Performance and Motivation of Students in an Electrical Engineering Course Using Programmable Logic Controller (PLC) for lab experiments.

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ABSTRACT:

The final goals of this study is to investigate the impact of using a Programmable Logic Controller (PLC) as a research based learning tool on the performance and motivation of each student in an industrial automation course. For this purpose, ten PLC's lab experiments are used to visualize the theories covered in the learning outcomes (CLO'S) of the course and investigate their applications in industrial automation. The success of the PLC as research-based tool are demonstrated by the fact the performance of 40 students (73%) is higher in this course than their corresponding average performance in the college. Moreover, using the Dadach Motivation Factor (DMF) as tool to measure motivation of students, our results also indicate that thirty-five students (63.63%) were motivated during the course. In overall, this investigation shows that the utilization of ten PLC lab experiments for the visualization of the opaque theory of industrial automation is successful.

Key words: industrial automation, Programmable Logic Controller , relative performance of students, motivation of students.

1. Literature Review

A programmable logic controller, PLC, or programmable controller is a digital computer used for automation of typically industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. PLCs are used in many machines and in many industries. However, a few industrial, chemical, and electrical engineering as well as various technology programs have included some introduction to PLCs into their programs, where they are often presented as part of a laboratory course. However, several programs have begun offering courses dedicated to learning and applying PLCs (Foster et al., 2010).

Anup Suresh (Suresh, 2013) presented some laboratory experiments for students to learn and explore the various industrial applications of PLC's. The control problems in the study were defined with respect to their applications in different industries such as automotive, steel, oil and electronics. Applications were typical processes that can be observed in these industries such as material conveying, material handling, cutting processes, system control and temperature control. All the problems were solved using Ladder Logic programming on Automation Studio to simulate these processes and provide students with a wholesome learning experience. A Programmable Logic Controllers (PLC) course is presented in the literature as a 3 credit hours course for junior/senior level Electrical Engineering Technology students of the Northern Illinois University

(DeKalb, IL, 60115, USA). Fundamentals of PLC hardware components, programming and troubleshooting were covered in lectures. Then students were expected to complete a PLC design project based on the topics covered in the course. Assessment of the course showed that students had very good response to the design projects. Communication skills of the students were enhanced from writing the final reports and giving the oral presentation in the class (Liping, 2009). Seke et al. (Seke et al., 2018) presented a Project-Based Learning in Programmable Logic Controller. They used experimental methods with experimental class and control class consisting of 24 students, with 12 students of high creativity and 12 students of low creativity. It was concluded that in the group of students who have high creativity, student learning outcomes PLC taught by project-based learning method is higher than the results of student learning taught by simulation learning method. According to the authors, the successful application of project-based learning methods to students with high creativity also lies in the ability of lecturers to effectively designing the learning process, emphasizing motivation, and supporting their project work, guide them during the learning process that can reduce their doubts to finding solution for finishing their project so that can be meaningful experience on skill or knowledge who will support their learning outcomes. The objective of this paper is to quantitatively measure the performance and motivation of each student in an industrial automation course supported by ten laboratory experiments using the Programmable Logic Controller (PLC) as a research based learning tool to visualize the opaque theory of industrial automation.

2. Introduction of the Course

The objective of the industrial automation course (ELE 2613), offered in Electrical Department of Abu Dhabi Men's College of the Higher Colleges of Technology of the UAE, aims to introduce the concepts of programmable logic controller used in industrial automation. It is intended to provide basic skills on how to program a PLC to solve simple industrial applications. The course is a four-hours lecture course per week where two hours are assigned for lectures and two hours are used for tutorials and lab experiments. The course described in this paper was taught to fifty five students of semester four of the program divided in three sections. This final aim of this course is to supply the students the basic information on the functions and configuration of PLCs with emphasis on the LOGO! Siemens. At the end of this course, students are supposed to be able to design an electrical automated circuit, program it using the PLC, make the necessary connections between the input and output devices and run it using the PLC trainer unit. The course has four learning outcomes (CLO's) supported by ten lab experiments conducted in the Programmable Logic Controller (PLC). The Learning outcomes (CLO's) and their corresponding lab experiments are as follow:

CLO1: Describe the PLC system structure in terms of hardware and components (Lab 1).

CLO2: Write documented programs using basic PLC programming techniques (Lab 2-5).

CLO3: Use the PLC, timer, and counter instructions to safely control simple systems (Lab 6-10).

CLO4: Use systematic fault finding and debugging techniques to implement an industry related applications (Lab 9-10).

3. Description of the Programmable Logic Controller (PLC)

The Programmable Logic Controller (PLC) utilized as research based learning tool in this course is a specialized computer used to control machines and processes. It uses programmable memory to store instructions and execute specific functions that include on/off control, timing, counting, sequencing, arithmetic, and data handling. While the specific applications vary widely, all PLCs monitor inputs and outputs and make decisions based on a stored ladder logic program, and control outputs to automate a process or machine as shown in Figure 1.

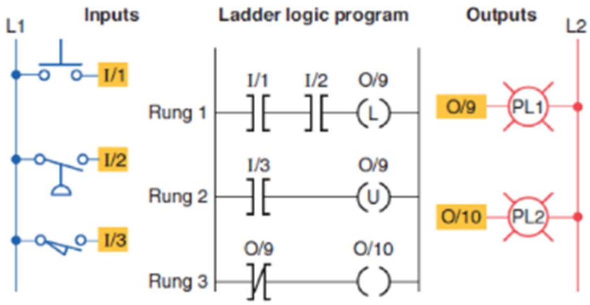

Figure 1: Input / Output PLC connection diagram (Suresh, 2013).

The Elements connected to the input module are such as Switches, Sensors and the elements connected to the output module are such Motors, Pumps, and Lights as shown in **Figure 2.** The LOGO! Siemens PLC used in this course is modular unit, 12/24 DC Volt, 8 digital inputs (4 AI) and 4 digital outputs.

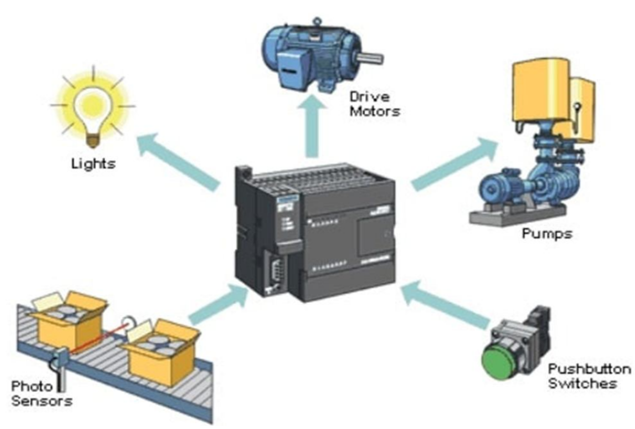

Figure 2: PLC input / Output Devices (Evghenii, 2017).

4. Laboratory Procedures:

The ten laboratory experiments covering the theories learned in learning outcomes (1) to (4) are divided in three parts. In the first part, the students start getting familiarized with the different connection points and programming the basic functions. This part contains five activities that covers CLO1-2. In the second part, the students learn how to program the relay, timer and counter instructions that is covering CLO3. The main objective of the last part is to start designing programs that are related to solving industrial automation systems using all what have been learned in the previous lab experiments including the fault finding techniques covered in CLO4. As we are applying a hybrid learning system, some lab activities will be conducted online and others on campus. The laboratory experiments include the following procedures:

a- Handout to read: a week before the laboratory , students are given a handout containing the main objective, the description of the apparatus, safety and procedure and a brief explanation of the theory. The students need to answer some questions before coming to the lab that are related to the electrical circuit and the ladder logic diagram. This part is the preparation phase which is a part of the lab assessment.
b- Short lecture (15 minutes): the new laboratory procedure is explained by linking what have been learned in the previous lab and what need to be done in the present lab.
c- First activity (lab experiment: 60-70 minutes): a team of 2-3 students follows the steps given in the handout while conducting the experiments by simulating and drawing the electrical circuit and the corresponding ladder logic diagram for the given question.
d- Second activity (lab oral assessment: 15 minutes): each student is asked few verbal questions in order to evaluate his / her part of participation in the team.
e- Third activity (lab report: after 1 week): every team needs to answer all the questions given in the handout including analyses, discussions of results and conclusion. One-week time is given to the students to submit the lab report.

5. Laboratory Experiments:

5.1 Lab #1: Logic Function Part 1:

In this first lab experiment, the students identify the different parts of the PLC and practice how to connect the input and output devices respectively to the input and the output modules (CLO1). The students also practice how to program the Ladder Logic Diagram using a new PLC software, upload it into the PLC and draw the connection diagram of the input and output devices as well as making the connection on the PLC trainer unit (CLO2). The final goal of the experiment is to exercise how to program the two logic functions (L_1 = A and L_2 = A x B).

5.2 Lab experiment #2: Logic Function Part 2.

This online activity is similar to the first experiment where students investigate two new logic functions (CLO 2). The two logic functions to simulate are the inverting function L_1 = A- (read A bar) and the OR function L_2 = A + B.

5.3 Lab experiment #3: Logic Function Part 3.

In this on campus lab experiment the students practice to program the following combined functions [L_1 = (A + B) C-] and [L_2 = A- + B x C] (CLO2).

5.4 Lab experiment #4: Logic Function Part 4.

In this on campus lab experiment, students investigate the following function [L = (A + B) (A- + C-)] where the function contains both the variable input A and its inverting input A- (read A bar) (CLO2). After performing this experiment, student will be able to program any learned function .

5.5 Lab experiment #5: Logic Function from PLC.

In the previous lab experiments, students have learned to program the functions from the personal machine which is the programmer device. In this on campus activity, students will apply these functions from the PLC itself. All the functions investigated in lab activities 1 to 4 will be now programmed from the PLC shown in Figure 3.

Figure 3: LOGO! PLC Screen Display (Sander van de Velde, 2019).

5.6 Lab experiment #6: Electromagnetic Relay and Motor Control.

This lab experiment allows students explore the electromagnetic relay covered during the lecture class (CLO 3). In this activity, students will investigate how to program a relay and control a DC motor through the motor starter as shown in Figure 4. All what the students have learned in the five previous labs will help them in the coming lab experiments to program the control of the electrical motor. From all the previous lab activities, the students now enjoy and understand the importance of controlling a motor directly through a PLC.

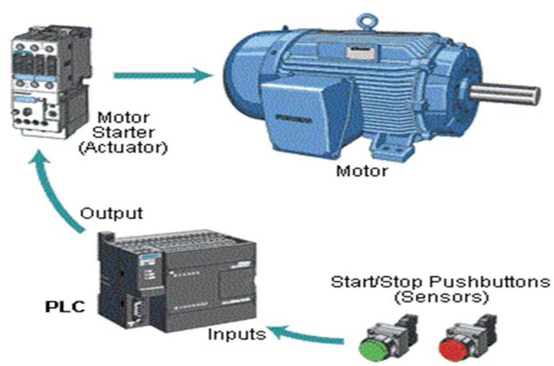

Figure 4: Motor Control through PLC (Evghenii,2017)

5.7 Lab experiment #7: Timer Instructions.

In this on campus lab experiment, students will examine how to program the different types of timers including ON-Delay timer, OFF-Delay timer, ON-OFF delay timer and the Retentive ON-Delay timers that are covered in the class lecture (CLO3). The students will program each of them from the personal computer and edit them from the PLC.

5.8 Lab experiment #8: Counter Instructions.

In this on campus lab experiment, students program the Up-Down Counter instruction that have been covered during the class lecture (CLO3). The students will program each of them from the PLC and edit them from the personal computer.

5.9 Lab experiment #9: Traffic Light one way

After the previous lab experiments, students have now gathered enough knowledge and expertise to program some basic industrial automated systems that have been covered in the class lecture (CLO3). The street traffic light one way is the first application where students program during this online lab experiment. Using the ON-Delay timers the students will also practice how the traffic signal Red, Green and Orange is controlled by the PLC.

5.10 Lab experiment #10: Charge and Discharge of a Reservoir.

The last lab experiment related to this industrial automation course is the charge and discharge of a reservoir. By using automated valves, this process can be completely automated. In this on campus lab experiment, the students are asked to design the ladder logic diagram to control the filling and the emptying operation of the reservoir by including the timer and the counter learned in the previous labs. After running the system on the trainer, a fault is inserted by the teacher inside the system and students are asked to use the proper method to find the fault and fix the problem which is part of the theory learned in CLO4.

6. Assessment Strategy of the Course

There are many options to collect evidence of student learning. To simplify the alternatives, assessment efforts are categorized as direct and indirect measures. According to the literature (Maki, 2004), direct methods prompt students to represent or demonstrate their learning or produce work so that observers can assess how well students' texts, responses and skills fit program level expectations. The strength of direct measurement is that faculty members are capturing a sample of what students can do, which can be very strong evidence of student learning. A possible weakness of direct measurement is that not everything can be demonstrated in a direct way, such as values, perceptions, feelings, and attitudes. Some typical examples of direct measurement done by faculty include (Breslow, 2007):

1) Grades
2) Standardized tests
3) Pre/post tests
4) Analysis of assignments designed to test conceptual understanding (e.g., concept maps, pro/con grids)
5) Observations of students performing a task
6) Analysis of student work products (e.g., exams, essays, oral presentations)
7) Senior thesis
8) Portfolios compiled over course of undergraduate study

In the Industrial Automation course described in this paper, a variety of direct measures were utilized throughout the semester-long course. First, two written exams (15 marks each) were organized in the middle and the end of the semester and a final exam (FWA :30 marks). Secondly, the assessment of the activities based on PLC (lab experiments and lab test) represented 30% of the total mark. In conclusion, the assessment strategy used in the course is shown in Table 1.

Table 1: Assessment Strategy of the Course ELE 2613

Activity	Mark
Theory-Exam 1	15%
Theory-Exam 2	15%
Lab Report	20%
Practical Test	10%
Theory-Quiz	10%
Theory- FWA	30%

Secondly, the assessment strategy for the lab reports is given in the Table 2 below:

Table 2: Assessment strategy for the lab experiments.

Criteria	Marks
Lab Preparation Lab document prepared as required before the starting of the lab session	**10**
Oral Quiz Answering verbal questions asked by the instructor during the lab session	**10**
Lab Involvement Student activity during the lab	**10**
Correctness of Answers Questions The lab experiment's questions were answered correctly	**30**
Completeness of Laboratory report Circuit diagram well drawn, and the required experiments and content is complete	**15**
Grammar/Spelling/Language Free of grammatical and spelling errors, the words were appropriate and ideas were clearly expressed	**10**
Conclusions States the final conclusion of the experiment based on the objectives and the ideas were clearly presented	**5**
Health & Safety All the safety rules were followed during the laboratory exercise	**5**
Promptness The laboratory report was submitted on time	**5**
TOTAL	**100**

Finally, at the end of the semester, a practical test is conducted for each student. A variety of exams will be prepared from each lab activity including logic functions, relay, timers, and counters. One-hour time is given for each student to complete the practical test which includes designing the electrical circuit, and its corresponding ladder logic diagram, connecting the input and output devices, upload the program into the PLC and execute it.

7. Quantitative Measurement of the Relative Performance of each student.

What students learn stays invisible in their brain. The main questions is: What can students perform with their learning? This means that learning must be assessed through performance. In this course both the retention of the theory (written exams) and the performance (lab experiments and practical test) are assessed. Some see performance as synonymous with success (Olusola, 2011). In this perspective, the universities must ensure and provide the students with high-quality service. They have an obligation of producing graduates who can suit the developing societal difficulties, for example, graduates producing high-quality profile and competence in their respective profession (Suryadi, 2007). Academic literature shows that grades and GPA are the most commonly used measures of academic success (York et al, 2015). For example, it was shown that GPA tops the list as most often used measurement of academic success accounting at 54.8% making academic achievement the most commonly assessed aspect of academic success within the empiric pieces we reviewed (York et al., 2015).

The grades of students and their GPA were utilized in a process control course to measure the relative performance of students (Dadach, 2013). The objective of the investigation was to compare the performance of each student in the course measured by the final grade (FGP) with the overall performance of the student in the college measured by the CGPA. For this purpose, Equation (1) was presented by the author as a tool to define, in percentage, the relative performance RP of each student (Dadach, 2013):

$$RP = \frac{(FGP - CGPA)}{CGPA} x\, 100 \qquad (1)$$

Based on equation (1), a positive or a negative value of the RP means that a student performance in the course was higher or lower than the average performance for all the courses taken in the college. The same methodoly is utilized in this paper to measure the relative performance of each student in this electrical engineering course (ELE 2613) where ten lab experiments were conducted using the Programmable Logic Controller (PLC) as the active learning strategy. The findings of the study are represented in figure 5.

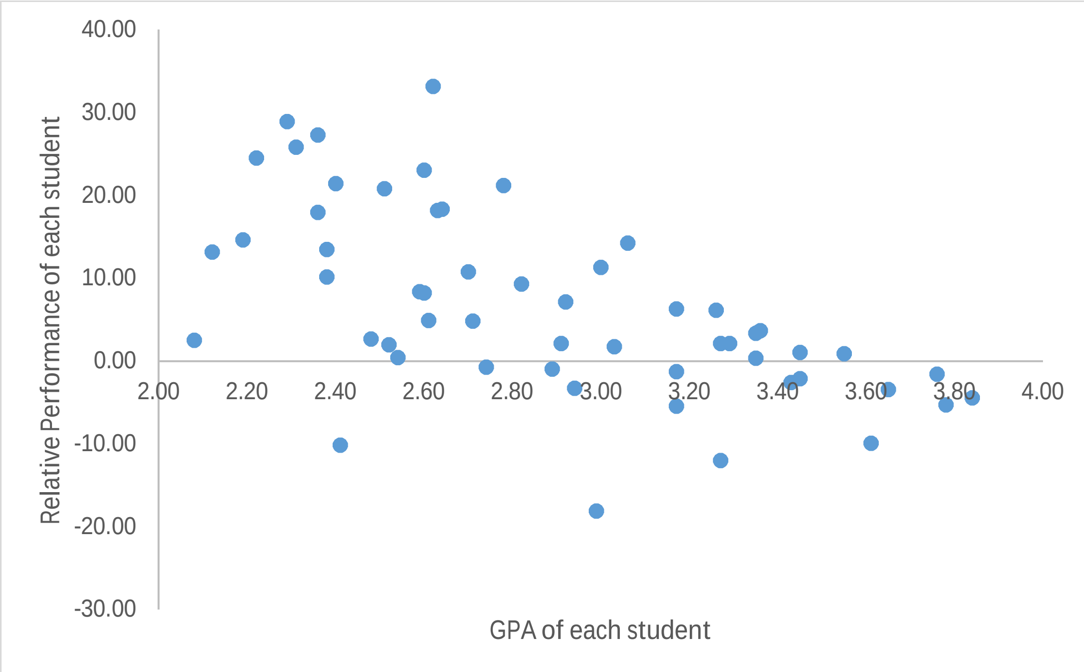

Figure 5: Relative Performance of Each Student in Relation to his Cumulative Grade Point

The overall analysis of Figure 5 indicates that 40 students (73%) had a positive RP and 15 students (27%) had a negative value of their RP. Figure 5 shows also that the highest values of the positive RPs are located in the lower CGPA region. This finding could be explained by the fact that the ten lab experiments could have affected more the students in the lower CGPA region and helped them enhance their performance. Finally, the sum of the positive and negative relative performances of all the students indicates that, in average, every student had a positive RP of +6.73%.

8. Quantitative measurement of the Motivation of the students.

Research has shown that motivation influences student involvement and performance (L. D. Gambrell et al., 1996). The measurements of student motivation presented in the literature are either through an assessment of the amount of time that students freely spent on an activity or by using tools such as questionnaires and interview (Savage, 2009). For example, Vroom's theory was used by Lanigan (Lanigan, 2009) to define the Motivational Force as the product of Valence, Instrumentation and Expectancy:

$$\text{Motivational Force (MF)} = \text{Valence} \times \text{Instrumentality} \times \text{Expectancy} \qquad (2)$$

where Valence refers to the emotional orientations people hold with respect to outcomes [rewards]. Instrumentality is the perception of students expressed as a probability that there will actually be an outcome associated with completing the assigned task and Expectancy refers to the different expectations and levels of confidence about what they are capable of doing. In this perspective, a pre- and post-test questionnaires using Motivated Strategies for Learning Questionnaire (MSLQ) were administered to the engineering freshmen in four selected engineering departments, quoted as Departments A, B, C and D, in a technology-based university in Malaysia (Samsuri et al., 2017). The results of this study show that students of Department A (which implements all four lenses of HPL framework) have improved their motivation after completing the introductory engineering course and this would help them to retain the program, as well as to improve their enthusiasm to learn.

Different from the qualitative methodologies, a quantitative method is presented in the literature (Dadach, 2013). The aim of the study was an attempt to quantify the impact of an active learning strategy on the motivation of students in a process control course by introducing a motivation factor (MF) for each student calculated from his Final Grade Point (FGP) and his Cumulative Grade point average CGPA.

$$MF = \frac{FGP}{CGPA} \quad (3)$$

In order to obtain a common scale for the motivation factor (MF), a correction factor (α) was introduced by the author by adjusting the values of the motivation factor (MF) based on the different values of α. As a result, the Dadach Motivation Factor DMF was introduced to measure the effects of an active leaning strategy on the motivation of students (Dadach, 2013):

$$DMF = \frac{FGP}{\alpha * CGPA} \quad (4)$$

Based on equation (4), values of the DMF higher than unity mean that the effects of the active learning strategy on the motivation of students were significant. This quantitative method is also utilized in this paper to investigate the motivation of each student in this course supported by ten lab experiments conducted in the Programmable Logic Controller (PLC) as the active learning strategy. Values of the DMF higher than unity mean that the effects of the active learning strategy on the motivation of students were significant. It is assumed in this paper that a Dadach Motivation Factor (DMF) is equal to unity if 0.95< DMF< 1.05. The findings of the investigation are shown in the Figure 6.

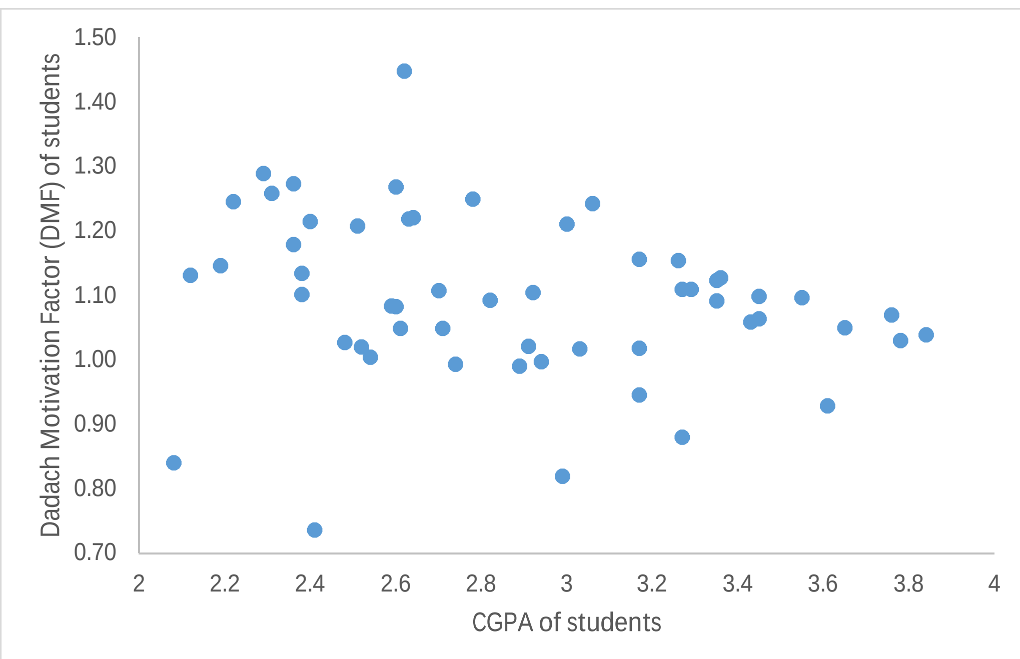

Figure 6: Dadach's Graph for Motivation

According to the DMF graph, thirty two students (58.18%) had a motivation factor higher than 1.05. It could be concluded that these students were motivated by the active learning strategy based on the lab experiments. Most students having a CGPA (2.06<CGPA<3.06) had the highest values of the Dadach Motivation Factor. As a consequence, motivation played an important role in the positive performance of these students (Figure 7). The combined results related to the performance (first part) and the motivation (second part) of students are shown in Table 3.

Table 3: Combined Results for the Relative Performance (RP) and Motivation Factor (DMF) of Student

DMF ≤ 0.95		0.95 < DMF ≤1.05		DMF > 1.05	
RP > 0	RP < 0	RP > 0	RP < 0	RP > 0	RP < 0
Frequency from a total of 55 students					
1 (1.81%)	5 (9.09%)	7 (12.73%)	7 (12.73%)	32 (58.18%)	3 (4.65%)

First, the thirty-two (58.18%) students with a Dadach Motivation Factor (DMF) higher than 1.05 also had a positive relative performance (RP).The performance of these students is therefore due to their high level of motivation during the course which could be linked to the positive effects of the ten lab experiments. In the other hand, three students (4.65%) who had Dadach Motivation Factor (DMF) higher than 1.05 had a negative performance value (RP). This finding is explained by the fact that these students were motivated but performed better in some other courses. Moreover, fourteen students (25.46%) had a Dadach Motivation Factor (DMF) close to unity (0.95 < DMF ≤1.05) which means that the teaching strategy and the ten lab experiments had no effect on their motivation. Most of these students have a CGPA between 2.48 and 3.17. Half of them (12.73%) performed better in this course than the other courses of the department. The other half performed better in the other courses. Finally, for six students (10.9%) who had a Dadach Motivation Factor (DMF) less than 0.95. The active learning strategy had a negative effect on their motivation. However, one student (1.81%) performed better in this course than the other courses of the department.

9. Conclusion

The main goal of this paper was to quantify the performance and motivation of each student in an industrial automation course using the Programmable Logic Controller (PLC) as a research based learning tool. The objective was to help students develop creativity, teamwork and practical problem solving skills during the ten lab experiments. The success of this active learning strategy can be shown by the fact that the performance of 40 (73%) students was higher in this course than their average performance in the college which was measured by the CGPA of each student. On the other hand, the teaching strategy has a negative effects on the performance of 15 students (27%). In conclusion, the sum of the positive and negative relative performances (RP) of all the students indicates that, in average, every student had a positive RP of +6.73%. Moreover, the graph corresponding to the Dadach Motivation Factor indicates that the active learning strategy based on the PLC's lab experiments motivated thirty five students (63.63%). However, three of these students (4.65%) had a negative performance value (RP). This finding is explained by the fact that these students were motivated but performed better in some other courses. Secondly. The teaching strategy based on the use of the PLC had no effects on the motivation of 14 students (25.46%). The half of these students had a negative value of RP which means they performed better in other courses. Finally, the teaching strategy had negative effects on the motivation of six students

(10.91%). In overall, this investigation showed that the utilization of ten PLC lab experiments for the visualization of the opaque theory of industrial automation was successful tool as shown by the performance and motivation of each student.

10. Acknowledgment:

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