue this year; the fact that it is a one credit course was mentioned by 24% of respondents. Comments included:

- "I felt that the labs at the end of the semester with students making the protocols and being the TA were fun, but overall the labs were easy and didn't really do much for students. We all got experience writing the experiment, but we had to give all the supplemental materials for other students to complete the lab"
- "[The instructor] would often leave the lab, thinking that the students teaching the lab would be enough and a lot of times, they didn't know what they were talking about…?"

These results showed that how technology is taught and used is critical for its acceptance in a course. OneNote had always been used previously but in the attempt to reduce student workload by removing assignments and raising expectations on this mode of assessment students responded negatively. Completely contrary to the goal, the complaints increased from occasional to frequent about the workload for credit earned. Also, since they had not previously been taught how to use tools to filter a signal and teaching the technique was added into this course, the students were less comfortable with the technique and may not have had adequate time to master it before being required to use it. Possibly with these other aspects of the class to complain about, the improvement of explaining the expectations and purpose, or the increased independence of this cohort of students, the lack of instructor presence was mentioned less.

Conclusions

Meaningful learning occurred while perceived learning declined compared to Year 1. Years 2 and 3 showed learning while the student's rated their perceived learning lower. As the objectives were continually clarified and were presented from the beginning, students knew what they needed to achieve and were able to meet the objectives independent of the support structure of the course or if they took advantage of it. The likely cause for a decrease in perceived learning were the distractions and lack of course or instructor satisfaction. Year 2 had a decline of instructor presence which may not have been informed correctly and clearly bothered the students while Year 3 had technology related complications. With a lack of support felt by students in Year 2 and lack of expertise with proper tools in Year 3, students may not have been comfortable likely playing a role in the decrease in student confidence. These distractors which impacted the students' satisfaction with the course would have an impact on their perceived learning gains [15].

For those students that entered the course with a desire to learn more about a particular physiological signal, they thrived during the inquiry-based learning. They enjoyed experimenting with the technique and their enthusiasm showed when helping their peers achieve the objectives (as observed in class). An example from Year 2 of a student who thrived commented, "Being a leader helped me really understand one subject (EOG) and that understanding could be translated into moderate understanding of EMG and EEG as well." However, some students did not embrace taking charge of their own learning or appreciate the decline in instructor guidance.

This technique of inquiry-based learning followed by peer-teaching is highly recommended but with very close monitoring by the instructor. The students in this program almost always have an instructor present in the classroom or lab. Some science labs in the first and second years of the curriculum are led by graduate teaching assistants, but our students have only been exposed to other undergraduates as assistants to an instructor which might have been part of the challenge. Some students do not embrace taking charge of their own learning or lack confidence in their or their peer's ability to perform.

A collaborative atmosphere has been designed into all labs within our department due to the benefits of more effective learning in that environment [13,16]. On the SALG survey when asked to comment on "how the support you received from others helped your learning," students tended to comment about either their peers or the instructor. For all three years, those comments addressing the support of their peers were generally positive; "discussions with peers also helpful, because I didn't understand things until we talked them through" and "the other students while working there through the same problems as myself and knew exactly what kind of troubles I could face and what solutions may help" were a couple examples. However, the students that commented on the support of their peers are likely the students looking for support from their peers instead of depending on the instructor.

Future offerings of the course will focus on better explaining the benefits of this pedagogical approach and how embracing it can help students learn and practice skills for their career including other modes of presentation, protocol development, training others, and networking. This course will continue to foster an atmosphere of comaraderie and introduce more independence in order to also increase confidence.

Table 3. SALG quantitative results. Italicized scores show a decrease in score compared to Year 1. Bolded scores show an increase in score compared to Year 1.

		Year 1: 2015	Year 2: 2016	Year 3: 2017
Total Course Enrollment / Number of responses to the survey		47 / 27	51 / 11	49 / 7
How much did the following aspect of the class help your learning? The instructional approach taken in this class (out of 5)		3.7	*2.3*	*2.9*
As a result of your work in this class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following? (5 = great gain, 1 = no gain)	The main concepts explored in class	3.9	*3.1*	**4.0**
	EMG	3.9	*3.3*	*3.6*
	EEG	3.9	*3.3*	*3.6*
	EOG	3.9	*3.8*	*3*
	Worm	3.7	*3.4*	*3.3*
	Human	3.8	-	*3.6*
As a result of your work in this class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following? (percent of respondents that marked a '5' for "great gain")	EMG	22	*9*	*2*
	EEG	30	*22*	*2*
	EOG	41	*36*	*0*
	Worm	19	*0*	*4*
	Human	22	-	*2*
Enthusiasm for physiological signals (out of 5)		3.5	*3.0*	*2.7*
Confidence that you understand the measurement of physiological signals (out of 5)		3.7	*3.1*	*2.9*
Confidence that you can analyze physiological signals (out of 5)		3.7	*3.1*	*3.1*
As a result of your work in this class, what gains did you make in the following skills? Teaching peers how to perform an experiment (out of 5)		4.0	*2.9*	*3.7*

-Human AP propagation question contained a significant mistake and was thrown out.

Table 4. Scores out of 10 (change compared to Year 1) on electronic notebook and lab report assessments. Notebooks were graded by undergraduate TAs for each section. Lab reports were graded by the same instructor for every section.

	Notebook Score out of 10 (change from Year 1)			Lab Report Scores out of 10 (change from Year 1)		
Year	**1**	**2**	**3**	**1**	**2**	**3**
AP worm	9.25	8.79 (-.46)	9.35 (+.10)	8.45	9.12 (+.67)*	8.25 (-.20)
AP human	9.73	9.22 (-.51)*	9.81 (+.08)	8.74	7.93 (-.81)*	8.78 (+.04)
EMG	9.41	9.67 (+.26)*	8.99 (-.42)	8.44	8.68 (+.24)	8.36 (-.08)
EEG	9.10	9.70 (+.60)*	8.87 (-.23)	8.59	8.14 (-.45)*	7.90 (-.69)
EOG	9.29	9.84 (+.55)*	9.73 (+.44)*	7.99	8.33 (+.34)	8.19 (+.20)

*indicates statistically significant change from Year 1 based on two-tail z-test at 95% confidence.

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