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Introducing Analysis of Experiments in Electrical Machines Laboratory

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Abstract— **The scope of the Conceive, Design, Implement, and Operate (CDIO) framework is to help the learner attain higher-order thinking skills (HOTS) in their courses. But most of the theory and practical courses offered in academic institutions are of a low-order thinking level. In outcome-based teaching and learning (OBTL), in order to achieve the graduate attribute of critical thinking, the learner needs to design and do the experiment and also be able to analyze and provide inferences about the data. Most laboratory courses offered in engineering colleges have an application level. To improve the course outcome from apply to analyze level, integrating a component of experiment analysis is required in the laboratory courses, which helps the students achieve higher-order thinking skills. An electrical laboratory course is given to the second semester students with the conventional experiments of machines at the application level. In order to inculcate analyzing skills, a case study of introducing a simple statistical analyzing tool based on MS-Excel in an experiment called 'load test on a 3-phase induction motor using variable frequency drive (VFD)' is presented in this paper. It was found from the laboratory assessment that the students using this analysis and visualization tool for interpreting the results scored well compared to the previous year's students.**

***Keywords*— Higher order thinking skills (HOTS); outcome based teaching and learning (OBTL); variable frequency Drive (VFD); ANOVA.**

I. INTRODUCTION

Theoretical knowledge and practical skills should go together in order to enhance academic performance among students. Most of the practical courses in engineering colleges have a curriculum of lower-order thinking levels. Students' creativity and problem-solving skills can be enhanced by providing higher-order thinking skills (HOTS) embedded in the curriculum and carried out in laboratory exercises [1]. Usually, designing a practical course with higher-order thinking skills is difficult without specialized tools to implement [1] and [2]. In most of the laboratory courses, due to a shortage of infrastructure, the curriculum is framed within the availability of resources [3]. Therefore, designing and implementing a curriculum that enhances higher-order thinking skills using the available resources [4] is challenging in engineering academic institutions.

Electrical Machines Laboratory is a practical course offered to second-semester Mechatronics students. In this laboratory, students will study the performance characteristics of different machines by operating them at different settings. They simply take the readings, plot the graphs, and write down the results without attaining any insight about the motor [5]. Since students start studying their engineering-related courses during their second semester, it is difficult for them to use any specialized tool for analysing the electrical machine parameters. It is also important for the mechatronics students to get proper insight into the motor characteristics in order to select the motor of the proper rating and type for the given applications. So it is necessary to provide a simple tool using which students can be able to analyse the machine parameters at different settings to get proper insight into the machine's performance and its characteristics [6]. The curriculum of the electrical machines laboratory consists of performance studies of transformers, DC motors, and AC motors. The motor characteristic study consists of both speed control tests and load tests [7]. In motor speed control tests, students will observe the motor operating parameters at different speed level settings [8]. In load tests, the mechanical load will be applied to the motor until the rated current is reached in order to study the different parameters associated with loading conditions [9]. The course outcome of the electrical machines laboratory is given in Table 1. In the outcome table, higher-order thinking skills are introduced into the CO6, where students will be able to select the motor for any application based on their insight into the different motor behaviours through analysis of motor operating parameters [10].

In this study, basic concepts of analysis and visualization of experiment results are introduced in order to relate the different operating parameters of the motor and provide the proper inference about the experiment. The data analysis tool available in the micro soft excel sheet is introduced to the students to perform the characteristic study of motor parameters [11] [12].
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II. PROPOSED WORK OVERVIEW

The second year students of Mechatronics Engineering in their 3rd semester doing their laboratory course in Electrical Machines. The students were doing their experiments in batches

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with 4 in each batch. As the conventional way of doing the lab experiments, they will do the electrical connections, run the motor, take the reading, plot the parameters in the graph and write the result. But this conventional way of doing the experiment won't enhance the student's practical skills. Also these experiments only develop lower order thinking skills in students, In order to develop higher order thinking skills, the statistical way of understanding and analyzing the experiments in is introduced in this lab.

TABLE I
COURSE OUTCOME OF ELECTRICAL MACHINES LABORATORY

CO Number	Course Outcome Statement	Weightage in %
CO1	Develop the characteristics of no load and load condition of various DC motors.	10
CO2	Compute the characteristics of no load and load condition of various AC machines.	10
CO3	Categorize the no load and load condition of DC Generators and practice the applications.	20
CO4	Illustrate the performance parameters of Electrical machines in different conditions.	20
CO5	Study and practice the function of different motor starters.	20
CO6	Select the suitable special machines for given real time application.	20

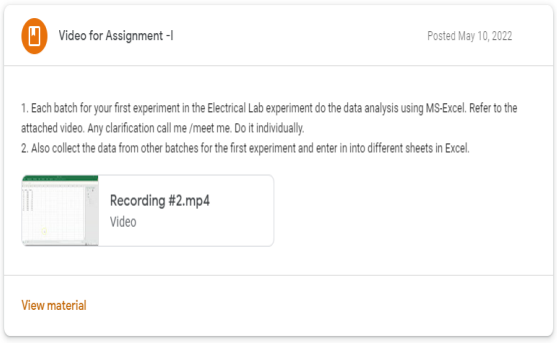

Fig. 1. Demonstration video posted in google class room

The students are shown how to use the excel 2013 statistical package both in person and through a video that is broadcast in the Google class room, as illustrated in Figure.
This video demonstrates how to run statistical tests such the z-test, t-test to compare two means, Anova test, correlation equation, and regression equation [13]. The students are given with a question as a sample shown below to carry out their experiments.

Q1 Perform the data analysis of power transformer at different loading conditions and write the inference on your observation.

Q2. Do the load test on 3-phase induction motor using DOL starter and find the regression equation that relates torque with load current and speed.

Q2 Select the voltage and frequency parameter to drive a three phase induction motor using VFD starter with a speed of 100 rpm and with 50% load.

Q4 Perform the load test on single phase induction motor and find the correlation between torque and speed using excel sheet.

Q5 Find the voltage, frequency, speed parameters to drive the 3-phase induction motor using VFD at three different load conditions. Check whether the torque and produced at the different load conditions or same or different using ANOVA [14].

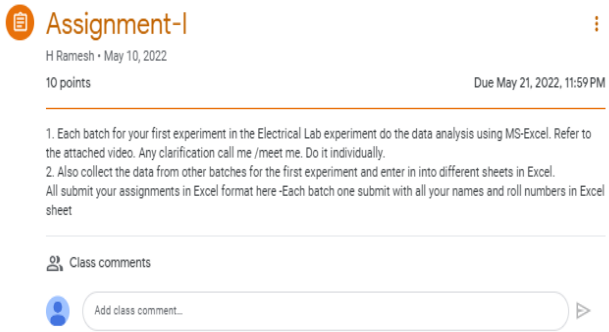

Fig. 2. Experiment question posted in google class room

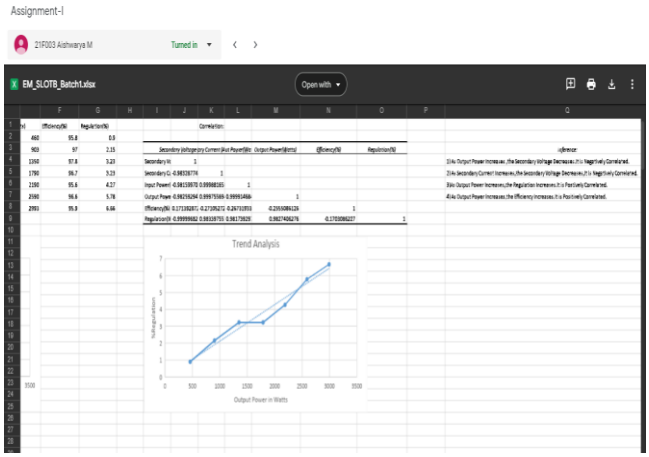

Fig. 3. Students submission in Google class room

Figure 2 shows the question posted in google class room to submit their practical analysis report in google class. The analysis report submitted by the student with their inference is shown in Figure 3.This new way of analyzing the machines parameter using statistical tests and generating interactive reports enhances the students' application and analyzing skills.

Question 5 is used in this study to illustrate the statistical analysis the student conducted.

III. EXPERIMENTAL SETUP FOR CONDUCTING LABORATORY EXPERIMENT IN VFD

VFD's are used in industrial applications where variable speed is required. It is used now a days in many applications to improve the energy efficiency. Because of its familiarity in many industrial applications, it is given in a Electrical laboratory experiment to control the speed of induction motor at different load conditions. The load test on 3-phase induction motor using VFD drive is given in Figure 4.It consists of a VFD connected to a 3-phase induction motor. The Speed of a VFD is controlled using the control supply of 0-10V dc [15]. By varying this voltage speed of a motor can be controlled from 0-1500 rpm. The schematic diagram of VFD drive is given in Figure 5.It consists of a DC converter which converts 3phase ac of fixed magnitude and frequency in to dc supply. The DC bus having LC filter filter-outs ripples present in the converter dc output. The control logic consists of algorithm to trigger the Insulated Gate bipolar transistors (IGBTs) for getting the required voltage and frequency to control the motor speed [16].

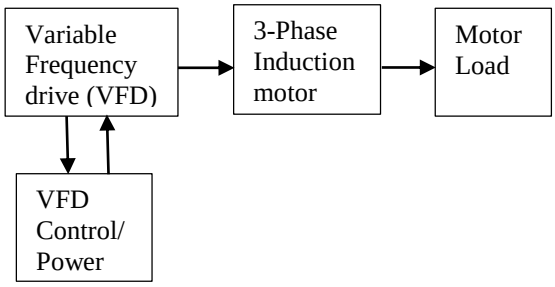

Fig. 4. Block diagram Load test on Induction motor using VFD drive

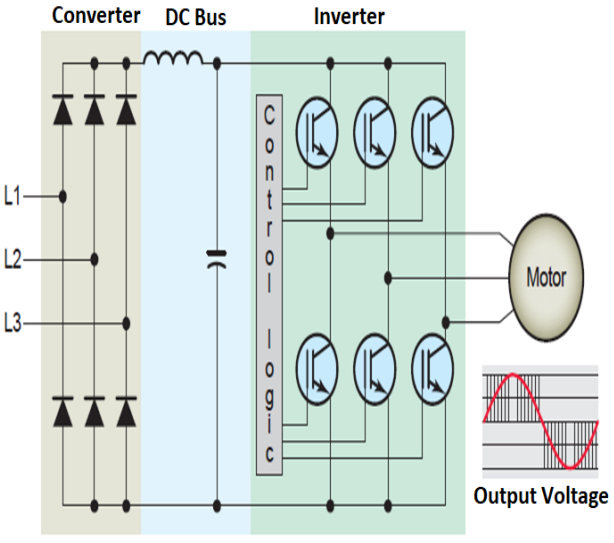

Fig. 5. Schematic diagram VFD drive

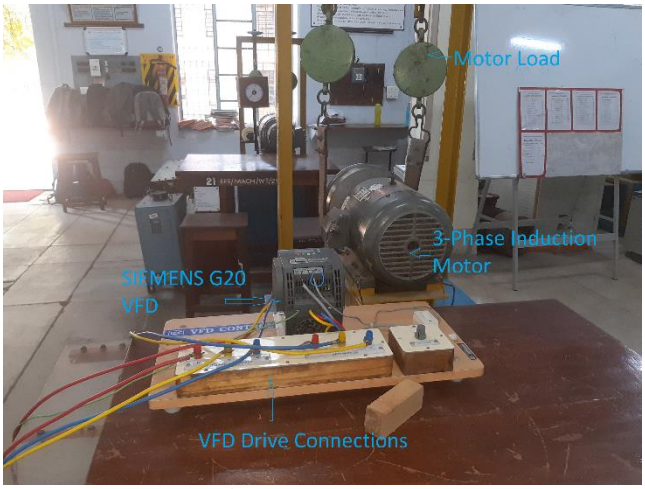

Fig. 6. Laboratory setup for load test on 3 phase induction motor

The laboratory set up for doing load test on 3-phase induction motor is given in Figure 6. It consists of a Siemens G20 VFD Drive connected to a 3-phase induction motor of specifications given below. The induction motor is connected to a pulley load to perform the load test on different speed from 0-1500 rpm [17].

The question posted in the google class room for collecting the data analysis report is shown in Figure 7.

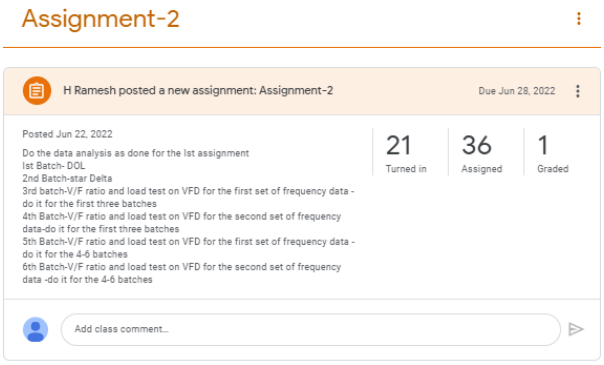

Fig. 7. VFD Question posted in Google class room

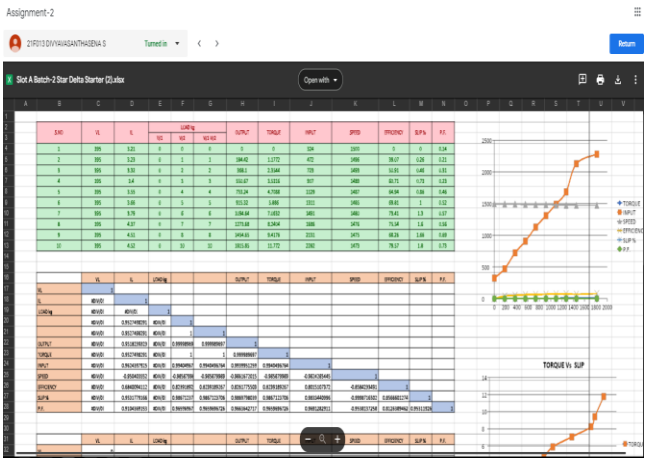

Fig. 8. Response received in google class room

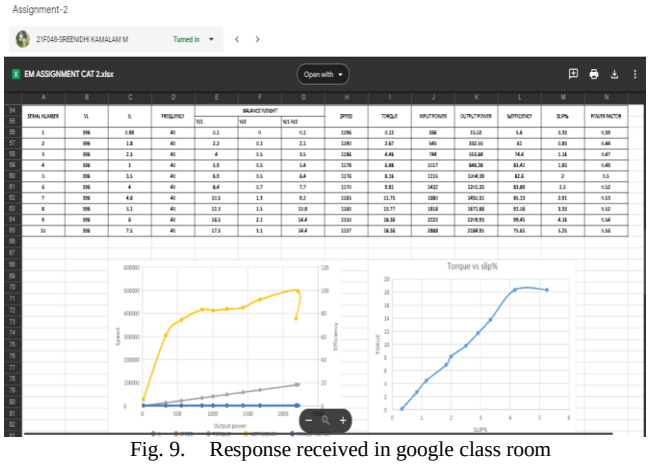

Fig. 9. Response received in google class room

The sample of analysis report submitted by students is shown in Figure 8 and 9.

TABLE II
VFD VOLTAGE, FREQUENCY AND SPEED PARAMETERS

Sl.No	voltage	Frequency out	Volt out/Frequency out	N(rpm)
1	67.3	9.03	7.45	217
2	87.6	12.14	7.21	363
3	140.3	20	7.015	605
4	204.9	30	6.83	903
5	273.3	40	6.83	1224
6	340	50	6.8	1522

The 3-phase induction motor speed is varied by changing voltage and frequency as shown in the Table.2.The regression of the above readings taken in VFD drive is done by students in excel sheet. The line fit plot generated in excel as shown in figure 10 and 11 indicates a linear relationship between frequency and speed as well as voltage and speed. These plots give a clear idea about the relationship between voltage and frequency to the speed. Table 3 shows the regression coefficients of relating speed to the voltage and frequency.

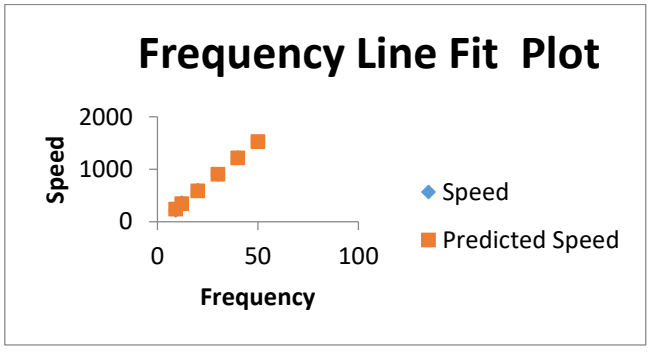

Fig. 10. Line fit plot of Frequency and Speed

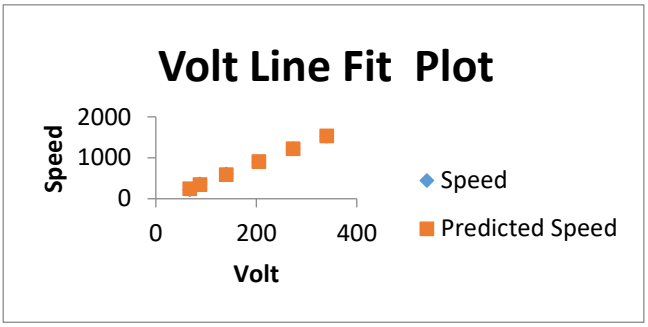

Fig. 11. Line fit plot of voltage and Speed

TABLE III
REGRESSION STSTISTICS

Regression Statistics	
Multiple R	0.999393
R Square	0.998787
Adjusted R Square	0.997979
Standard Error	22.75187
Observations	6

TABLE IV
LOAD TEST ON INDUCTION MOTOR USING VFD

SERIAL NUMBER	VL	IL	FREQUENCY	BALANCE WEIGHT			SPEED	TORQUE
				W1	W2	W1-W2		
1	395	1.65	45.31	2.4	0	2.4	1352	3.06
2	395	2	45.31	3.2	0	3.2	1348	4.08
3	395	2.8	45.31	3.8	0	3.8	1342	4.84
4	395	3	45.31	5.1	0	5.1	1339	6.5
5	395	3.53	45.31	6	0	6	1335	7.65
6	395	4.03	45.31	6.4	0	6.4	1332	8.16
7	395	4.55	45.31	7.2	0	7.2	1330	9.182
8	395	5.05	45.31	8.9	0	8.4	1323	11.35
9	395	5.6	45.31	10.4	0	10.4	1317	13.263
10	395	6.05	45.31	11.8	0	11.8	1313	15.048

INPUT POWER	OUTPUT POWER	%EFFICIENCY	SLIP%	POWER FACTOR
491	433.23	88.2	0.43	9.886
622	575.94	92.5	0.45	10.13
931	680.05	73.8	0.48	10.53
987	911.25	92.3	0.4839	10.73
1172	1069.27	91.23	0.488	11
1420	1137.99	80.07	0.51	11.2
1606	1278.6	79.6	0.519	11.33
1841	1572.18	85.3	0.53	11.8
2102	1828.83	87	0.54	12.2
2224	2068.66	93.01	0.55	12.4

The load test parameters of induction motor using VFD in 3-phase induction motor set with a frequency of 60 Hz is shown in Table.4.These readings are taken by varying the load by setting the frequency at 45 Hz by VFD [18].

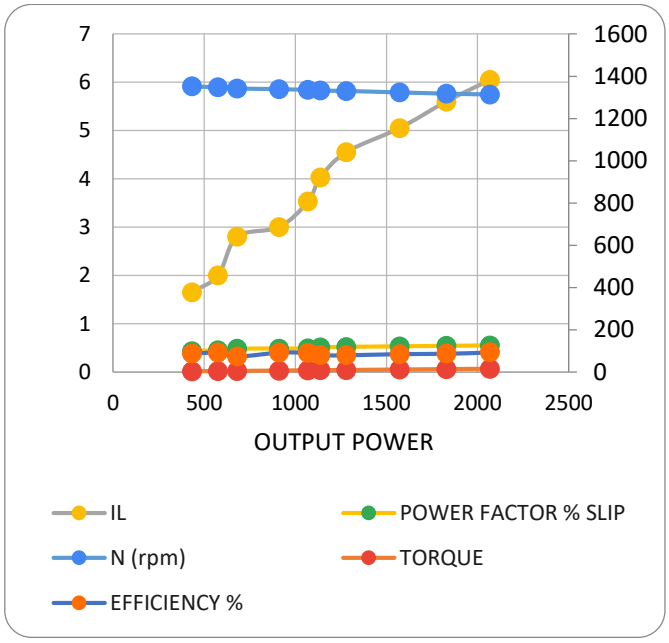

Fig. 12.Performance curves of 3-phase induction motor

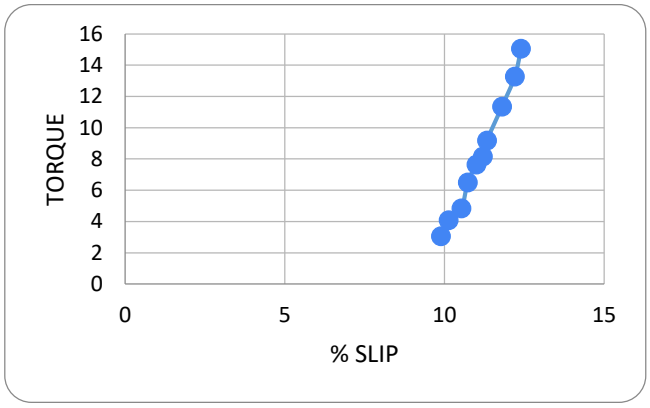

Fig. 13.Torque-Slip relationship

The performance parameters of 3-phase induction motor for different load conditions are shown in figure.12 and 13.Students can easily plot different parameters and can study the effect of one parameter on the other using these plots. The torque taken for different frequency conditions is given in Table 5.Students can perform the single factor anova using the excel sheet to find the variance in mean values of torque for different frequency setting [19]. The anova result displayed in Figure 14 shows that the three means are not statistically significant at significance level of 0.05.Hence the students can conclude that the change in frequency not affect the torque produced by the motor at different load conditions. Similar tests can be carried out using anova to analyze the more than 2 group means.

TABLE V
VFD LOAD TEST TORQUE VALUE AT DIFFERENT FREQUENCY

Torque at 40 Hz	Torque at 45 Hz	Torque at 60 Hz
0.12	3.06	2.5
2.67	4.08	2.5
4.46	4.84	3.8
6.88	6.5	3.8
8.16	7.65	5.1
9.81	8.16	5.1
11.73	9.182	6.3
13.77	11.35	7.6
18.36	13.263	7.6
18.36	15.048	7.6

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
40 Hz	10	94.32	9.432	38.7722
45 Hz	10	83.133	8.3133	15.68503
60 Hz	10	51.9	5.19	4.112111

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	96.67019	2	48.33509	2.475789	0.102983	3.354131
Within Groups	527.124	27	19.52311			
Total	623.7942	29				

Fig. 14.Single factor anova test result for torque at different frequency/speed.

IV. RESULTS AND STATISTICAL ANALYSIS

The results of 2nd year students of 2021 and 2022 batches done their electrical machines laboratory courses are compared to show that the implementation of analysis of experiments using MS-Excel enhances the students apply and analyze skills in the course outcomes CO4, CO5, CO6.The practical assessment marks are compared using the Minitab statistical tool [20]. The individual value plot and boxplot of CO6 for the year 2021 and 2022 is given in Figure 15 and 16.The result of 2022 shows that most of the students scored well compared to the previous year due to the easy understanding of the motor performance using statistical analysis and visualization methods.

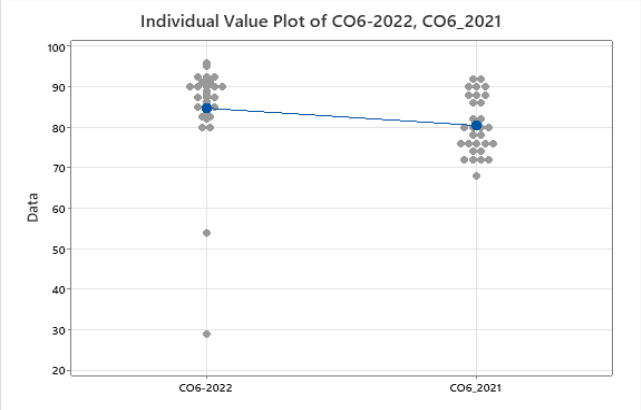

Fig. 15. Individual value plot for CO6 for the year 2022 and 2021

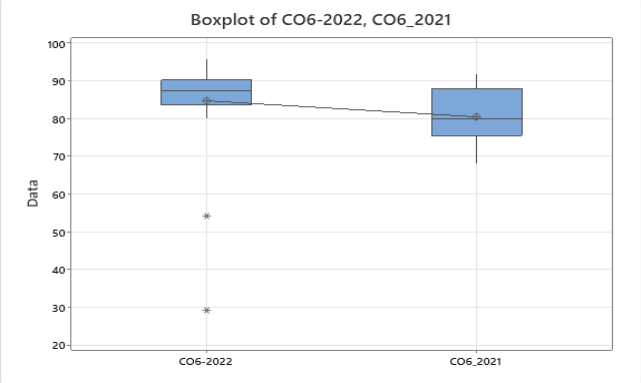

Fig. 16.Boxplot for CO6 for the year 2022 and 2021

TABLE VI
DESCRIPTIVE STATISTICS

Sample	N	Mean	StdDev	SE Mean
CO6-2022	30	84.7	12.9	2.3
CO6_2021	30	80.45	6.98	1.3

TABLE VII
TWO SAMPLE T-TEST

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 > 0$

T-Value	DF	P-Value
1.59	44	0.059

The two sample t test is carried out to find the statistical significance of CO6 in electrical machines laboratory between the year 2021 and 2022 and results are shown in Table 6 and 7 [21].Even the t-test result shows the there is no statistically significant difference between the marks in CO6 for both years, the box plot provides the clear information that 2022 students scored well than 2021 students.

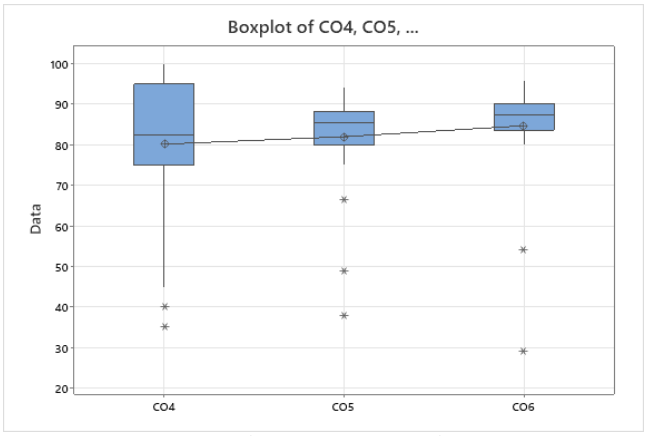

Fig. 17. Boxplot for CO4, CO5 &CO6 for the year 2022

The box plot, individual value plot and interval plot of CO4, CO5 and CO6 are shown in Figures 17, 18 &19.From the figures, it is concluded that most of the students scored better results in the CO6 compared to the other outcomes due to the analysis of experiments with MS-Excel statistical tools implemented in CO6.Individual value plot shows that most students scored marks 80-90 due to this statistical analysis implementation.

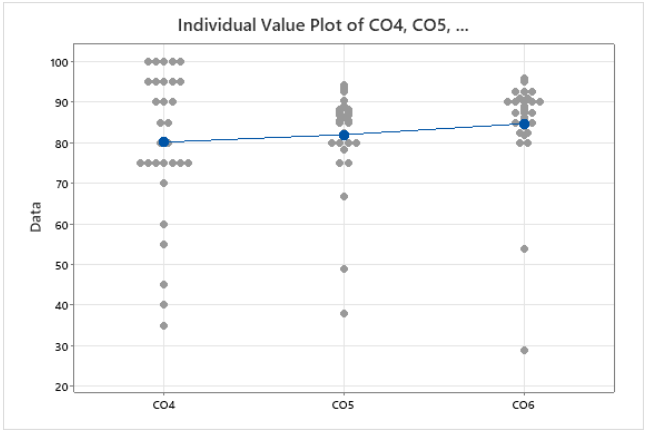

Fig. 18.Individual value plot for CO4, CO5 &CO6 for the year 2022

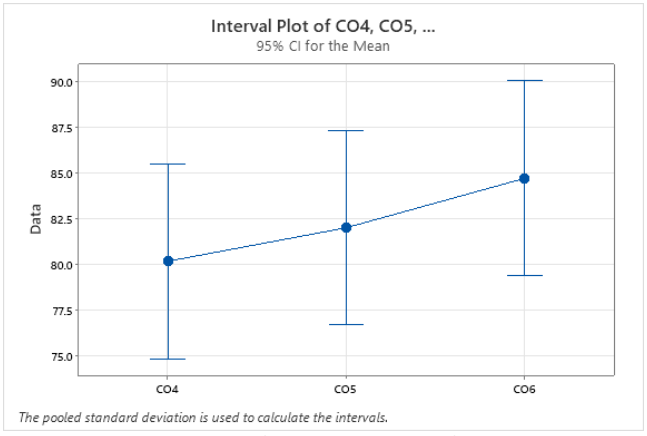

Fig. 19.Interval plot for CO4, CO5 &CO6 for the year 2022

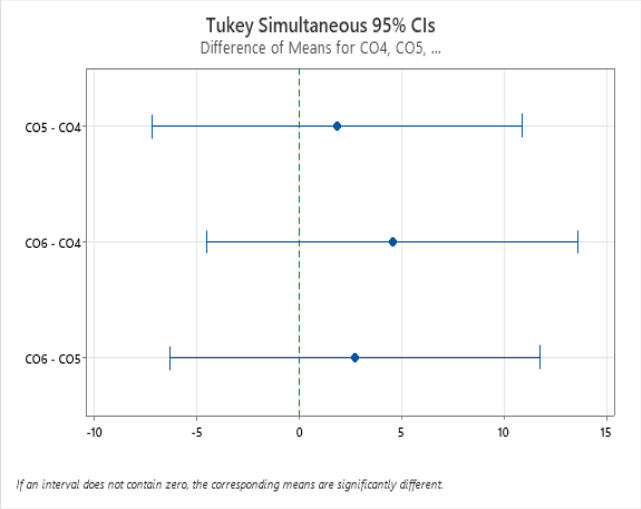

Fig. 20. Tukey plot for comparison of CO4, CO5 &CO6 for the year 2022

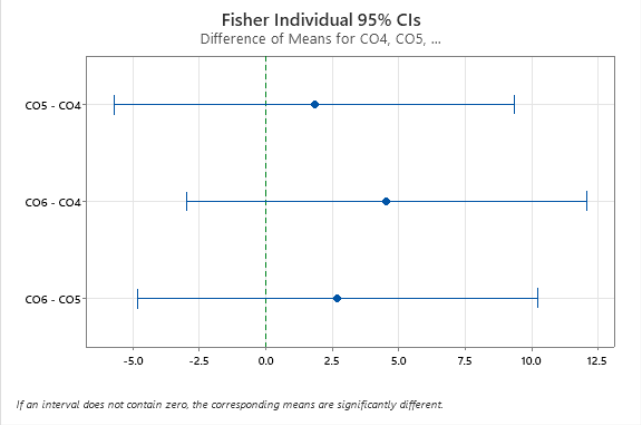

Fig. 21.Fisher plot for comparison of CO4, CO5 &CO6 for the year 2022

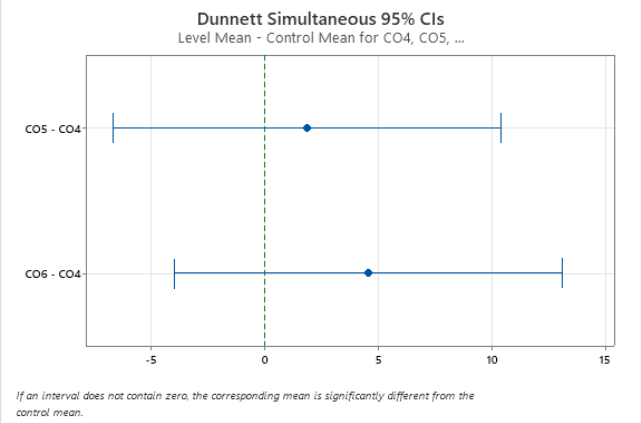

Fig. 22.Dunnett plot for comparison of CO4, CO5 &CO6 for the year 2022

The Tukey, Fisher and Dunnet plot shown in Figures 20-22 show that the students scored well in CO6 compared to Co4 and CO5 due to the implementation of analysis of experiment in CO6.

V. CONCLUSION

The achievement of higher-order thinking skills in laboratory courses is the prime objective of this study. Since the conventional way of interpreting the results in laboratory courses does not benefit much in developing higher-order thinking skills, a statistical way of analyzing and visualizing the experimental data is introduced in this study. Students can easily generate the report using the MS-Excel data analysis package tool and show the inference using graphical visualization aids. It is found from the assessment results that students scored well in CO6 compared to CO4 and CO5 due to the implementation of this analysis tool. Also, the CO6 of 2022 batch students is better than previous year's students. Since this tool has been successfully implemented for the particular CO, it can be extended to the other COs in the coming year.

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