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Evaluating the Effectiveness of Peer-Led Learning for a Hardware Course

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Abstract

In this paper, we describe the effectiveness of peer-led learning for a hardware course (computer organization) in the Computer Science and Engineering department at a large public university. The proposed peer-led learning in the format of online recitations extends in-class activities to after-lecture recitation hours, encourages students' deep learning and understanding with extra challenging questions and peer-guided group discussions. In this paper we will describe the format, design, and improvement of the peer-led recitation sessions and how we choose peer leaders. The implementation of the peer-led online recitation sessions began in Fall 2021. Since then, students' feedback has been monitored continuously to adjust recitations' formats, frequency, discussion topics, etc. Surveys have been conducted and analyzed to evaluate the effectiveness of peer-led recitations and identify areas of improvement. Most students (more than 90%) expressed positive feedback in the end of semester survey. Based on the survey results conducted in the past several semesters, we conclude that peer-led online recitations help students' study in concepts understanding, problem solving techniques, and assembly language programming. Moreover, we observe that course pass rate improved for students attending peer-led recitations.

KEYWORDS

Peer-led learning, recitations, peer instructions, peer leaders, hardware course, computer organization

Introduction

Problem solving recitations have been shown to improve student retention and performance in engineering disciplines such as statics and mechanics [1-4]. Some Universities have added recitation hours to several foundation engineering courses or recitation courses have been designed to guarantee the recitation hours [1, 4]. In the recitation sessions, no new materials are covered. Instructors use the recitation hours to answer questions, solve example problems, involve students in cooperative learning. Problem solving recitations offer students more practice opportunities to correct their own core conceptual understanding and problem-solving techniques.

Peer instruction [5-10] is also a well-documented pedagogical method to improve students' conceptual performance in engineering courses such as introductory computing courses and cyber security courses. Peer instruction is designed for active engagement of students in class by supporting student-centric classroom activities. It involves conceptual multiple-choice questions and group discussion activities aimed to provoke students' deep conceptual thinking and understanding. In peer instruction, the instructor introduces or reviews a topic, then the instructor typically guides students through a series of multiple-choice questions that aim to elicit common misconceptions about a topic. Students attempt to solve the question by themselves, then students are encouraged to discuss their answers with peers. Finally, the instructor shares the answers and common mistakes. The main idea of peer instruction is to challenge students to work with a deep understanding of the core concepts of a subject rather than the simpler application formula. In peer instruction, students are challenged to answer the multiple-choice questions individually, then challenge each other on their answers through group discussions, which evokes deep understanding of core concepts. To implement peer instruction well, the questions must be carefully selected, and they cannot be too easy or too hard. If these questions are too easy, students can easily become bored and disengage from completing the learning activities. If questions are too hard, students can become overwhelmed and discouraged. Also, peer instruction is constrained by the lecture time. Peer instructions have been shown to improve student performance on conceptual questions [5-10]. Constrained by the lecture time, peer instruction limits the cooperative peer learning activities from questions involving multiple topics or other formats of questions, such as live programming.

Peer instruction can be extended to problem solving recitation hours. Problem solving recitations offer students more practice time and opportunities to correct their own core conceptual understanding and problem-solving techniques. Peer instruction offers students a challenging environment though group peer discussion. In the recitations, the questions are not limited to multiple choice questions focusing on one or two topics. Some questions can cover the contents of several lectures. The questions can be discussed from easy to harder ones. No new contents will be covered in the recitations. Students attending recitations have already gone through the topics discussed during lectures. In recitation hours, students are challenged by completing some medium to hard questions individually and challenged by peers through group discussions.

The dominant educational model for engineering and science instruction in many higher educational institutions is a combination of lectures, homework assignments, instructors', and teaching assistants' (TAs) office hours. Recitations are optional and they are not offered in the computer organization course before Fall 2021 in our department. In the traditional recitation sessions, the recitations are conducted in a classroom. The recitation attendance is optional, which means we do not know how many students will join the recitations and it is hard for the facility department to plan a classroom for recitations. Also, online delivery has been implemented and is still being implemented for many courses since the breakout of COVID pandemic. Hence, peer-led online recitations are implemented since Fall 2021 semester and continued in several semesters for the Computer Organization course.

In this paper, we report the design and evaluations of the peer-led online recitation in a hardware course, Computer Organization. Section II describes the details of the design of the peer-led recitation from the aspects of peer leader selection, content discussion topics, recitation formats and practice problem developments. Section III presents the evaluations of the effectiveness of peer-led recitations with the three semesters' end-of-semester surveys, course pass rate and recitation attendance. Finally, section IV summarizes the paper.

Peer-led Online Recitation Design

This section describes how the peer leaders are selected for recitations, how the recitation sessions are organized, the contents discussed in recitation sessions, and how the practice questions are developed.

a) Peer Leader Selection

Peer leaders for this hardware course are selected based on the following aspects: course knowledge, in-class exercises participation, document organization and oral communication. In our peer-led online recitations, undergraduate students who have passed this hardware course with grade A+ and participated in class exercises actively when they took the hardware course form selection pool as peer leaders for this hardware course. Also, undergraduate students with good communication skills. Moreover, undergraduate students who can keep their homework assignment submissions neat are preferred for better organization of recitation documents and problem-solving demos.

b) Recitation Format

This hardware course has two sections per semester and each section is assigned one peer leader. To minimize the time conflicts of recitations with students' other classes, two peer leaders are shared by both sections. Two one-hour sessions are scheduled per week at the beginning of the semester by each peer leader. So, four one-hour sessions are offered each week and students only need to attend two out of four sessions.

Weekly recitation topics are included in the course syllabus and posted to students at the beginning of the semester, which ensures that the recitation topics match the progress of lectures. Moreover, peer leaders need to create an outline of each recitation session, prepare the practice questions, and announce them the day before the session. Hence, the students have enough time to complete these practice questions individually in advance to save more time for peer discussions during the recitation session.

During the online recitation sessions, no new content will be discussed. Students have learned all the topics in the lectures and have the capability to solve the related questions on their own. The basic structure of peer-led online recitations are topic reviews followed with practice question demonstrations and discussions. Practice questions in the recitations can be classified into two categories, topic questions and comprehensive questions. Topic questions are specially developed for one or two topics while comprehensive questions may relate to multiple topics. Examples for topic questions and comprehensive questions can be found in the next section: practice question development. The recitation discussion iterates through the following steps:

1. The peer leader reviews a topic.
2. The peer leader demonstrates how to solve a question about the topic.
3. Students review and revise their own answer to the question.
4. The peer leader shares students' answers, then students are organized into groups to discuss their answers with peers before constructing their answer a second time.
5. The peer leader discusses the answers and corrects students' misunderstandings or mistakes.

Step 1 can be skipped for comprehensive questions. In recitations, the practice questions are discussed with increasing difficulty and always discussed before comprehensive questions. Hence, all the topics related to one comprehensive question have been reviewed in the topic questions already. So, topic reviews for comprehensive questions can be skipped. Step 4 is optional depending on the problem topics and recitation time.

c) Content Recommendations

Content discussed in recitation sessions are recommended as follows:

- Sneak previews for topics in future courses.
- Lecture reviews for recitation sessions related topics.
- Homework assignment solutions review after they have been graded.
- Problem-solving demos.
- Live coding of assembly program snippets.
- Conversations about career advice and internships.
- Answer questions regarding homework assignments, recitation practice problems, etc.

d) Practice Questions Development

Most of the practice questions discussed in recitations were developed from easy to hard by starting with practice questions covering one or two topics and ending with a comprehensive question covering more than three topics. Instructors provide some typical comprehensive practice questions for recitation discussions. Hence, peer leaders can organize students for deep practice and discussions.

Sign Number Representation and Arithmetic

a. Express the following decimal numbers 38_{10} , 86_{10}, -38_{10} and -86_{10} as an 8-bit binary number sign-magnitude form, 1's complement form, and 2's complement form.

	38_{10}	86	-38_{10}	-86_{10}
Sign Magnitude				
1's Complement				
2's Complement				

b. Complete the following two operations.

Compute the result for $-38_{10} - 86_{10}$ using 8-bit 2's complement operation. Verify if the result is correct. If not, explain why.	Compute the result for $-38_{10} - 86_{10}$ using 8-bit 1's complement operation. Verify if the result is correct. If not, explain why.

Figure 1. A Binary Number Representation and Arithmetic Operation Practice Question.

I will use sign number representations and arithmetic operations as an example to describe the procedure for practice questions development. The recitation can start with conversation of positive and negative decimal integers to binary numbers in sign-magnitude, one's complement and two's complement format. Then, it continues with conversion of signed binary number in sign-magnitude, one's complement and two's complement formats to decimal integers. Further, the recitation practices with signed binary arithmetic operations with or without overflow. Finally, three practices are combined into one comprehensive question as shown in Figure 1. In this question, students first represent positive and negative decimal integers in binary sign-magnitude, one's complement and two's complement formats. Then, students perform binary arithmetic operations and determine whether overflow occurs or not. Finally, students convert the calculated binary arithmetic result into a decimal integer to verify if the result is correct or not. This practice covers major topics of one whole chapter in this hardware course.

Some topics in computer organization are abstract, hard to understand and hard to imagine how it works in a computer. Hence, some practice questions in recitations are developed to show how it works in a computer. For example, one practice question is developed to show students how the direct-mapped cache memory is updated. The recitation starts with the practice of creating the memory address format with the given information, including the main memory capacity, the cache memory capacity, and the size of memory block. Then, it continues with practice of how to determine cache hit or missing for a given memory address and a given cache memory state. Finally, the recitation went through one comprehensive practice as shown in Figure 2. In this practice, it requires students to perform the first small practice to determine the format of a memory address, then it asks students to repeat the second practice several times in the sequence of required memory address. During this process, the cache memory is updated if cache missing occurs. Figure 3 shows the data access procedure with a given memory address for direct mapped cache memory. After completing this practice, students should have a better and clear view of how the cache memory is updated.

- Suppose we have a computer that uses a memory address word size of 8 bits. This computer has a 16-byte cache with 4 bytes per block. Suppose this computer uses direct-mapped cache.
- Assume the cache memory is initially empty.
- The computer accesses several memory addresses in this exact order: 0x6E, 0xB9, 0x17, 0xE0, 0x4E, 0x4F, 0x50, 0x91, 0xA8, 0xA9, 0xAB, 0xAD, 0x93, and 0x94.

a. What is the hit ratio for the entire memory reference sequence given above, assuming we count the first four accesses as misses?
b. What memory blocks will be in the cache after the last address has been accessed?

Figure 2. A Direct Mapped Cache Memory Practice Question.

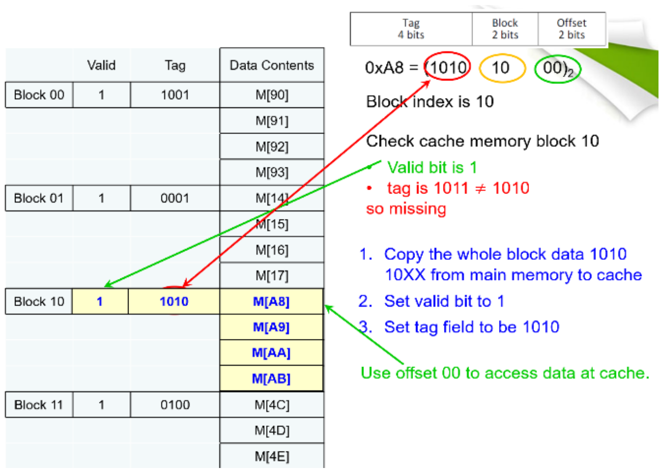

Figure 3. Data Access Procedure for a Given Memory Address.

Some topics in computer organization course are challenging for most students such as assembly programming. Again, practice questions are designed from easy to hard. The recitation can start with instructions understanding, especially focus on some instructions that are difficult to be understood by some students such as memory access instructions, conditional and unconditional branch instructions. Then, it continues with some assembly programming snippet practice including if-else structure and loops. Further, the recitation continues with some simple function calls practice questions. Eventually, the recitation ends with one large comprehensive assembly programming question with multiple function calls. One such comprehensive assembly programming practice question is shown in Figure 4. In this question, students are required to develop three functions, one non-leaf function and two leaf functions. After this practice, students are expected to be able to create function calls involving multiple functions, loop structures, if-else structures, and pointers.

```c
void swap(int *xp, int *yp) {
    int temp = *xp;
    *xp = *yp;
    *yp = temp;
}
int findMinimum(int arr[], int N) {
    int min_idx = 0;            // variable to store the index of minimum element
    int min_E = arr[min_idx];
    // Traverse the given array
    for (int i = 1; i < N; i++) {
        if (arr[i] < min_E) {   // If current element is smaller than min_idx then update it
            min_idx = i;
                min_E = arr[min_idx];
        }
      }
    return min_idx;
}
/* Function to sort an array using selection sort*/
 void selectionSort(int arr[], int n) {
     int i, min_idx;
     // One by one move boundary of unsorted subarray
     for (i = 0; i < n-1; i++) {
         min_idx = findMinimum(&arr[i], n-i); // Find the minimum element in unsorted array
         // Swap the found minimum element with the first element
         if(min_idx != 0)
             swap(&arr[min_idx+i], &arr[i]);
     }
 }
```

Implement the above C code snippet in RISC-V assembly language. Use `s0 and s1` to hold the variable `i, and min_idx` in the function `selectionSort`. Be sure to handle the stack pointer appropriately. Clearly comment on your code.

Figure 4. An Assembly Programming Practice Question.

Results and Discussions

This section presents the survey results and feedback from students on peer leaders, recitation contents and recitation time. The effectiveness of peer-led recitations on students' performance for three semesters is also discussed.

a) Evaluations on the Peer Leaders

Figure 5 shows the survey questions and results on the evaluations of peer leaders' knowledgeability about the course and recitation management. From the survey results, we can conclude that more than 90% of students think that peer leaders are knowledgeable about the course materials, adequately answer students' questions and manage discussions effectively. More than 90% of students feel comfortable asking questions. From these survey responses, we conclude that undergraduate students we selected based on the selection criteria have the capability to work as peer leaders for the course. Moreover, this hardware course is an earlier course for majors of computer science and computer engineering, which means the selected undergraduate students can work as peer leaders for 3 or 4 semesters if they received positive feedback from students at the end of semester survey. By working as peer leaders for more than one semester, peer leaders should know the topics and concepts that students may have difficulty mastering. Hence, peer leaders can improve their discussion management and time management across different topics during the recitation sessions.

Survey Question	Semester	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
Peer leaders are knowledgeable about the course material.	Fall 2022	0.00%	0.00%	2.27%	2.27%	31.82%	63.64%
	Spring 2023	3.20%	0.80%	0.00%	8.00%	47.20%	40.80%
	Fall 2023	2.16%	0.00%	0.72%	3.60%	28.78%	64.75%
Peer leaders were able to adequately answer questions.	Fall 2022	0.00%	0.00%	2.27%	2.27%	36.36%	59.09%
	Spring 2023	3.20%	0.00%	0.80%	10.40%	45.60%	40.00%
	Fall 2023	0.72%	0.72%	0.00%	2.88%	35.97%	59.71%
I feel comfortable asking the recitation session leaders questions.	Fall 2022	0.00%	0.00%	2.27%	6.82%	34.09%	56.82%
	Spring 2023	4.00%	0.80%	0.80%	4.00%	42.40%	48.00%
	Fall 2023	0.72%	0.00%	1.44%	10.07%	28.78%	58.99%
I feel the recitation session leaders encourage everyone to participate.	Fall 2022	0.00%	0.00%	2.27%	2.27%	47.73%	47.73%
	Spring 2023	4.03%	0.81%	4.03%	12.10%	42.74%	36.29%
	Fall 2023	0.72%	0.00%	0.72%	10.79%	33.81%	53.96%
Recitation leaders managed discussions in the sessions effectively.	Fall 2022	0.00%	0.00%	0.00%	4.55%	40.91%	54.55%
	Spring 2023	4.00%	0.00%	2.40%	9.60%	42.40%	41.60%
	Fall 2023	0.72%	0.00%	0.00%	5.04%	38.85%	55.40%

Figure 5. Survey results on peer leaders' knowledgeability about the course and recitation management.

b) Evaluation on the effectiveness of peer-led recitations

Figure 6 shows the survey questions and results on the effectiveness of peer-led online recitations. In this part of survey, we focus on evaluating whether the selected topics discussed in recitations are helpful to master the course topics, whether the problem-solving demonstrations in recitations are helpful to improve students' problem-solving techniques, and whether peer-led recitations better prepare students for exams. The survey results suggested that more than 90% of students think that peer-led online recitations are helpful to master the course topics, improve students' problem-solving techniques and better prepare students for exams.

Survey Question	Semester	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
The problems discussed in the recitations are helpful to master the course topics.	Fall 2022	2.27%	0.00%	2.27%	4.55%	31.82%	59.09%
	Spring 2023	0.80%	0.00%	1.60%	16.00%	48.80%	32.80%
	Fall 2023	1.44%	0.72%	2.16%	10.79%	41.01%	43.88%
The problems discussed in the recitations are helpful to improve problem-solving techniques.	Fall 2022	2.27%	0.00%	0.00%	6.82%	13.64%	77.27%
	Spring 2023	5.56%	0.00%	0.79%	15.08%	26.19%	52.38%
	Fall 2023	2.88%	0.00%	0.00%	5.04%	21.58%	70.50%
I believe peer-lead online recitations better prepared me for exams.	Fall 2022	0.59%	0.65%	0.87%	1.06%	35.27%	61.56%
	Spring 2023	1.59%	0.55%	4.21%	2.23%	38.25%	53.17%
	Fall 2023	0.72%	1.08%	1.80%	2.06%	23.12%	71.22%

Figure 6. Survey questions and results on effectiveness of peer-led recitations.

c) Recitation topics

The survey also studies the contents discussed during the recitations, including lecture reviews, exam reviews, assembly coding examples, problem-solving demos, study tips and the conversions about the future courses in the major, research opportunities, and internship opportunities. Based on survey results shown in Figure 7, exam reviews, lecture reviews and problem-solving demos and tips are the top 3 most helpful to improve students' study performance.

Answer	Fall 2022	Spring 2023	Fall 2023
Lecture reviews	20.00%	20.61%	20.72%
Exam reviews	23.86%	23.25%	23.00%
Coding examples	17.20%	18.64%	16.35%
Problem-solving demos and tips	20.25%	20.39%	19.01%
Study tips	11.93%	10.09%	13.31%
Conversions about future courses, research, & internships	6.80%	7.02%	7.60%
Total	100%	100%	100%

Figure 7. Survey results for the question recitation topics.

d) Recitation time

The survey also studies the length of each recitation. In the first semester (Fall 2021) when peer-led online recitations were offered for computer organization course, two 90-min recitation sessions per week are scheduled. However, more than half of students feedback that 90-min recitation is too long, so we adjust to 75 mins per recitation and settle down to 60 mins per recitation finally. Figure 8 shows the survey results on the recitation time for three semesters. The survey results suggest that more than 90% of students think two 60-min recitation sessions per week are just right, or a little bit long or short.

Survey Question	Semester	Too long	A little bit long	Just right	A little bit short	Too short	No opinion
How do you think about two 60 mins recitations per week to cover the content review and problem-solving discussion?	Fall 2022	4.55%	14.65%	60.61%	11.62%	1.01%	7.58%
	Spring 2023	3.97%	15.08%	66.67%	6.35%	5.56%	2.38%
	Fall 2023	4.32%	10.07%	61.87%	12.95%	3.60%	7.19%

Figure 8. Survey Results on two 60-min recitations per week.

e) Students' performance

In this section, we present the effectiveness of peer-led recitation on the students' pass rate for three semesters, fall 2022, spring 2023 and fall 2023. In this hardware course, students need grade A or B to pass the course. We use the same teaching materials and course syllabus in these three semesters. Figure 9 shows the course pass rates of three semesters, fall 2022, spring 2023 and fall 2023. The pass rate of spring 2023 is about 2% higher than fall 2022, while the pass rate of fall 2023 is about 6% higher than spring 2023. Figure 10 shows students' peer-led recitation attendance rates for three semesters. The percentage of students who attended more than half of recitations increased every semester. From these three semesters' pass rates and recitation attendance data analysis, we can observe that students' performance can be improved with peer-led recitations.

We also study the effectiveness of peer-led recitation on the female and male students' pass rate for these three semesters. The female student's percentages for these semesters are 21.46%, 17.24%, and 27.18%, respectively. In fall 2023, more female students registered to the course. Figure 9 shows that female students' pass rates were higher than male students' pass rate in fall 2022 and spring 2023. Figure 10 presents that the percentage of female students who attended more than half of recitations were higher that of male students in fall 2022 and spring 2023. In fall 2023, female students' pass rate was lower than male students' pass rate. We also observed that female students' recitation attendance was lower than male students also in fall 2023. From three semester pass rates and recitation attendance analysis for female and male students, we observe similar positive effectiveness of peer-led recitations on both female and male students' course performance.

Grades	Fall 2022			Spring 2023			Fall 2023		
	Female	Male	All	Female	Male	All	Female	Male	All
Total Count	41	150	191	30	144	174	56	206	262
A + B	34	104	138	24	105	129	41	170	211
C + D + F + W	7	46	53	6	46	52	15	36	51
A + B %	82.93%	69.33%	72.25%	80.00%	72.92%	74.13%	73.21%	82.52%	80.53%

Figure 9. Female and male students' pass rates for three semesters.

Recitation Attendance	Fall 2022			Spring 2023			Fall 2023		
	Female	Male	All	Female	Male	All	Female	Male	All
0	21.95%	46.67%	41.36%	6.67%	26.39%	22.99%	17.86%	10.50%	12.11%
< 50%	14.63%	24.00%	21.99%	6.67%	12.50%	11.49%	28.57%	16.00%	18.75%
max	63.41%	29.33%	36.65%	86.67%	61.11%	65.52%	53.57%	73.50%	69.14%

Figure 10. Female and male students' peer-led recitation attendance rates for three semesters.

Conclusion

In this paper, we report the design of peer-led learning for a hardware course from the aspects of peer leader selection, recitation session format, content recommendations for recitation sessions, and the practice questions development. This paper also presents the evaluations of the effectiveness of peer-led learning with end-of-semester survey, course pass rates and recitation attendances of three semesters (fall 2022, spring 2023 and fall 2023). The survey results conducted in the past several semesters suggest that more than 90% students expressed positive feedback in the end of semester survey, and peer-led online recitations help students' study in concepts understanding, problem solving techniques, assembly language programming, and exam preparing. The survey results also show that undergraduate students meeting the peer leader selection criteria are satisfied with the role of peer leaders. Moreover, we also observed that the course pass rate improved for students attending recitation sessions. This phenomenon can be observed in both male and female students.

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