Pair-to-Pair Peer Learning in a Lab Environment

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Pair-to-pair peer learning (PPPL) is the simplest form of group-to-group peer learning (GGPL). GGPL may be defined as a learning method where two or more peer groups interact and thus increase the knowledge of all group members; while PPPL may be defined as GGPL with group sizes of only two members each. A simple PPPL experiment was conducted and analyzed indicating an increase in knowledge gain as compared to peer learning (PL) alone. The experiment was conducted in an undergraduate engineering lab in a required computer-integrated manufacturing course for two engineering programs, mechatronics and industrial engineering.

Keywords: peer learning, pair-to-pair peer learning, group-to-group peer learning

INTRODUCTION

Peer-learning (PL) methods and their applications are a vibrant area of education research. In engineering education literature, many examples are presented in ASEE journal articles and ASEE conference proceedings. There are many facets of PL like cooperative learning, tutorship by peers, group learning, etc. However, group-to-group peer learning (GGPL) is not addressed in literature. GGPL can be defined as a learning method where two or more peer groups interact and thus increase the knowledge or skills of all group members. Pair-to-pair peer learning (PPPL) represents the simplest form of GGPL where groups include only two members per group. Thus, the scope of this work is limited to only students working in pairs on their lab design projects and receiving help only from other student pairs.

This article presents an extension of a conference paper published in the 2020 ASEE Virtual Conference proceedings (Jaksic, 2020). The work analyzes educational experiences of students with a novel PPPL learning method implemented in a lab. Two different groups of students are included, mechatronics engineering and industrial engineering. The described lab experience is a part of a three credit-hour one semester Computer-Integrated Manufacturing (CIM) course consisting of lectures, exercises, laboratory examples, and projects.

Next, presented are sections on previous work, curricular context, description of the lab design problem, and students' experiences. Also, analyzed are results of a questionnaire consisting of three quantitative questions, lab reports consisting of two open-ended questions, and students' test performance.

PREVIOUS WORK

The importance of practical laboratory experiences and projects is well documented in education literature (Dewey, 1939 and Bandura, 1997). This work is inspired by Kolb's experiential learning cycle learning theory (Kolb, 1984). In his work, Kolb claims that learners learn best, regardless of their preferred learning style, when they follow a procedure (cycle/spiral) consisting of four steps: experiencing, watching, thinking/modeling, and applying/doing. Thus, learning activities like designing on paper, computer modeling and simulation, and implementations of the designs in the physical world are crucial parts of learning. These activities have been applied in engineering education in many undergraduate engineering curricula such as civil engineering (Harb, et. al., 1993, Harb, et. al., 1995, and Ortiz & Bachofen, 2001), mechanical engineering (Ortiz & Bachofen, 2001), chemical engineering (Harb, et. al., 1993, Harb, et. al., 1995, and Abdulwahed & Nagy, 2009), aeronautical engineering (Ortiz & Bachofen, 2001), industrial engineering (Wyrick & Hilsen, 2002), and manufacturing engineering (Harb, et. al., 1993, Harb, et. al., 1995, and Harding, et. al., 2002). Project based learning (PBL) as a part of experiential learning is also well-represented in engineering education research (Shekar, 2014, Guerra, et. al., 2017, and Mills & Treagust, 2003). Peer learning (PL) methods are well described and justified in education and psychology literature (Vigotsky, 1962, Vigotsky, 1978, Kozulin, 2004, Damon, 1984 and O'Donnel & O'Kelly, 1994). In engineering education, PL is addressed in mechanical engineering (Reckinger, 2016), computer science (Straub, 2019), and electrical engineering (Buck & Wage, 2005). Also, flipped classroom methods often include PL (Lo & Hew, 2019). However, the current author did not find any relevant research addressing pair-to-pair or group-to-group learning methods.

CURRICULAR CONTEXT

The lab design project example addressed here is part of a CIM course – a required design-based one-semester three credit-hour undergraduate senior-level course taught in two undergraduate engineering programs, mechatronics engineering and industrial engineering. Students meet for two hours of lecture and two hours of lab per week for fifteen weeks. The course builds students' knowledge and problem-solving skills in CIM and automation starting with topics on discrete process controls, then switches and sensors (digital and analog), actuators (electric, hydraulic, and pneumatic), and relays. After this, relay ladder logic and programmable logic controllers (PLC) based ladder logic are introduced. Automation topics like industrial robotics, computer-numerical controls (CNC), and additive manufacturing are also discussed.

Four sets of lab design projects comprise the laboratory portion of the course: discrete controls, PLCs, robotics, and rapid prototyping (subtractive with CNCs and additive with fused filament fabrication (FFF)). The labs and lectures are using the latest automation hardware and software: NI Elvis II workstations with Multisim for discrete controller designs; Allen-Bradley Micro800 series PLCs with human-machine interface (HMI) devices and the current version of its integrated development environment (IDE) Connected Components Workbench (CCW) for PLC programming; ABB IRB 120 small industrial robots with FlexPendants and RobotStudio IDE for robot task programming, and a Haas CNC toolroom milling center with MasterCam software for CNC programming.

Lectures and labs share student learning objectives. At the end of the course, students are expected to possess the following knowledge, attitudes, or skills. (Code in parentheses indicates related ABET student outcomes)

a) Ability to demonstrate an understanding of various concepts used in CIM (1, 4, 7)
b) Ability to design and implement small automation projects using digital electronics devices, relays and PLCs (1, 2, 3, 5, 6)
c) Ability to perform end-of-tool special manipulations using robots (1, 2, 3, 5, 6, 7)
d) Ability to successfully program a CNC machine (1, 2, 3, 5, 6)
e) Ability to successfully create a part using a rapid prototyping machine (1, 2, 3, 5, 6)
f) Ability to develop criteria for the selection, justification, and implementation of selected CIM technologies (2, 4, 7)

Lab design projects are graded on a straight grading scale, i.e. 90-100 A, 80-89.9 B, etc. For each lab project, the total grade is the sum of the lab project implementation grade and the lab report grade. The lab project implementation grades are 0 for non-fully functional projects and 50 for fully functional projects. The lab report grade (from 0 to 50) consists of two parts: the group part that includes the title page, problems encountered with corresponding solutions, figures, pictures, schematics, graphs, and charts (as needed) and the individual answers part of the report addressing students reflections on the lab project. Students work in pairs whenever possible.

LABORATORY ENVIRONMENT AND LAB DESIGN PROBLEM

The lab experience with transistor-transistor-logic (TTL) and analog sensors consists of two design problems. The first design problem is a pure digital logic problem where students familiarize themselves (or get re-acquainted) with designing and building of TTL logic circuits using a solderless breadboard, an NI Elvis II workstation, and a bank of single-pole double-throw (SPDT) switches and LEDs. It is designed to build student confidence in designing and implementing digital logic circuits and to help industrial engineering students catch up. The second lab design problem described in Figure 1 requires the use of two different analog sensors that need to be correctly interfaced with student-designed digital logic controllers.

In lectures, analog sensor interfaces to digital logic circuits are analyzed, and sensor voltage/resistance equations are derived for simple voltage divider circuits. Students are also instructed how to calibrate the sensors. After an introduction to the lab and a review of safety procedures, the instructor declares a hands-off approach. In this role, the instructor helps students by providing generic answers only no matter how specific their questions are. This forces students to work together without depending on the instructor's expertise. For example, when students ask if their sensors are properly wired on their breadboard, they are directed to the lecture notes on the specific analog sensor and troubleshooting practices.

FIGURE 1
INTERFACING ANALOG SENSORS WITH TTL LOGIC CONTROLLERS

Computer-Integrated Manufacturing Lab
Interfacing Analog Sensors with TTL Logic Controllers

INTRODUCTION

This lab is designed to introduce students to implementations of basic sensor in digital logic controls. Two representative analog sensors, one for light detection (photo-resistor) and one for heat detection (thermistor), are implemented in a typical industrial alarm circuit.

The photo-resistor simulates a light curtain safety device implemented around many industrial machines. When the light path to the sensor is intercepted an alarm condition signal is sent to the controller.

A soldering iron simulates a motor overheating condition, while the thermistor monitors whether the motor temperature is within the specs. When the temperature becomes too high, the resistance of the thermistor decreases to the point of triggering an alarm.

DESIGN PROBLEM

Design and implement a digital logic controller with two analog sensors to perform the following:

1. When the START switch is made a green LED turns on – indicating normal operation of a machine.
2. When the STOP switch is made a red LED turns on and the green LED turns off – indicating that the machine is stopped.
3. When a hand is placed above the circuit, the red LED turns on and the green LED turns off – again, indicating that the machine is stopped.
4. When the thermistor is heated the red LED turns on and the green LED turns off – again, indicating that the machine is stopped.

CONSIDERATIONS

Photo-resistors vary greatly in their light/dark resistance values. Some of them may not be able to supply an adequate amount of current to the input of the logic gate. Also, photo-resistors should be calibrated before each use to account for current lighting conditions.

The students taking the class/lab were seniors in mechatronics and industrial engineering. The mechatronics engineering students already had a Digital Circuits class with lab (three credit hour lecture and one credit hour lab), so they were familiar with Multisim IDE simulations, NI Elvis II workstations, and TTL logic gates integrated circuits (IC) used in digital logic circuits. However, the industrial engineering students did not have any previous experiences with physical logic gates or digital circuit simulators and/or breadboarding. None of the students had any experience in working with analog sensors and banks of single-pole double-throw switches.

Before beginning to work on their first lab design problem, the students in the lab were divided into pairs; each industrial engineering student was paired with a mechatronics engineering student. As the student pairs were implementing their design solutions for the first design problem, industrial engineering students were learning from their mechatronics engineering lab partners through PL. In addition, the student pairs that finished their lab early were instructed to help other student pairs that were still building/troubleshooting their designs. This is where the students were engaged in PPPL. At the end of the lab session, there was a crowd of students around the last pair helping them implement the first lab design.

The same two-step process (PL and then PPPL) was used for the second lab design project. Due to the increased complexity of the project, the student pairs that successfully implemented their designs were required to come back for an additional lab session just to help the student pairs that were not able to implement their designs. At the end, all students were successful in implementing the second lab design project.

As mentioned earlier, all student pairs had to write lab reports providing the working designs, the problems they encountered, and the solutions they created. In addition, each student had to include at least two self-reflection paragraphs to close the experiential learning feedback loop. Student lab reports and designs were used as evaluation and assessment instruments.

The final lab report written by a student pair had to include their lab design solution and a description of problems encountered with corresponding solutions. Also, there were two general, reflection-based, open-ended questions asked of each student.

1. *What did you learn from this lab experience?*
2. *What is it that you liked the most about this lab experience?*

Students were instructed to write at least one paragraph for each question. The first question was designed to force students to think about the lab exercise in a more general way and to "buy in" into the learning process by articulating some concrete learning outcomes. The second question was written specifically in a positively biased manner because the question was meant to be a motivational tool, not necessarily a part of the assessment. While self-reflections are important components of experiential learning (Kolb, 1984, Harb, et. al., 1993, and Harb, et. al., 1995), positive self-reflections are significant components of the self-efficacy theory (Bandura, 1997).

STUDENT DESIGN SOLUTIONS

All students were able to successfully design and implement both lab design projects. For both problems, students simulated their designs in Multisim. Only after successful simulations did they proceed to building the circuits. This ensured that their designs (at least in simulation) were correct. However, they could not simulate the analog sensors in software, so they had to use switches instead of sensors in simulations. Figure 2 shows a successful simulated design. After building the physical circuit, students were able to demonstrate successful operation of two switches and two sensors, both a thermistor and a photo-resistor. Figure 3 shows a photograph of a successful student design. The two sensors in the middle of the breadboard are adequately separated so that they don't interfere with each other during sensor calibration achieved by changing the resistance of the two potentiometers (two white blocks shown in Figure 3).

FIGURE 2
CIRCUIT SIMULATION IN MULTISIM USING SWITCHES FOR SENSORS

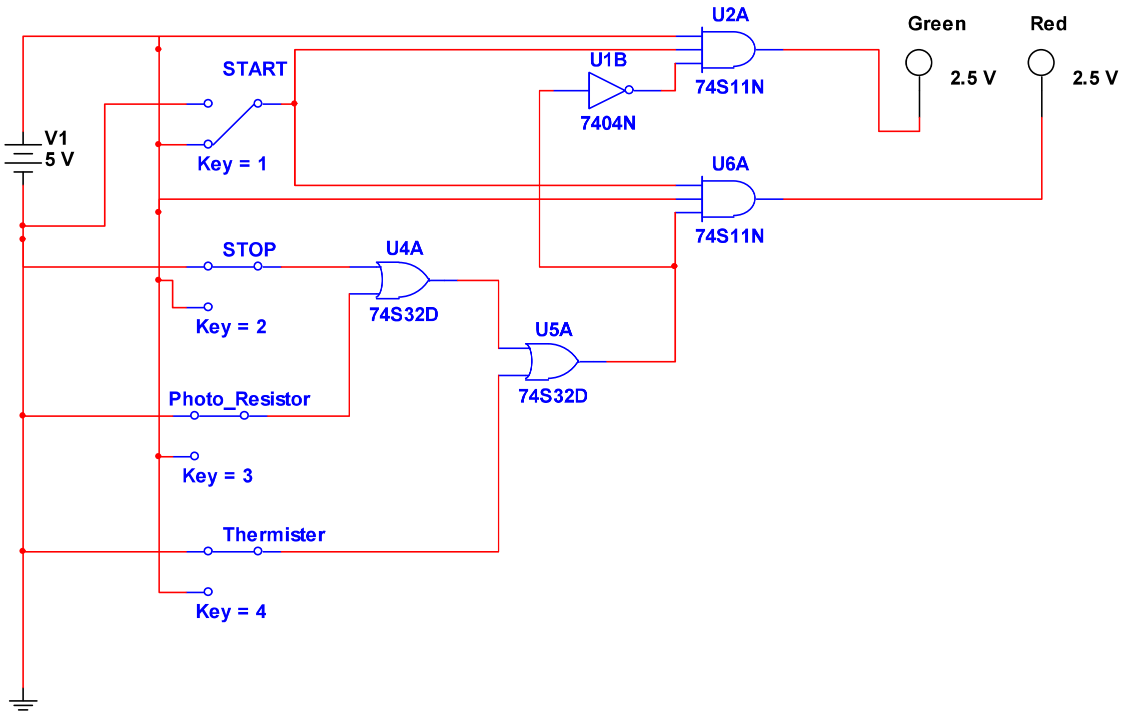
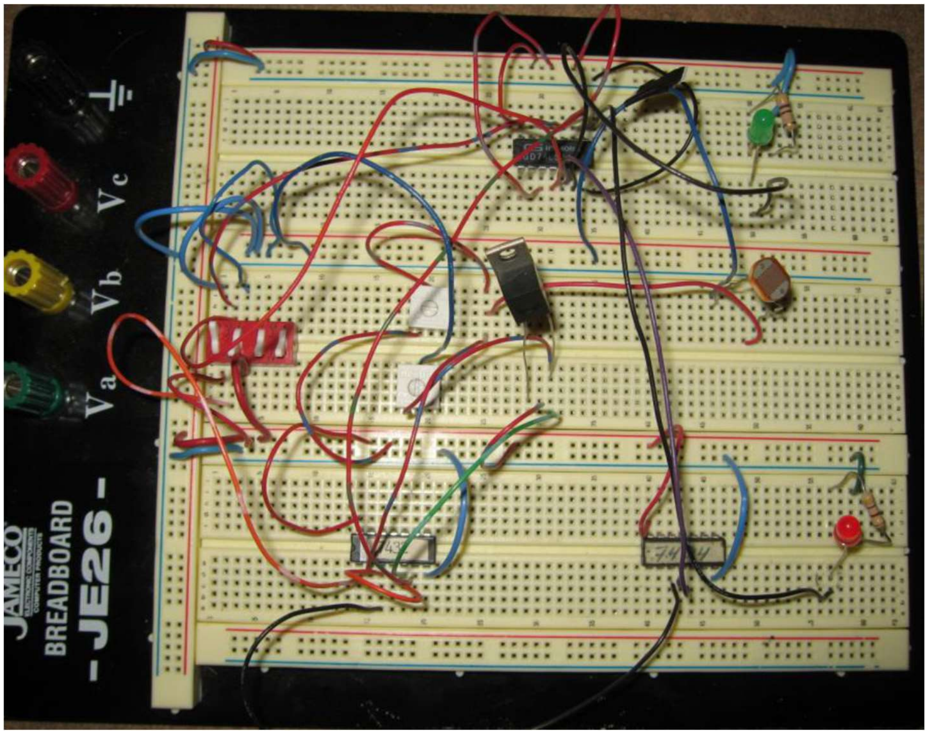


FIGURE 3
AN EXAMPLE OF A CORRECTLY FUNCTIONING STUDENT DESIGN



STUDENTS' EXPERIENCES ASSESSMENT OF STUDENTS' KNOWLEDGE GAINS, PERCEPTIONS, AND ATTITUDES

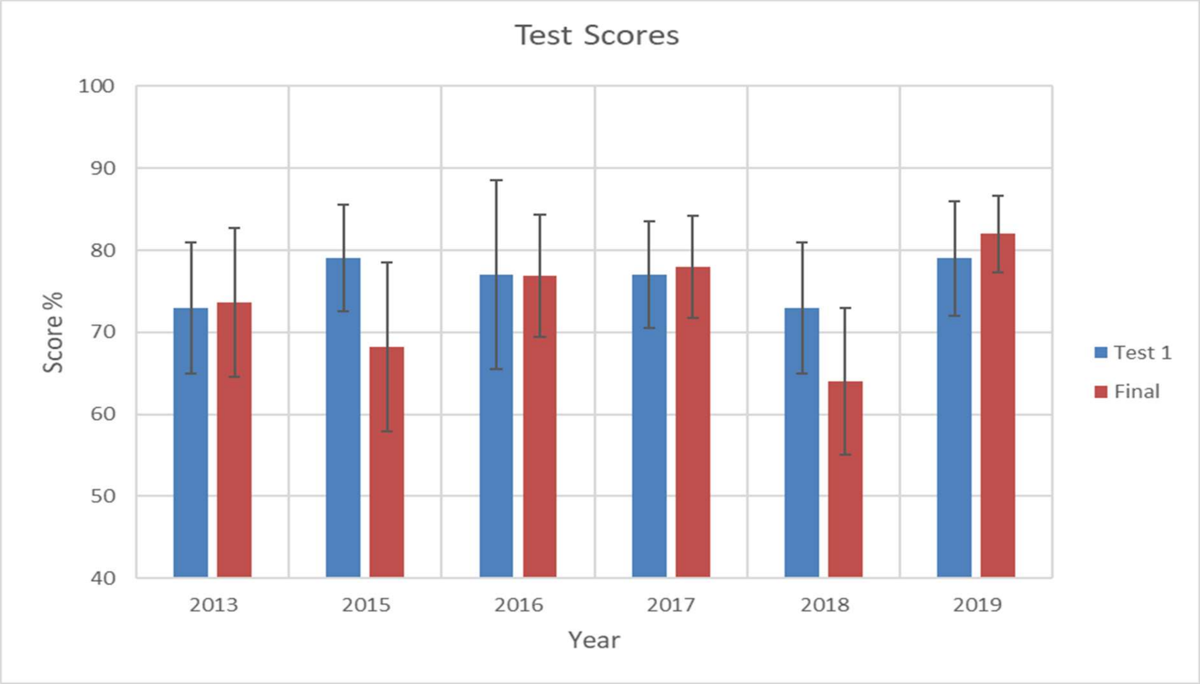
Quantitative Assessment

There were 22 participating students (PL and PPPL) in the Fall 2019 semester. The same lab exercise was offered previous years where students were engaged in PL only (total of 120 students). Figure 4 shows the test score statistics for six generations of students. The figure includes the results of the test administered immediately after the lab experience and the results of the course final exam administered about ten weeks after the lab experience. The final exam has a significant portion dedicated to the digital circuits design.

According to Figure 4 test 1 data and the comparative analysis of six groups of students, one can claim that there was a small knowledge gain that could be contributed to the Fall 2019 class PPPL experience. In addition, when analyzing Figure 4 final exam data, one can claim that the long term knowledge gains are significant. Also, when comparing the standard deviation data from final exams, one can note that the standard deviation for students with the PPPL experience is lower than for any other student group, suggesting that the students' knowledge gain is more uniform among the students.

The above results are based on the assumption that all student groups are from the same student population. To support this assumption, statistical correlation tests were performed using regression analysis in MS Excel. With the largest $p \leq 0.006$ for all student group results (test 1 and final), which is much lower than $p = 0.05$, the null hypothesis that the groups are not correlated is rejected. Thus, there is strong evidence that all student groups belong to the same student population.

FIGURE 4
TEST SCORE STATISTICS FOR SIX GENERATIONS OF STUDENTS



To assess students' perceptions on the effectiveness of PL and PPPL quantitatively, a three-question five-point Likert scale questionnaire shown in Figure 5 was developed, administered and analyzed.

FIGURE 5
STUDENT QUESTIONNAIRE ON EFFECTIVENESS OF PEER LEARNING METHODS IN A LAB ENVIRONMENT

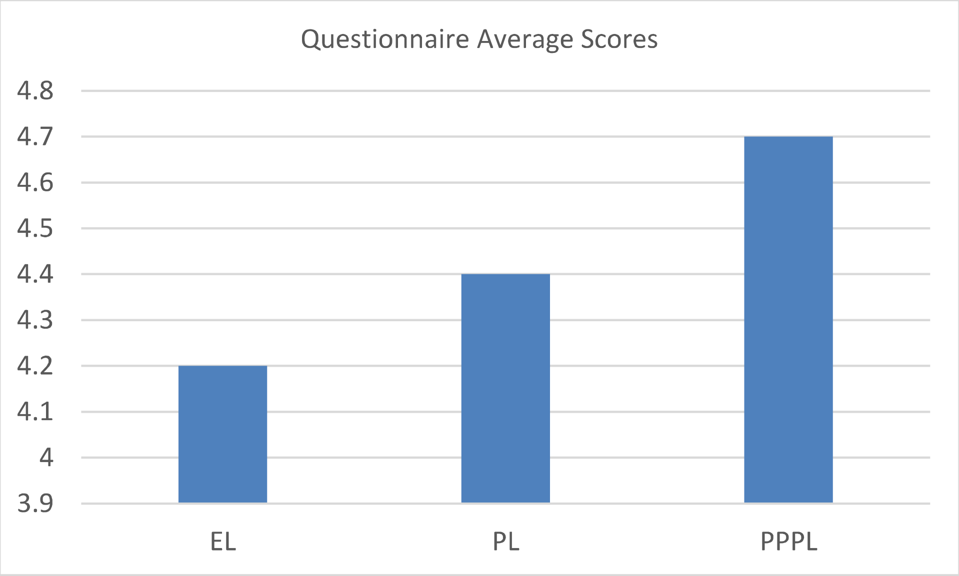
Students' Perceptions on Learning Method Effectiveness

Please rate the following three questions on a scale from 1 to 5 where: 1 = very unhelpful, 2 = somewhat unhelpful, 3 = neither unhelpful nor helpful, 4 = helpful, and 5 = very helpful

1. In general, this lab experience was ________________ in learning how to design digital circuits with analog sensors.
2. The peer learning experience was ______________________ in learning how to design digital circuits with analog sensors.
3. The pair-to-pair peer learning experience was _____________ in learning how to design digital circuits with analog sensors.

The questionnaire in Figure 5 based on a five point Likert scale (1 – 5) was administered after the students finished the course. The three questions addressed general experiential learning (EL), PL, and PPPL. Figure 6 shows the results of the questionnaire. All student responses were positive (4 or 5). This indicates that the students perceived EL, PL, and PPPL as effective learning methods.

FIGURE 6
EFFECTIVENESS OF LEARNING METHODS RESULTS



Qualitative Assessment

For the Fall 2019 semester student pairs engaged in PPPL. A previously mentioned instrument consisting of only two open-ended questions was constructed and implemented as a part of the student lab reports' individual portions. The main goal of the first question was to close the experiential learning loop through self-reflection, while the main goal of the second question was to reinforce positive self-reflections, thus increasing students' self-efficacy.

Students' perceptions of knowledge gains are exemplified in the following student statements.

> *I learned how to quickly diagnose my logic, check functionality of my components, and what wires to keep an eye out for.*

> *Tuning the sensors one at the time while grounding the other sensor was a nice thing to learn as it isn't something I would have thought about to use to tune a device…*

Specifically addressing PL within a pair, the following statement from an industrial engineering student shows the perceived knowledge gain.

> *The first lab taught me a lot because I have never seen digital logic or anything about the chips that we used in the lab before going in to this class. My lab partner was great in explaining everything even though we rebuilt the second circuit 4 times.*

Student statements directly addressing students' PPPL experience, either from the side of the "peer teacher" pair(s) or the ones receiving help i.e. "peer student" pairs, exemplify perceived knowledge gains.

Peer Teachers:

> *I learned several new methods of troubleshooting when helping my classmates.*
> *I learned how to troubleshoot other groups' issues.*

Peer Students:

> *I was frustrated at the beginning, because I was confident that I wired the circuit correctly and I couldn't figure out why it wasn't working. But after some other classmates help, it wasn't the wiring that was the problem, it was the components! We had a bad component within our circuit, and working with other teams to troubleshoot allowed us to enhance our teamwork and bonding skills.*

The next group of student testimonials presents students' responses to the following question. *What is it that you liked the most about this lab experience?*

> *This lab has gotten me excited for the future labs to come. It was a great feeling when the logic was perfect and the sensors were connected correctly and you could see the circuit working.*
>
> *I enjoyed seeing the word problem develop into a working circuit of logic to complete the desired outcome. This was cool because we got to see the thermistor and photo-resistor work in real life. Tuning the resistors to react at the desired amount of heat and light was incredible to see. The feeling I get when I complete something and it works correctly is unmatched by anything and I hope to see myself become more confident in what I'm expected to do.*
>
> *I liked that the lab had an immediate potential practical use. I felt like what I was trying to figure out was something useful. Something that not every person in the world can do…As you had said before, the point of being an engineer is being the person that people flock too [sic] when they experience an issue. I feel like this lab was the first small stepping stone towards being a glimpse of that person. I also like that I felt like I actually learned something after walking away from the Lab.*
>
> *I liked that we were instructed to help other students out once we finished our lab. I have had several labs where we move on as soon as we finish our lab and that leaves several other students who were struggling to continue to struggle and fall very far behind. This class makes it very easy to get stumped if there is a small problem in your circuit like a bad*

> *wire; or if you are new to digital logic. This method ensures no one gets left behind and allows us to sharpen our diagnostics skills.*

The above students' testimonials confirm their perception of positive knowledge gains due to EL, PL, and PPPL experiences. Also, the testimonials show a sense of accomplishment which increases students' self-confidence and therefore students' self-efficacy.

CONCLUSIONS

This work introduced GGPL and PPPL to the education research community via a simple engineering laboratory experiment. GGPL and PPPL are formally defined. Then, a simple PPPL experiment was created, implemented, and analyzed. In an undergraduate engineering laboratory environment, students were exposed to two learning method, PL and then PPPL. Two laboratory design problems dealing with digital logic designs and interfacing analog sensors were described. In the lab, students from two different engineering programs were paired together. At the beginning, a student-teacher one-on-one PL method was implemented to guide the students without sufficient background to become proficient with simulations and implementations of digital circuits. After this, a second design lab was introduced, where analog sensors were used in a digital logic controls problem. In this part of the lab, the student pairs that were successful in implementing their designs quickly, helped other student pairs thus engaging in PPPL. As a result, based on the results of two relevant tests, the students engaged in PPPL performed better than the control group i.e. the student pairs that were enrolled in this course for the previous five years and that engaged in PL only. Perceptions of knowledge gains from students engaged in PPPL, both quantitative and qualitative, were all positive. Finally, student testimonials strongly indicated that students increased their self-confidence levels and appreciated their PPPL experience. It is hoped that this extremely easy to implement PPPL experiment can be quickly adapted to other disciplines and courses with experiential components.

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