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Pair-to-Pair Peer Learning

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Pair-to-Pair Peer Learning

Abstract

In this work, pair-to-pair peer learning (PPPL) as the simplest form of group-to-group peer learning (GGPL) is defined. GGPL is defined as a learning method where two or more peer groups interact to increase the knowledge of all members; while PPPL is 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 when compared to peer learning (PL) alone. The experiment was conducted as a part of an experiential learning portion of an undergraduate engineering lab in a required computer-integrated manufacturing course for two engineering programs, mechatronics and industrial engineering. In the lab, students designed and implemented digital logic-based controls for a typical manufacturing operation. The students participating in the lab experiments were seniors majoring in mechatronics and/or industrial engineering. The mechatronics students had previous experiences with building digital circuits while their fellow students from industrial engineering did not. First, the students were divided into pairs where each industrial engineering student was paired with a mechatronics student. As the students were creating and implementing their designs, industrial engineering students learned from their mechatronics counterparts, thus engaging in PL. In addition, the student pairs that were able to finish the lab quickly were required to help the students that had problems implementing their designs thus engaging in PPPL. All student pairs had to write lab reports providing the working designs, the problems they encountered, and the solutions they devised. In addition, each student had to include two self-reflection paragraphs (part of closing the experiential learning feedback loop) about what they learned and what they liked. A students' questionnaire, test grades, lab reports, and lab designs were used as evaluation and assessment instruments. Student lab reports (qualitatively) and questionnaires (quantitatively) indicated that students learned much from their peers – from both the lab partners (PL) and other pairs (PPPL). In addition, the "teaching" pairs who were helping others also learned from troubleshooting other students' circuits and by facing the misconceptions of other students. Finally, the PPPL participating students performed better on the tests dealing with digital logic circuit designs than the students that engaged in PL only.

Introduction

There are a number of peer-learning (PL) methods with applications discussed in educational literature. A number of examples are, also, described in ASEE journal articles and ASEE conference proceedings. There are many facets of PL exemplified by cooperative learning, tutorship by peers, group learning, etc. However, one type of PL, 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 to increase the knowledge of all members. Here, the scope of the work is limited to only classmates working in pairs on their lab design projects and receiving help only from other classmate pairs. This pair-to-pair peer learning (PPPL) represents the simplest form of GGPL where group size includes only two members per group.

This paper mainly addresses students' experiences with a novel PPPL method as it is implemented in a lab setting during a lab design project encompassing two different engineering programs, mechatronics and industrial engineering. The lab project is a part of a three credit-hour semester-long course consisting of lectures, laboratory examples, exercises, and projects. Since this work deals with human subjects, all student work is presented with their permission. An Institutional Review Board (IRB) approval under the "exempt" review category was obtained from the university's IRB for the questionnaire.

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

Previous Work

Practical laboratory experiences and projects are important parts of learning [1]. This work is based in part on Kolb's Experiential Learning Cycle [2] learning theory which states that learners learn best, regardless of their preferred learning style, when they follow a certain process (cycle/spiral) consisting of four steps: experiencing, watching, thinking/modeling, and applying/doing. Thus, design on paper, computer modeling, and implementing the designs in the physical world are crucial parts of learning. Kolb's learning cycle has been applied in engineering education in many undergraduate engineering curricula such as civil engineering [3-5], mechanical engineering [5], chemical engineering [3, 4, 6], aeronautical engineering [5], industrial engineering [7], and manufacturing engineering [3, 4, 8]. Project based learning (PBL) as a part of experiential learning is also well-researched in engineering education literature [10-12]. Peer learning (PL) methods are well described and justified in education and psychology literature [13-17]. In engineering education, PL is addressed in mechanical engineering [18], computer science [19], and electrical engineering [20]. Also, flipped classroom methods often include PL [21]. However, this literature search did not yield any results dealing with pair-to-pair or group-to-group learning methods.

Curricular Context

The lab design project addressed in this work is part of a Computer-Integrated Manufacturing (CIM) course which is a required one-semester three credit-hour undergraduate senior-level course taught in two undergraduate engineering programs, mechatronics engineering and industrial engineering. This design-based second course in the manufacturing sequence meets for two hours of lecture and two hours of lab for fifteen weeks. The course builds students' knowledge and problem-solving skills in CIM and automation starting with discrete process controls (digital logic circuits), then switches and sensors (digital and analog), actuators (electric, hydraulic, and pneumatic with associated circuits), and relays. After this, relay ladder logic and programmable logic controllers (PLC) based ladder logic are introduced. Fundamentals of industrial robotics, computer-numerical controls (CNC), and additive manufacturing are also discussed.

Four sets of lab design projects are included in the laboratory portion of the course: digital logic controls, PLCs, robotics, and rapid prototyping (subtractive with CNCs and additive with fused filament fabrication (FFF) 3D printers). The labs and lectures are using the latest automation hardware and software: NI Elvis II workstations with Multisim; 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); ABB IRB 120 small industrial robots with FlexPendants and RobotStudio IDE, and a Haas CNC toolroom milling center with MasterCam software.

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 the related current 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 manipulation 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. The total lab project 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 project and 50 for fully functional projects. The lab report grade (from 0 to 50) also has 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. Only when there is an odd number of students, one group is allowed to have three students.

Digital Logic Controller Lab Design Problem and Laboratory Environment

The lab experience with TTL logic consists of two design problems. The first design problem is a pure digital logic problem where students become familiar (or re-acquainted) with designing and building transistor-transistor-logic (TTL) 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 to 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 the student-designed digital logic controller.

In the lecture portion of the course, analog sensor interfaces to the digital logic circuits are analyzed, and sensor voltage/resistance equations are derived for simple voltage divider circuits. Students are also warned about bad practices when calibrating the sensors. After the lab introduction and review of the safety procedures, the instructor’s role is changed to a hands-off approach as to only help students with generic answers no matter how specific their questions. This forces students to work together and not depend 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.

EN 473
Lab Set 1
Part II: Interfacing Analog Sensors to a TTL Logic Controller

SUPPLIES
1. All the material from "Logic Controls"
2. Potentiometer 5 KΩ or 10 KΩ (2)
3. Photo-resistor (1)
4. Temperature Sensor, thermistor (1)
5. Soldering iron (1)

INTRODUCTION

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

The photo-resistor simulates a light curtain safety feature implemented around many industrial machines. When the light path to the sensor is intercepted an alarm condition 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 will decrease to the point of triggering an alarm.

DESIGN PROBLEM

Design and implement a digital logic controller 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, they should be calibrated before each use.

Figure 1. Lab Design Problem 2: Interfacing Analog Sensors to a TTL Logic Controller

The students taking the class/lab were seniors majoring in mechatronics and/or 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, ICs, 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 starting the first lab design problem, the students were divided into pairs; each industrial engineering student was paired with a mechatronics engineering student. As the students pairs were creating and implementing their designs for the first design problem, industrial engineering students were learning from their mechatronics engineering lab partners through PL. Then, the students engaged in PPPL. Namely, the student pairs that finished their lab early were required to help other student pairs that were still building/troubleshooting their designs. Finally, there was a crowd of students around the last pair helping them implement the first lab design.

The same process with a two-step approach (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 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 devised. 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 the lab design solution and the 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 allow students to think about the lab exercise in a more general way and to “buy in” to 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 [2-4], positive self-reflections are significant components of the self-efficacy theory [9].

Student Solutions

All students were able to successfully design and implement both lab design projects to perform as specified. For both lab design 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 on paper) were correct. However, they could not simulate the analog sensors directly, so they had to use switches in simulations. Figure 2 shows an “almost” finished second lab project. The students were able to demonstrate successful operation of the two switches and the two sensors. Note that the student demonstrating the operation of the overheat sensors (Figure 2. d) was careful to approach the overheat sensor without triggering the hand sensor located in the top left corner of the breadboard. However, in this stage of the design, these students mistakenly connected two on-board green LEDs until they were reminded to correctly connect two external LEDs, one green and one red, with the accompanying current-limiting resistors.

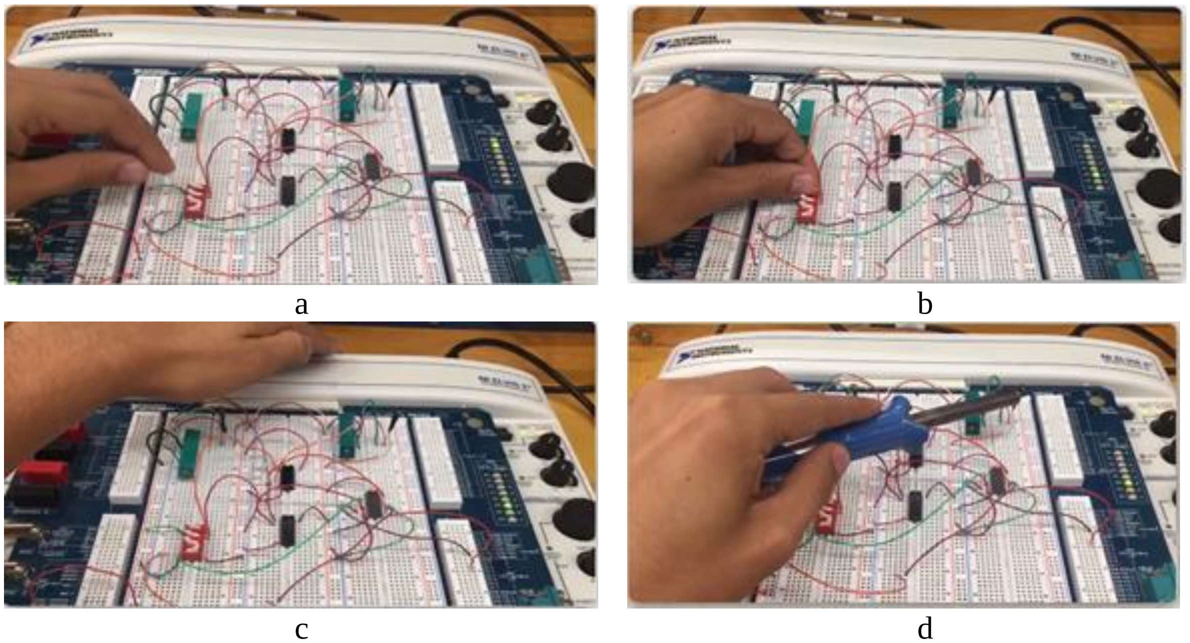

Figure 2. An Example of an Almost Working Circuit: (a) Demonstration of the START Switch, (b) Demonstration of the STOP Switch, (c) Demonstration of the "Hand" Sensor, and (d) Demonstration of the Overheat Sensor

Students' Educational Experiences: Evaluation and Assessment of Students' Knowledge Gains, Perceptions, and Attitudes

Quantitative Assessment

There were 22 participating students (PL and PPPL) in Fall 2019. The same lab exercise was offered in previous years with only PL experience. Table 1 shows the test score statistics for six generations of students. The table includes the results of the test administered right 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 Table 1 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 Table 1 final exam data, one can claim that the long term knowledge gains are even more pronounced.

The above results are based on the assumption that all student groups are from the same population. However, no statistical correlation tests were performed.

Table 1. Test Score Statistics for Six Generations of Students

Year	Learning Method	No. of Students	Industrial Eng. Students	Test 1 Avg.	Test 1 Std. Dev.	Final Avg.	Final Std. Dev.
2019	PL+PPPL	22	5	79	14	82	9.4
2018	PL	35	10	73	16	64	18
2017	PL	20	4	77	13	78	12.5
2016	PL	25	8	77	23	76.9	15
2015	PL	20	3	79	13	68.2	20.6
2013	PL	20	9	73	16	73.6	18.3

To assess students' perceptions on the effectiveness of PPPL quantitatively, the three-question five-point Likert scale questionnaire shown in Figure 3 was developed, administered and analyzed.

Students' Perceptions on Learning Method Effectiveness in Digital Circuits Design Lab

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
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.

Figure 3. Student Questionnaire on Effectiveness of Peer Learning Methods in a Lab Setting

The questionnaire was administered after the students finished the course. All the answers were positive. Based on a five point Likert scale (1 – 5), the Question 1 average was 4.2, the Question 2 (addressing PL) average was 4.4 and the Question 3 (addressing PPPL) average was 4.7 indicating that the students perceived both PL and PPPL as effective learning methods.

Qualitative Assessment

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

The following general student statements describe student perceptions of knowledge gains.

> *I learned how to quickly diagnose my logic, check functionality of my components, and what wires to keep an eye out for.*
>
> *This lab showed me the importance of being precise and accurate when dealing with designing circuits because everything must be perfect so one can get the output needed. If one small wire is loose, then the whole circuit will not work.*
>
> *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…*

Here are some statements specifically from industrial engineering students on PL within the pair.

> *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.*
>
> *I was able to get a big refresher using circuit boards. [Name] also helped me learn how to translate a digital drawing to a circuit.*

Here are some student statements directly addressing their PPPL experience, either from the side of the "peer teacher" pair(s) or the ones receiving help, "peer student" pairs.

Peer Teachers:

> *I learned several new methods of troubleshooting when helping my classmates.*
>
> *Once we finished our circuit, we had to assist other groups, and since no group built the circuit the same way, being able to navigate each component was difficult. By the last group, I was able to work through their circuit and help them finish before the class period ended.*
>
> *I learned how to troubleshoot other groups' issues.*

Peer Students:

> *We had a bad component within our circuit, and working with other teams to troubleshoot allowed us to enhance our teamwork and bonding skills.*
>
> *Issues that we had were bad components and bad logic for part 2. But once we got help from fellow classmates, they were able to assist with helping us and diagnose the problem so we can fix it.*
>
> *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!*

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

> *I enjoyed this lab even though it was difficult…It reassured me that I understood what I was doing.*
>
> *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 also liked how helpful the other students were. When one group finished, they would walk around and help the other groups who are struggling.*
>
> *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 knowledge gain due to the lab design PPPL experience. Also, the testimonials show a sense of accomplishment which increases students' self-confidence and therefore students' self-efficacy.

Summary and Conclusions

The aim of this work was to introduce GGPL and PPPL to the engineering education research community via a simple laboratory experiment. First, GGPL and PPPL are formally defined. Then a simple PPPL experiment was created, implemented, and analyzed. Students were exposed to a two-step learning method, PL and then PPPL, in an undergraduate engineering laboratory setting. Two laboratory design problems dealing with digital logic designs and interfacing analog sensors are described. In the lab, students from two different engineering programs (mechatronics engineering and industrial engineering) were paired together. At first, a student-teacher one-on-one PL method was established to guide industrial engineering students 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. Here, the student pairs that were successful in completing their designs helped other student pairs thus engaging in PPPL. As a result, the students engaged in PPPL performed better on two digital circuits tests than the control groups (students that were enrolled in this class for the previous five years that engaged in PL only). In addition, the PPPL students' perceptions of knowledge gains, both quantitative and qualitative, were all positive. Finally, student testimonials showed 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 in all engineering disciplines and many courses.

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