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Flipping a Computer-Integrated Manufacturing Course

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This study evaluates the use of different active learning strategies for a computer-integrated manufacturing course. The laboratory used for this course has experienced recent renovation, including installation of state-of-the-art automation equipment. With this updated equipment, newly designed coursework has been created to enhance active learning, improve student engagement, and enrich student learning. Three automation topics were included in this study: (1) programmable logic controllers (PLC), (2) computer numerical control (CNC), and (3) robotics. These topics were selected as they are similar in how students understand the logic behind the techniques. Different instructional approaches were used for each of the three methods. For the PLC work, students were required to watch videos and take a quiz prior to starting the laboratory session. For the CNC work, students were evaluated for enhanced learning through supplemental instruction. For the robotics laboratory work, the effectiveness of increased student-instructor interaction was evaluated. Student surveys were used to assess both teaching effectiveness and enhancements in student learning. Based on student survey feedback, it was found that the active learning strategies assisted students in learning the course materials more effectively. Students who were more prepared prior to the laboratory session had a more effective learning experience during the experimental work. In addition, students more effectively learned a subject through supplemental instruction and increased student-instructor interactions.

Introduction

Many studies have been conducted to examine the role of a flipped, or inverted, classroom to promote student learning and create an effective learning environment. Detailed reviews of the flipped classroom method has been done by Bishop and Verleger[1] and O'Flaherty and Philips[2], in which it was pointed out that the flipped classroom provided a more effective use of student-instructor interactions than the traditional lecture setting. Such interactions, along with hands-on learning[3] and collaboration with other students[4], are the basis of effective student learning. In a study done by Reeve[5], it was shown that student engagement creates a more supportive learning environment for students. The flipped classroom approach was evaluated by Redekopp and Ragusa[6] showing that active learning was the key to improving student learning outcomes.

Specifically in a manufacturing curriculum, a study was done to investigate the teaching of an undergraduate manufacturing course in a flipped classroom environment[7], and has shown that watching pre-recorded videos prior to class time have a favorable effect on both student learning through increased interaction with their instructor. Another study of a manufacturing course on plastics engineering technology[8] examined how the flipped classroom approach affected student performance and learning outcomes. It was seen that the flipped classroom helped students retain course materials better than a traditional approach. Based on the evidence from these studies, it is the goal of the author to encourage student engagement and active learning in the classroom through a flipped classroom approach and determine how a flipped classroom can help improve other manufacturing courses, such as a computer-integrated course involving automation.

Background

Over the last few decades, the Department of Industrial and Manufacturing Engineering at the California State Polytechnic University, Pomona (Cal Poly Pomona) has identified that manufacturing courses have benefited from additional instruction given outside the classroom. Courses within the department covering manufacturing processes include both a lecture and a laboratory component. The laboratory component involves hands-on instruction on equipment, including casting, machining, and welding. When these manufacturing processes courses were initially offered, students taking these courses would rely solely on the instructions given by the course instructor. However, since different sections of a given course did not always have the same instructor and different instructors have different experiences, course sections would be taught with varying degrees of information. Furthermore, limited or varying knowledge to instruct these laboratories on how to do such things as make casting molds, pour molten metal into a mold, use a lathe and milling machine, or handle welding torches, would pose a safety risk to both students and instructors. In addition, the manufacturing processes courses comprise a large amount of material that students are required to learn in a single academic term. Having taken these concerns into consideration, videos and slide modules were created for the manufacturing processes laboratories to promote safety during the laboratory sessions, provide a consistent information format for all instructors to provide to students, and offer a study guide to assist students in learning the large amount of material covered in the manufacturing processes courses.

The work presented in this study was done in an effort to deliver a similar solution for an upper-level course on the Introduction to Computer Integrated Manufacturing and Automation. This course involves aspects of an automated manufacturing environment, including programmable logic controllers (PLCs), computer numerical control (CNC), and robotics. Over the last two years, a continuing effort has been made to rejuvenate this laboratory with new equipment, including new student PLC trainer stations and their corresponding integration software. These systems were created for students to learn the functions of PLC hardware components, ladder logic, timer and counter functions, and human-machine interface. The curriculum created around this new equipment was not part of previous course work. Therefore, to keep instructional materials consistent in all course sections, slide modules were created to provide an introduction to the PLC concepts covered in the laboratory sessions. In addition, videos were selected from the PLC manufacturer to give students a background on the different PLC topics. Also, for the safety of students and instructors, and the proper use of the laboratory equipment, a laboratory manual was created for each PLC laboratory session.

Within the Department of Industrial and Manufacturing Engineering, two degree programs are offered: industrial engineering and manufacturing engineering. Manufacturing engineering students are required to take a course on computer numerical control (CNC), while the industrial engineering students can choose to take this course as an elective. The Introduction to Computer Integrated Manufacturing and Automation course includes some CNC laboratory sessions to ensure that industrial engineering students do not miss this topic. However, this means that there is an overlap in the CNC coursework for some students. This study evaluates if this additional instruction is beneficial for student learning of CNC.

Finally, robotics is another key topic in the Introduction to Computer Integrated Manufacturing and Automation course. While an instruction or laboratory manual can be easily provided for students to program and control a robot, issues in troubleshooting the operation of a robot can be time consuming with little learning as a result. The present work therefore evaluates if student interactions with the instructor enhanced their learning experience.

Methods

Programmable Logic Controllers (PLCs)

Student PLC trainer stations were created to teach students the operation of PLC hardware, the function of inputs and outputs, and to simulate a factory environment. Each PLC trainer station included the necessary PLC hardware with pre-wired inputs and outputs, such as buttons, switches, and lights. The PLC trainer stations were operated with a software provided by the PLC manufacturer. Therefore, each PLC trainer station was connected to a personal computer with the software installed. Students conducted four experiments using the software to upload programs to these PLC trainer stations.

To provide the background for each experiment, students were given pre-class work to complete prior to each PLC laboratory session. For this, students were provided with videos, which were created by the PLC manufacturer, and slide modules, which were created by the author. Each video covered a broad application of the major topic of the corresponding laboratory session, while each slide module gave a more detailed background on each topic. In addition, the slide modules were analogous to a study guide that was available to students for reference throughout their PLC laboratory sessions. Students were required to view the corresponding video and slide module for each laboratory session, so that they would be prepared to conduct the laboratory experiment more effectively.

To verify if students did the pre-class work, as described above, a quiz was given at the beginning of each of the four PLC laboratory sessions. Each quiz consisted of five questions and was based on the corresponding video and slide module, which provide more detailed information on the given PLC topic.

During each PLC laboratory session, students were separated into groups of four to complete a laboratory assignment. The assignments were a more advanced extension of the information provided in the slide modules. Groups were able to ask as many questions as needed from their group members and the instructor.

At the completion of each PLC laboratory session, students were asked how effective the pre-class assignments (namely the videos and slide modules) were in preparing them for the laboratory sessions. They were also asked how effective the pre-class quizzes were in assessing their preparation for the laboratory sessions. Since these survey results were based on individual responses, it was possible to link student quiz grades to this feedback.

Computer Numerical Control (CNC)

In addition to the PLC laboratory session, three computer numerical control (CNC) laboratory sessions were evaluated in this study. For the CNC laboratory sessions, students were separated into groups. Each group had a mixture of students who had and had not taken a course involving CNC programming prior to the course evaluated in this study. These 'mixed' groups allowed those students who had prior experience with CNC to instruct their group members who did not have prior CNC experience. In addition, groups were able to ask the instructor as many questions as needed to complete the assignment during the laboratory session.

At the completion of the three CNC laboratory sessions, students who had taken prior CNC coursework were asked how effective the supplemental instruction was in learning CNC programming. Those students were also asked how effective the 'mixed' group was in learning CNC programming.

Robotics

The robotics laboratory was evaluated for enhancement of student learning through interactions between the student and instructor. Students were given basic instructions on how to use a selective-compliance-articulated robot arm, or SCARA, for a pick-and-place operation. Working in groups, students were tasked to write a program to move small parts from one location into a common bin for all parts. During the robotics laboratory session, students were allowed to ask their group and the instructor as many questions as needed to complete the task. At the completion of the robotics laboratory session, students were asked how effective their interactions were with the instructor in enhancing their learning in this laboratory session.

All Laboratories

All of the surveys employed in this study were on a 5-point Likert scale. The sample size for this study was 19. Weighted averages were calculated to evaluate the student experience in these laboratory sessions, in which the following weights were assigned:

5 = Very Effective
4 = Somewhat Effective
3 = Neither Effective Nor Ineffective
2 = Somewhat Ineffective
1 = Ineffective

Results and Discussion

Programmable Logic Controllers (PLCs)

The effectiveness of the pre-class assignments given for the PLC laboratory sessions were assessed through both student feedback and grades. Survey data taken from the PLC laboratory sessions determined how students evaluated the effectiveness of the pre-class assignments in their preparation for the PLC laboratory sessions. Figure 1a shows student feedback on how effective the pre-class assignments were in preparing them for the PLC laboratory sessions. The data in the figure has been separated to show those students who did and those who did not complete the pre-class assignment. It is seen in the figure that the students who completed the work, by viewing the videos and slide modules, rated the pre-class assignment more effective in preparing them for the PLC laboratory sessions than those students who did not complete the pre-class work.

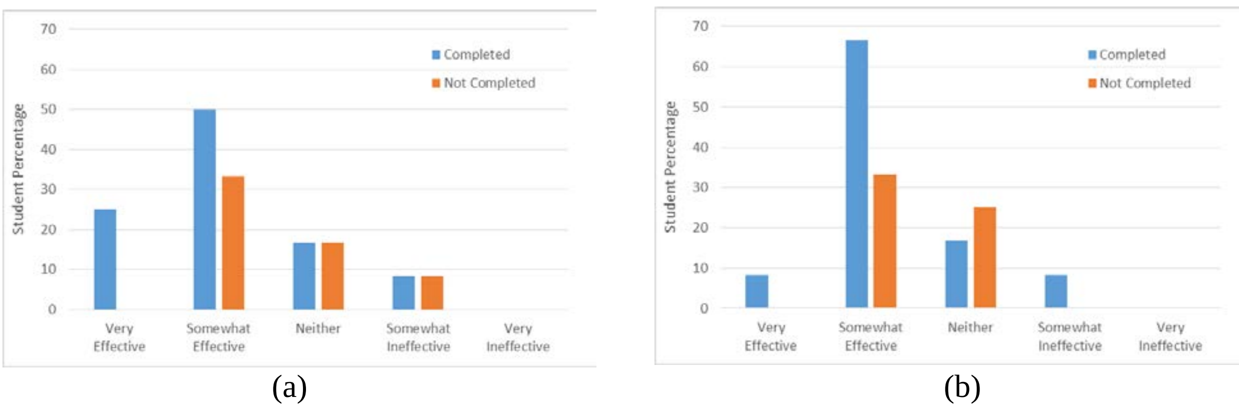


Figure 1: Student feedback on the effectiveness of (a) the pre-class assignments and (b) the pre-class quizzes on their preparation for the PLC laboratory sessions.

In addition, students were asked to evaluate the effectiveness of the pre-class quiz in preparing them for the PLC laboratory sessions. Figure 1b shows student feedback, again separated for those students who completed and those who did not complete the pre-class assignment. It is seen in the figure that the students who completed the work prior to the quiz, rated the pre-class assignment more effective in preparing them for the quiz than those students who did not complete the pre-class work.

The student assessment for the pre-class work for the PLC laboratory sessions coincides with their resulting grades from the pre-class quizzes. Table 1 shows the weighted averages of the student survey data for the effectiveness of the pre-class assignment and quiz for preparing them for the PLC laboratory sessions, and the quiz grades for the students who did and those who did not complete the pre-class assignment. It is seen that the students who did the pre-class assignment believed that the pre-class assignment was effective in preparing them for the PLC laboratory sessions. The average quiz score of the students who did the pre-class assignments was also higher (82.7) than that for the students who did not do the pre-class assignment (70.0). Therefore, students who did the pre-class work believed that their efforts in completing the pre-class assignment provided them with a more effective preparation for the PLC laboratory sessions and their quiz grades supported this assessment. In other words, the students who did the pre-class assignments were better prepared for the quizzes and considered themselves effectively prepared. Furthermore, students having higher quiz grades are believed to be more prepared for the laboratory sessions, since they have acquired the basic information for a given PLC topic in order to conduct the experiments.

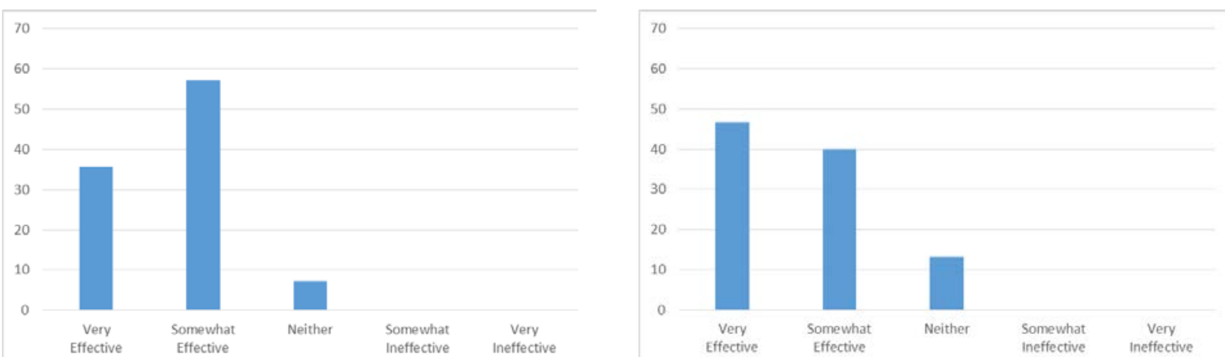
Table 1: Student assessment of the effectiveness of the pre-class assignments and quizzes on their preparation for the lab sessions and their corresponding quiz grades.

Assessment Method	**Completed**	**Not Completed**
Pre-Class Assignments (weighted average)	3.92	2.00
Pre-Class Quizzes (weighted average)	3.75	2.08
Quiz Grades (average)	82.7	70.0

Computer Numerical Control (CNC)

Students who had taken a course on CNC programming, prior to the course evaluated in this study, were asked how effective supplemental instruction was in learning CNC programming. Survey data seen in Figure 2a, taken from the CNC laboratory sessions, showed that students found the supplemental instruction effective in helping them learn CNC programming. The weighted average of this survey data was 4.29.

Students were also asked how effective the ‘mixed’ group formation was, with students who previously had CNC instruction with those students who did not. Figure 2b shows a summary of student feedback of how effective it was to learn CNC programming in a ‘mixed’ group. Students who had taken CNC instruction prior to enrolling in the course were evaluated in this study. These students believed that learning CNC programming with others, who had not taken CNC instruction previously, was effective. The weighted average of this survey question was 4.33.



(a) (b)

Figure 2: Student feedback on the effectiveness of (a) supplemental instruction and (b) ‘mixed’ groups for learning CNC programming.

Robotics

After being given the basic operating instructions for a SCARA robotic arm, and having interactions within a group and with the instructor, students were asked how effective their interactions with the instructor were in enhancing their learning experience in the robotics laboratory session. Figure 3 shows the feedback given by students. The data showed that they believed that their interactions with the instructor were effective in enhancing their learning experience. The weighted average for this data was 4.53.

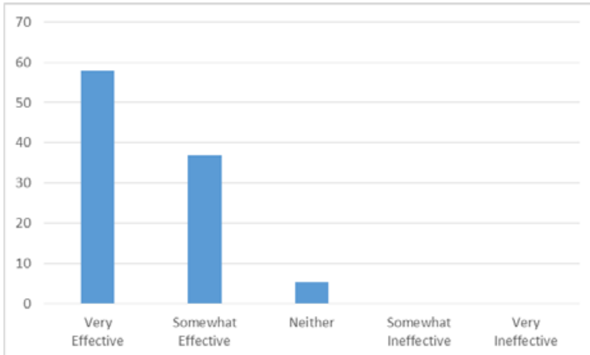


Figure 3: Student feedback on the effectiveness of student interaction with the instructor in enhancing student learning experience in this lab.

Conclusions

In this study, the author evaluated a flipped classroom approach for an Introduction to Computer Integrated Manufacturing and Automation course at the California State Polytechnic University, Pomona (Cal Poly Pomona). Student feedback that was linked to quiz grades, showed that flipping this course was an effective method for introducing a new topic to students. Through videos and slide modules, students became familiar with a new topic outside of class, while they were then able to use their time in-class to dive deeper into the topic. Given that videos and slide modules would take approximately 30 minutes to view, having that time in class with peers and the instructor was proven to be a more effective use of student time.

In addition, it was shown that supplemental instruction was beneficial in learning a topic. By using ‘mixed’ groups, in which there were students who did and did not have prior instruction on a given topic, students were able to learn more effectively through peer collaboration within their groups.

It was also shown that students found interactions between them and the instructor effective in enhancing their learning experience in the laboratory. This indicates that while students may have the necessary information provided to them, such as in the form of a lab manual, they find that additional interactions, through questions to the instructor, are beneficial in furthering their learning.

When considering teaching a course in which laboratory equipment is involved, such as that discussed in this study, it is concluded that written instructions alone are not sufficient in allowing students to complete a given project or task using that equipment. It was observed that learning is advanced more effectively when students have the opportunity to get answers to their questions throughout their operation or programming of the equipment. Therefore, it is concluded that while, such things as pre-class work to introduce a new topic to students can be effectively automated through videos and slide modules, student learning the operation of a new piece of equipment requires instructor-student interactions. Additionally, in the interest of safety for both students and equipment, an initial tutorial, such as pre-class work and the presence of the instructor during laboratory sessions is recommended.

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